

International Whaling Commission

Sperm Whales: Special Issue

**Reports of the International Whaling Commission
Special Issue 2**

Cambridge 1980

Preface

This volume contains the reports and papers on sperm whales from three meetings of the IWC Scientific Committee in 1977 and 1978.

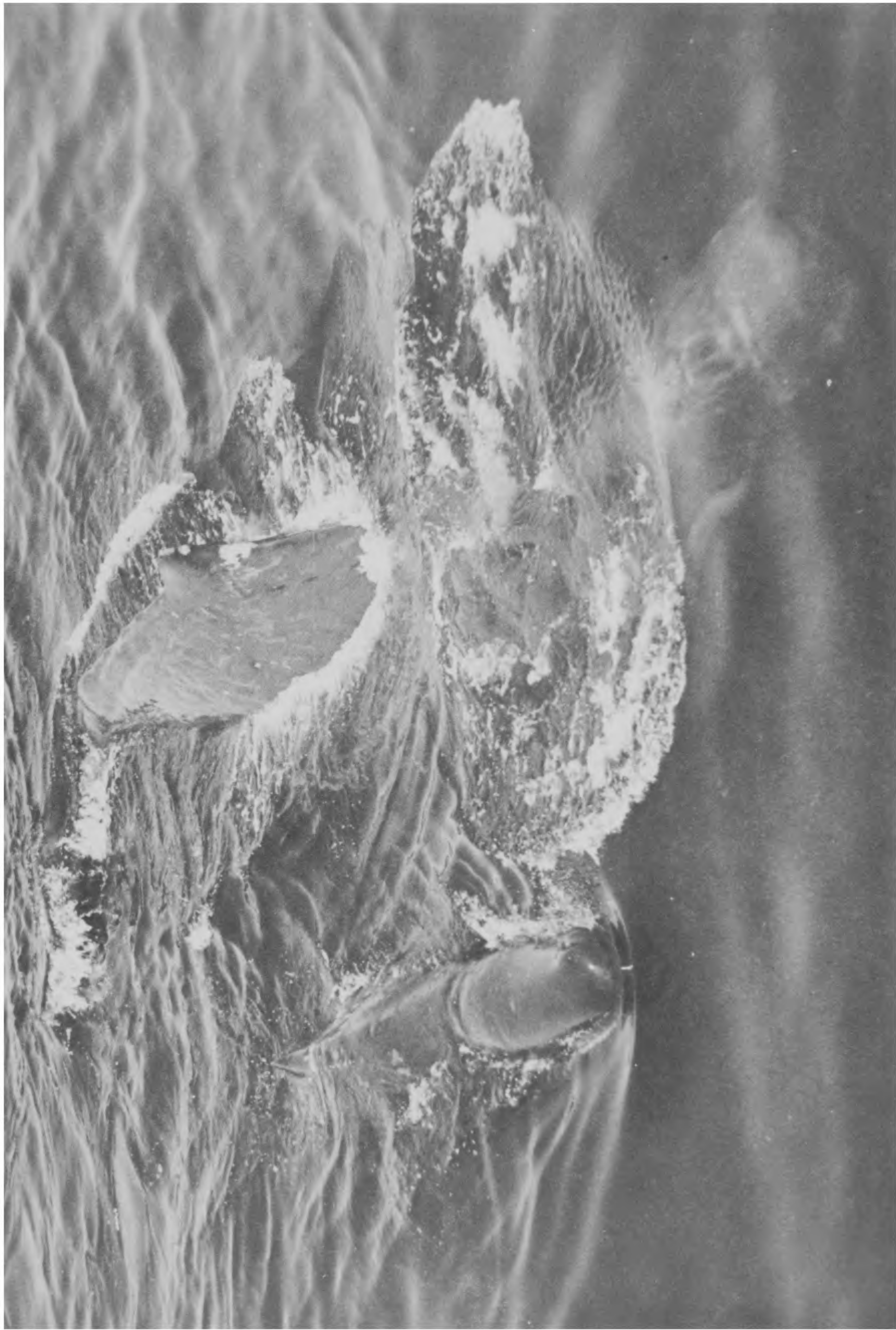
1. The Special Meeting on North Pacific Sperm Whale Assessments held in Cronulla, Australia in December 1977.
2. The Annual Meeting held in Cambridge, June 1978. The Report of the Sub-Committee on Sperm Whales was also published in *Rep. int. Whal. Commn* 29.
3. The Special Meeting on Sperm Whale Stock Assessments held in La Jolla, USA in November–December 1978.

Greg Donovan
Scientific Editor

Cover photograph:

Sperm whale taken in the Indian Ocean off Cape Province, February, 1971.

By courtesy of the Institute of Oceanographic Sciences, UK.



Mother and calf from a nursery school approaching the vessel on 30th November 1964, 29° 35'S, 71° 38'W.

Photograph by courtesy of Robert Clarke.

Contents

		Page
Report of the Special Meeting on North Pacific Sperm Whale Assessments, November 1977		1
SC/SPC/1	Ohsumi, S. — Catches of Sperm Whales by Modern Whaling in the North Pacific	11
SC/SPC/2	Ohsumi, S. — Criticism on Japanese Fishing Effort for Sperm Whales in the North Pacific	19
SC/SPC/3	Ohsumi, S. — Population Assessment of the Sperm Whale in the North Pacific	31
SC/SPC/4	Masaki, Y. — On the Pregnancy Rate of the North Pacific Sperm Whales	43
SC/SPC/5	Fukuda, Y. — A Consideration Towards Possible Step Procedures	49
SC/SPC/9	Allen, K. R. — Size Distribution of Male Sperm Whales in the Pelagic Catches	51
SC/SPC/10	Beddington, J. R. — Analysis of the Pregnancy Rates of Sperm Whales in the North Pacific Models	57
SC/SPC/17	Chapman, D. G. — Estimates of Pregnancy Rates — North Pacific	59
SC/SPC/18	Chapman, D. G. — Natural Mortality Rate — Males	61
SC/SPC/19	Beddington, J. R. — Analysis of the Pregnancy Rates of Sperm Whales in the North Pacific	63
Report of the Sub-Committee on Sperm Whales, Cambridge, June 1978		65
SC/30/Doc 4	Beddington, J. R. and May, R. M. — A Possible Model for the Effect of Adult Sex Ratio and Density on the Fecundity of Sperm Whales	75
SC/30/Doc 11	Kirkwood, G. P. — A Note on the Assessment of North Pacific Sperm Whales	77
SC/30/Doc 14	Kirkwood, G. P. — A Note on the Modelling of Sperm Whale Pregnancy Rates	79
SC/30/Doc 15	Kirkwood, G. P. — Sensitivity Tests for the Sperm Whale Model	81
SC/30/Doc 17	Botkin, D. B., <i>et al.</i> — Some Comments on Density Dependent Factors in Sperm Whale Populations	83
SC/30/Doc 22	Kirkwood, G. P. and Bannister, J. L. — Revised Abundance Indices for Sperm Whales off Albany, Western Australia	89
SC/30/Doc 33	Best, P. B. — Pregnancy Rates in Sperm Whales off Durban	93
SC/30/Doc 52	Fowler Charles W. — A Rationale for Modifying Effort by Catch, using the Sperm Whale of the North Pacific as an example	99
SC/30/Doc 58	Veinger, G. N. — Intraspecies Structural Data of Sperm Whales in the North Pacific	103
Report of the Special Meeting on Sperm Whale Assessments, 27 November to 8 December 1978		107
SC/SP78/1	Best, P. B. and Butterworth, D. S. — Timing of Oestrus Within Sperm Whale Schools	137
SC/SP78/3	Allen, K. R. — The Influence of Schooling Behavior on CPUE as an Index of Abundance	141
SC/SP78/4	Kirkwood, G. P., Allen, K. R. and Bannister, J. L. — An Assessment of the Sperm Whale Stock Subject to Western Australia Catching	147

		<i>Page</i>
SC/SP78/5	Clarke, R., Aguayo, A. and Paliza, O. — Pregnancy Rates of Sperm Whales in the Southeast Pacific between 1959 and 1962 and a Comparison with those from Païta, Peru between 1975 and 1977...	151
SC/SP78/6	Rørvik, C. J. — Biases in a Time Budget Model for Modern Whaling	159
SC/SP78/7	Ohsumi, S. — The Sperm Whale Catch by Japanese Coastal Whaling in the Sanriku Region	161
SC/SP78/8	Ohsumi, S. — Examination of the Pregnancy Rate of the Sperm Whale in the North Pacific	169
SC/SP78/9	Ohsumi, S. — Time Budgets of Sperm Whaling Operations by Japanese Whaling	177
SC/SP78/10	Ohsumi, S. — Index of Abundance of the Male Sperm Whale in the Pelagic Whaling Ground of the North Pacific	185
SC/SP78/11	Doi, T., Ohsumi, S. and Tedorì, J. — Theoretical Aspects Analyzed by Introducing Age-Specific Maturity and Age-Specific Availability into Population Analysis — III. Sperm Whales in the North Pacific	197
SC/SP78/12	Wada, S. — On the Genetic Uniformity in the North Pacific Sperm Whale	205
SC/SP78/14	May, R. and Beddington, J. — The Effect of Adult Sex Ratio and Density on the Fecundity of Sperm Whales	213
SC/SP78/16	Bannister, J. L. and Mitchell, E. D. — North Pacific Sperm Whale Stock Identity: Distributional Evidence from Maury and Townsend Charts	219
SC/SP78/17	Holt, S. J. — Two Concerns About the Sperm Whale Model	231
SC/SP78/18	Ralls, K., Brownell, R. L. and Ballou, J. — Differential Mortality by Sex and Age in Mammals, with Specific Reference to the Sperm Whale	233
SC/SP78/18	Horwood, J. W. — Comparative Efficiency of Catcher Boats with and without Asdic in Japanese Pelagic Whaling Fleets	245
SC/SP78/24	Allen, K. R. — Relation Between Catch Per CDW and Indices of Abundance Allowing for Non-Searching Time and Operation on Schools	251
SC/SP78/25	Holt, S. J. — Calculations from Best, SC/30/Doc 33 Table 3 — Apparent Pregnancy Rates	255
SC/SP78/26	Horwood, J. W. — Relative Increases in Population Pregnancy Rate of Sperm Whales	257
SC/SP78/30	Chapman, D. G. — An Alternative Procedure for the Scientific Committee's Recommendations with Respect to Sperm Whale Management	259
SC/SP78/33	Fortom-Gouin, J. and Holt, S. J. — Reasons for Recommending Zero Female Catch Limits for Sperm Whales	261
SC/SP78/36	Smith, T. — Catches of Male and Female Sperm Whales by 2-Degree Square by Japanese Pelagic Whaling Fleets in the North Pacific 1966–77	263

Report of the Special Meeting on North Pacific Sperm Whale Assessments

The Scientific Committee of the International Whaling Commission recommended at its June 1977 meeting that a special meeting should be convened as soon as possible to consider the problems and to review the assessments of North Pacific sperm whales. In particular, it would examine the uncertainties surrounding stock separation, effort data and age at recruitment. This recommendation was endorsed by the Commission, who also directed that the Committee should try to apply quotas to the separate stocks recognised and consider step procedures to minimise the economic dislocation resulting from their analyses from a biological standpoint.

The Committee met at 9.30 a.m. on 21 November 1977 and following days in the Conference Room of the CSIRO Division of Fisheries and Oceanography, Cronulla, New South Wales, under the Chairmanship of Allen. Mr D. J. Rochford, Chief of the Division, welcomed participants to Cronulla.

There were present:

K. R. Allen	
G. R. Anderson	
J. L. Bannister	Australia
A. E. Caton	
G. P. Kirkwood	
A. Mazanov	
E. D. Mitchell	Canada
Y. Fukuda	
S. Ohsumi	Japan
S. Kimura	
M. V. Ivashin	
R. G. Borodin	USSR
I. G. Tsenker	
J. W. Horwood	UK
G. A. Bertrand	
D. G. Chapman	USA
M. F. Tillman	
J. R. Beddington	IUCN
P. Spong	Greenpeace Foundation (Observer)
R. Gambell	Secretary to the IWC

I. OPENING REMARKS

The Chairman welcomed participants indicating that in addition to national representatives, Beddington was attending as an invited participant and as an observer on

behalf of IUCN, and Spong was observer for the Greenpeace Foundation, an accredited international organisation.

2. ELECTION OF CHAIRMAN

As the report of the special meeting was to be conveyed directly to the Commission, the meeting was regarded formally as a full session of the Committee; consequently Allen was *ex officio* Chairman of the meeting. However, for the working session on sperm whales, Bannister took the Chair.

3. APPOINTMENT OF RAPPORTEURS

The duties were shared between Caton and Gambell.

4. ADOPTION OF AGENDA

The Agenda adopted is shown in Annex A.

5. REVIEW OF DOCUMENTS AND STATISTICAL MATERIAL

The documents submitted are listed in Annex B. These included the statistical material used by the Committee. Other data are identified in Agenda Item 10.

Three documents were submitted to the Committee by J. P. Fortom-Gouin, the first (SC/SPC/12) in time for inclusion in the meeting documentation. The Committee invited Fortom-Gouin to attend the meeting while aspects of that document were discussed. It noted that modification of Rules of Procedure might be considered at the next Annual Meeting to include provisions that

- (1) The Committee may receive and consider unpublished scientific documents from non-members of the Committee provided that they are received under the same conditions (with respect to timing, etc.) that apply to members.
- (2) At the Committee's discretion authors of such documents may be invited to attend for a limited time for the specific purpose of discussing their documents.

6. EFFORT MODIFIERS

The Committee reviewed SC/SPC/2 prepared by Ohsumi in response to the Committee's general request at the June 1977 meeting (*Rep. int. Whal. Commn* 28:61) that sources of uncertainty surrounding Japanese pelagic CPUE data be examined as soon as possible. The prompt and thorough preparation of the document was commended. Specific modifiers of CPUE data were examined separately:

Catch Effect of Asdic

Ohsumi (SC/SPC/2) calculated a correction factor of 1.055 for Asdic operations in the Japanese pelagic fleet by com-

parison of CPUE for boats with and without Asdic. He indicated that a study of the component activities of catcher boat operations showed that Asdic was only useful and effective in the chasing component of the hunt for sperm whales. This activity represented a minor component of a catcher day's work.

The Committee noted that this value is lower than the correction factor used at the June 1977 meeting which was based on Antarctic efficiency estimations in the Japanese fleet where the comparable Asdic correction factor for sperm whale catches was 1.38 (*Rep. int. Whal. Commn* 27: 272; 306, Table 3). It was pointed out, however, that no Asdic correction factor would be necessary for any assessments using CPUE data time series after 1962, because all Japanese North Pacific catchers had been equipped with Asdic since then.

Some members expressed the opinion that the correction factor expected on the basis of their qualitative estimation of the value of Asdic was difficult to reconcile with the low North Pacific value calculation. Mitchell referred to the usefulness of Asdic in determining where a whale would surface, and in determining if it was 'wild', in which case chasing time could be considerably reduced.

The Committee agreed that a comparison was needed of the increase of searching time available as a result of reduced chasing time since the introduction of Asdic; it noted that Ohsumi was attempting to quantify this from recollections of gunners who operated before its introduction. In addition it agreed that an examination of the breakdown of the daily operations of catchers working in both the Antarctic and North Pacific should provide a basis for considering the differences in Asdic correction factors for the two regions as well as in coastal operations. The Committee noted the urgent need for re-examination of the Southern Hemisphere correction factor before re-assessment of Southern Hemisphere stocks.

The Committee also recommended that the time spent 'searching' in all whaling operations should be recorded in future.

One point which the Committee felt should be emphasised in view of comments from Fortom-Gouin and Spong* was that whales are NOT located initially by Asdic. The equipment is used to keep track of a whale which has dived, to facilitate positioning of the vessel when the whale re-surfaces. Asdic in fact can scare whales and so has to be used with caution in this respect.

In view of the difference observed between the calculated figures for the correction factor in the North Pacific and the Antarctic, the Committee agreed to pool the data for the comparable period of years in each area (1958/62) when the same Asdic sets and catcher boats were in use, giving a geometric mean of 1.16. It was agreed that this should be used as a conversion factor for Japanese pelagic CDW data in current assessments.

It was noted that a comparison of the relative fishing power of the same catcher boats before and after the introduction of Asdic would provide a more refined estimate of the efficiency factor; Committee members were urged to provide such analyses before the next meeting. Asdic has not been used in the Soviet pelagic fleet.

The Committee noted that if density of whales decreases, the amount of time available per CDW for searching would increase. This would tend to counteract any increased

efficiency in the use of Asdic due to the change in the ratio of chasing time to searching time.

Tonnage correction

Ohsumi (SC/SPC/2) indicated that, in contrast to the situation in baleen whaling operations, a correction for tonnage of catcher vessels taking sperm whales was only appropriate up to 600 tons; above this size, increased speed and power was of little advantage. Capacity to turn speedily was the main requirement when chasing; for searching, the optimum steaming speed was 12–13 knots.

Ohsumi used the data for the *Matsushima-maru* operations in 1956 (SC/SPC/2, Table 8) on the basis of its high correlation coefficient, to represent the relationship between catcher tonnage and efficiency, for application in his assessment in SC/SPC/3.

Mitchell drew attention to the significance when chasing, of a vessel's capacity to accelerate to full speed but agreed that vessels above 600 tons might not show any increase in efficiency in this regard. He made specific reference to the inherent superiority of vessels fitted with variable pitch propellers which could maintain steady engine rpm while accelerating and thus reduce the tendency to scare whales. Variable pitch propellers have not been used in the Soviet pelagic fleet.

The Committee noted that since 1948 (Tillman, 1978, *Rep. int. Whal. Commn* 28; 345) all Soviet catchers have been above 600 tons thus it was not necessary to make a tonnage correction in Soviet effort data.

Zero catcher days

The Committee agreed it would be desirable for an examination of data on changes in the proportion of days on which no whales were caught to be undertaken. While data other than those included in SC/SPC/2 (Table 5) were not available at the meeting, it noted that a time series of Japanese fleet data could be examined but that data recording on an individual catcher basis had commenced only recently. It was agreed that distinction between zero catch days when steaming and zero catch days when searching should be incorporated in effort data records.

Weather correction

SC/SPC/2 (Fig. 6) indicated that catcher efficiency declined when the wind exceeded Beaufort force 4. Smaller vessels up to 600 tons were more affected than larger vessels but above this size there was no relative advantage as size increased. The Committee noted that SC/SPC/2 (Fig. 7) showed a slight downward trend in average annual wind force. Ohsumi indicated that at noon, Japanese factory ships recorded wind force, water temperature and visibility. He stressed that the data may not be strictly representative because of the separation of hunting grounds and catching vessels from the factory ships. The Committee believed that a more useful statistic would be the proportion of days on which wind force exceeded the critical value and agreed this should be examined.

In the absence of such data the Committee developed a correction factor from SC/SPC/2 (Figs 6 and 7). Average wind force (over sperm whale operations) was read graphically from SC/SPC/2 (Fig. 7). An equation was fitted to visually smoothed data on Fig. 6 of the same document. The equation is

$$\text{Relative CPUE} = 90 + 0.25 (\text{Wind Force}) - 1.4375 (\text{Wind Force})^2$$

*Fortom-Gouin, J. P. and Spong, P. A note on the correction for Asdic.

A 'weather index' was then calculated using the values read from Fig. 7; it is shown in Table 1 for 1954/1976 and applied to Japanese CPUE.

Table 1.

Weather index for Japanese North Pacific pelagic whaling operations

Year	Index	Year	Index	Year	Index
1954	59	1962	70	1970	71
1955	66	1963	67	1971	66
1956	48	1964	64	1972	71
1957	73	1965	69	1973	71
1958	81	1966	69	1974	73
1959	75	1967	68	1975	74
1960	63	1968	69	1976	66
1961	49	1969	67		

Sex factor

The increased female sperm whale component in pelagic catches generates a lower apparent CPUE for males than the real CPUE because the effort directed towards males is less than the total whale effort.

Information for 1977 provided in SC/SPC/2 (Table 1) allowed adjustment of the total CDW by subtracting a factor based on the number of females caught and the operation time devoted to dealing with that catch, using the formula:

$$\text{CDW (adjusted)} = \text{No. of CDW} - \text{S.F.}$$

$$\text{where S.F.} = \frac{(\text{Female catch} \times 1.20)}{11.83}$$

(11.83 is the average daily number of hours searching and 1.20 is the average daily number of hours 'retrieving' - i.e. chasing, killing, handling, towing).

Hence, $\text{CDW (adjusted)} = \text{CDW} - 0.1 (\text{females caught})$.

The Committee agreed to adjust the Japanese pelagic effort data accordingly.

Scouting boat effort

The Japanese pelagic fleet uses scouting boats which operate independently from the main fleet. The Committee reviewed the information presented in SC/SPC/2 and agreed that there was justification for CDW for the scouting boats being combined with CDW data for the rest of the fleet on an equivalent basis. It noted that BIWS statistics already incorporate the scouting boat effort data.

Other effort modifiers

The Committee considered other factors which may have influenced the efficiency of catcher boat operations and was provided with the following information from scientists familiar with whaling operations in the particular fisheries:

- helicopters* - Neither Japanese nor Soviet North Pacific whaling fleets had used helicopters in their operations.
- nylon forerunners* - Japanese and Soviet catchers had used nylon ropes since 1947 and 1950 respectively; changes in efficiency would not be expected after 1950 as nylon rope was used on all catchers thereafter.
- harpoon heads* - Japanese and Soviet catchers had used flat-headed grenade harpoon heads since 1947 and the beginning of the 1950 respectively.
- 'stop-catch' days* - A change of factory ship processing from sperm whales to baleen whales involves a cessation of catching operations until processing equip-

ment is cleaned down. Japanese pelagic activities had remained constant in this respect but a change in the Soviet fleet emphasis from oil production to meat and meal production since 1972 (SC/SPC/16) had introduced stop-catch days in that operation.

- selection of whales chased* - The imposition of quotas in 1971, particularly by sex, caused a modification of catching operations. Prior to quotas, the industry sought to maximise the catch of whales. With quotas, its objective has been to maximise the net production from each whale taken. This has imposed a need to select whaling grounds (because of different proportions of sexes on different grounds) and to select individual whales taken more carefully. Selection between males and females to satisfy quotas has increased the time taken in chasing. Ivashin and Borodin (SC/SPC/16) indicated that the recent Soviet pelagic fleet emphasis on increasing meat yield had led to a marked decline in the CPUE for male sperm whales in the combined taking of baleen and sperm whales.
- changes from steam to diesel engines* - Whereas steam allowed a quiet approach, the increased noise associated with diesel engines tended to reduce the efficiency of catchers as whales were more scared. The Japanese and Soviet pelagic fleets had converted from steam to faster and more economic diesel power by the mid-1930s and the early-1960s respectively.
- 'killer' harpoons* - Nylon forerunners allow rapid recovery of harpooned whales and the use of untethered harpoons to kill whales not killed by the first harpoon. The Committee was advised that neither the Japanese nor the Soviet pelagic fleets used this method, it being associated in general with industries based on Norwegian techniques (e.g. Australian, South African and UK operations).
- radar reflectors and radio buoys* - The use of such equipment permits catchers to buoy whales taken and resume hunting more rapidly. The Japanese pelagic fleet had used radar reflectors and radio buoys since the late-1940s. The Soviet pelagic fleet had used radio buoys prior to the imposition of quotas; since then buoys had not been used because catchers promptly towed whales to the factory vessel for processing.
- tow boats* - The Committee noted that both the Japanese and Soviet fleets had used some catchers for towing during the 1960s. At that time also, one Japanese boat per fleet was used solely as a towing vessel. Since the introduction of quotas both the Japanese and Soviet factory ships have controlled and accompanied catchers more closely to reduce the time between kill and processing. The increased involvement of catchers in towing would have tended to depress CPUE.

While recognising that a few of these factors could have modified the efficiency of catchers during the time span of North Pacific operations, some increasing CPUE and others reducing it, the Committee did not have any quantitative data available on their effects to enable it to allow for them in the assessments.

7. STOCK IDENTITY

At its June 1977 meeting the Committee recognised at least two stocks of sperm whales in the North Pacific and delineated a boundary between Eastern and Western stocks. It also noted that males from both regions intermingled in

higher northern latitudes to the extent that separate stock assessments were not possible at that time.

While the Committee believes that there may be three male stocks in the North Pacific, there is not sufficient evidence for it to define stocks adequately for separate assessments to be made. It was agreed that the question of stock identity required urgent examination and members were urged to explore all the available data (e.g. historical distribution records, mark and recapture analyses and blood sampling) so that review documents could be compiled sufficiently in advance of the June 1978 meeting to allow members computing assessments to analyse data on an individual stock basis. In particular, it was requested that:

- Mitchell and Bannister should undertake studies of historical records of distribution
- Ohsumi and Ivashin should arrange for reviews of past and recent mark-recapture data.

The Committee agreed that despite the uncertainty surrounding stock identity it would be unwise for the meeting to recommend catch limits for males for the North Pacific as a whole; a more conservative approach would be on the basis of divisions such as those proposed at the June 1977 meeting. The Committee recognised that the boundary specified at that time may well represent the western limit of an eastern stock and the eastern limit of two western stocks. Mitchell believes that there is sufficient evidence from historical and other records (SC/SPC/20) to recognise at least three biological stocks.

8. BIOLOGICAL PARAMETERS

At the June 1977 meeting the Committee adopted the same parameter values for the North Pacific as for the Southern Hemisphere (*Rep. int. Whal. Commn* 28: 58, 61), apart from the mean age at recruitment. The Committee reviewed the parameters and agreed on the values shown in Table 2. Values for average age at maturity and for number of mature females available to a school master remain unchanged. The following notes provide an explanation of the modification of other parameters:

8.1 Average age at recruitment

The figures shown for males are obtained from SC/SPC/3 (Fig. 3).

The Committee compared information from age distributions (SC/SPC/3 and Ohsumi CPOP runs) and growth curves (Best, 1970, *Invest. Rep. Div. Sea Fish. S.Afr.* 79: 1–27). It took into account the coastal and pelagic sperm whale size limits shown in Table 3 and recognised that over 30 ft (at which length both males and females are aged 10 years), females grow more slowly than males. The Committee agreed on values of mean female age at recruitment of 10 years for the period to 1960, 15 years for 1961/1972 and 13 years for the period from 1973/77. The pre-1960 figure was based on the high coastal component in the catch and data in Ohsumi (1966, *Sci. Rep. Whales Res. Inst., Tokyo* 20: 1–16). The 1961/72 figure represented an average of a 1961 value of 10 years and a 1972 value of 20 years, the latter representing the age of a 35 ft female from the growth curve; the values were averaged because of the increasing component of pelagic activities over the period. The 1973/77 figure was the same as that for males because of the same age at a length of 30 ft in both sexes.

Table 3
Effective size limits for sperm whales (ft)

	Coastal	pelagic
1947/48*	30	30
1949/51	35	35
1952/72	35	38
1973/77	30	30

*national size limits

8.2 Natural mortality rate

Mature

The Committee studied the available data on the mortality rate (M) of mature whales, analysed in SC/SPC/18. This analysis suggests the values 0.07 (late-1940s) and 0.06 (1970s). Previously the Committee had used M = 0.05 from

Table 2.
North Pacific sperm whale population parameters

		Present Values (Cronulla, 1977)			(Canberra) 1977
Average Age at Recruitment (para. 8.1)		Pre 1960	1961–72	1973–77	All years
	Male	13	15	13	(9)
	Female	10	15	13	(9)
Natural Mortality Rate (both sexes) (para. 8.2)					
	Mature	0.0589	(unexploited & exploited)		(0.05)
	Juvenile	0.0589	(unexploited & exploited)		(0.133–0.05)
Average Age at Maturity (para. 8)					
	Male (social)	25	(unexploited & exploited)		(25)
	Female	10	(unexploited & exploited)		(10)
Mean Number of Mature Females available to a School Master (para. 8)		10			(10)
Reserve Male ratio (para. 8.3)		0.3			(0.3)
Pregnancy Rate (para. 8.4)		0.20 0.25	(unexploited) (exploited)*		(0.19) (0.25)
Density dependent exponent		1.4			(1.4)

*i.e. at zero population level; at 25% population level the value is 0.248

less complete data. While $M = 0.07$ was tentatively considered, it was found that $M = 0.0589$ is the most appropriate value taking into account two basic biological assumptions. These are that the population was in balance at the onset of exploitation in 1946 and that the mortality rate of immature animals is at least as great as that for mature animals. By balance it is meant that the number of animals born and surviving to the age of maturity equals the number of mature animals dying in any year.

While most of the Committee believe that the mature natural mortality rate should be held constant, some believe that the figures in SC/SPC/18 show that there may be a density dependent effect. The Committee was not able to identify the mechanism by which, or to estimate the degree to which this may occur. It noted the difficulty of interpreting Heinke estimates for periods when the total mortality rate is changing and because these may include migration factors.

Juvenile

It was agreed from consideration of the balance equation described above that the immature mortality rate was the same as the mature rate, i.e. 0.0589.

8.3 Proportion of reserve males (= 'harem reserve' in *Rep. int. Whal. Commn* 27: 42)

The Committee adopted the same value as used at the June meeting (*Rep. int. Whal. Commn.* 28: 61) to allow for a reserve of one additional school master for 10 mature females.

Bertrand disagreed with the use of 0.3 as a reserve male ratio. He stated the information presented in SC/29/Doc 50 by Best may be inappropriate for sperm whales because the populations examined by Best had harems breeding in close proximity. Reserve males had the opportunity to move between harems when opportunities arose. More appropriate models may be found in other harem species such as lions, hyenas and elk which have harems more widely separated. Bertrand believes that the present ratio of two males per harem is not sufficiently conservative in light of the lack of information on the role of reserve bulls in formulation and maintenance of harems. A reserve male ratio of 0.5 would provide a greater margin of safety. Mitchell agreed that the reserve bull ratio should be increased from observations in the North Atlantic (Mitchell, 1972, Paper SP 72/12 submitted to the sperm whale meeting, Parksville, 1972).

8.4 Pregnancy rate

Masaki (SC/SPC/4) provided a review of North Pacific pregnancy rate data. Using these data, Chapman (SC/SPC/17) calculated an average pregnancy rate in the western North Pacific of 0.21. The Committee believed that this probably approaches the lower limit, as the female stocks in the North Pacific have so far been only lightly exploited.

The range adopted, 0.20–0.25, consistent with a reduction from a five-year to a four-year breeding cycle, appears to be biologically appropriate since it can be achieved by reducing the resting period from two years to one. Higher figures, e.g. 0.33 recorded off California (Rice and Wolman, 1970, Paper SP/3 submitted to the special meeting on sperm whale biology and stock assessments, Honolulu, 1970) may represent the maximum of the range but such data are based on small samples.

The Committee resolved that Gambell, Ivashin,

Bannister, Ohsumi and Best would send pregnancy data, on forms to be provided by Bannister before mid-December, to Chapman by the end of March 1978 for him to analyse before the June 1978 Scientific Committee meeting. The Committee recognised that the female stock in Southern Hemisphere Division 4 has been reduced to almost the same extent as that in Division 9; it is therefore particularly important to obtain pregnancy rate data from both these Divisions to determine the extent to which pregnancy rate may change in response to heavy exploitation of females.

The Committee was grateful to Masaki for providing at short notice during the meeting, a breakdown of the data on which his paper is based. An analysis of these by Beddington (SC/SPC/19) gave no statistically significant indications of a trend in pregnancy rates with time by latitudinal Zones.

9. POPULATION MODELS

The Committee had available the information in Beddington and Kirkwood (SC/SPC/10) and the analyses by Ohsumi (SC/SPC/3). It agreed to continue to use the Allen model (*Rep. int. Whal. Commn* 23: 70–4) in assessments of North Pacific stocks at this meeting.

10. POPULATION ESTIMATES

The basic data available for obtaining estimates of population sizes were:

- (a) *total catches* obtained from NP forms and the BIWS, checked against a tabulation provided by Ohsumi (SC/SPC/1). As far as is known these include all catches for the North Pacific over the period except for the years 1951 and 1959 which are available in total but not by 10° squares on the Soviet NP forms. A report that the People's Republic of China had taken sperm whales had been investigated through the Australian Trade Commissioner in Peking, who provided information that no sperm whales had been or are being caught by that country.
- (b) *effort data* — Japanese and Soviet pelagic data over the period 1954/76 were tabulated by Kirkwood in SC/SPC/11. Effort units were:
 - Japanese pelagic: gross catcher days (GCD) outside the baleen season and net catcher days (NCD) within the baleen season;
 - Soviet pelagic: gross catcher days, both outside and within the baleen season.

Estimates of Population Size

The Committee decided to develop abundance estimates for different regions using effort data corrected by the effort modifiers agreed to above. Initially it was agreed that calculations should be undertaken for seven data combinations as follows:

- (i) the total area
- (ii) 10° squares, P23–26 (Aleutian grounds)
- (iii) & (iv) 'west' and 'east' areas (divided as proposed at the June 1977 meeting, *Rep. int. Whal. Commn* 28: 61)
- (v–vii) 'Asian', 'Central' and 'American' areas as proposed by Tillman (*Rep. int. Whal. Commn* 27: 342)

For all the above, both Japanese and Soviet data were used where possible. Inspection of the abundance indices over the period in each of these groupings was carried out

to determine which series would provide estimates by the CHPOP technique. Where no downward trend was observed, the data could not be used.

The Committee recognised that use for abundance estimation of only those series which show a downward trend would lead to underestimates of population size.

In examining the density estimates in these groupings over the time span, the Committee recognised that since the fishery began there had been a trend of movement of the fishery southwards and eastwards from its origins in more northern areas, as documented by Ohsumi (SC/SPC/1, Fig. 3). The Committee also noted that this movement was associated with a change in emphasis in the baleen whale fishery during the period (Tillman, 1977. *Rep. int. Whal. Commn* (special issue 1): 98–106).

The Soviet data were found not to show a decline in CPUE and were therefore unusable as a basis for the estimation procedures; Japanese data were used in obtaining the population estimates given in Table 4. The small subset of data (P23–26) was rejected as it did not represent any likely stock division. The other sub-division combination (v–vii) is not included in Table 4, as no downward trend was observed in either the Japanese or Soviet CPUE data for the American component.

Examination of the estimates in Table 4 led to the rejection of all those for the Eastern and Western stocks since they did not give relative stock sizes between the two areas which were consistent with the CPUE data. The Total Stock estimates by the CHPOP (CPOP) and CHPOP (CNST) techniques were unacceptable when considered with the known catches. Because the POPDYN model required a constant mean age at recruitment, calculations of the initial population size used a value of 15 years over the period, whereas a value of 13 years was appropriate for the period for 1947/58. When initial population size values were adjusted to allow for this difference, the population size data were consistent with observed CPUE data. Thus the Committee agreed that the adjusted POPDYN estimates in Table 4 were the most appropriate estimates of population size available at this time. It noted that the approach was also more consistent with the SPDYN techniques used in yield calculations.

Although the estimates for possible sub-divisions were quantitatively unreliable, it is clear that the western component is at a lower level relative to the original than that in

the east in the pelagic whaling area. However, the Japanese coastal data indicated that the stock in that area has not changed in density to the same extent as that in the adjacent pelagic area. The Committee therefore considered it was essential to divide any catch limits obtained for the area as a whole into sub-divisions.

Three proposals were considered:

- (1) to classify the stock on the basis of the population estimate of the total area, determine a catch limit for the total area, and then to divide the catch limit between possible divisions on the basis of the 1977 indices of abundance;
- (2) to sub-divide the initial total population estimate on the basis of initial indices of abundance, sub-divide the total 1978 estimate by the current indices of abundance, and then to classify and obtain appropriate catch limits for each division;
- (3) to sub-divide the initial total population estimate on the basis of initial indices of abundance, obtain present levels of those divisions using the SPDYN program, and then to classify and obtain appropriate catch limits.

The Committee agreed that proposal 2 was most appropriate. Proposal 1 would not give a depleted management division any protection, while proposal 3 relies on a proper separation of management divisions at the onset which has not been possible to achieve so far. Proposal 2 allows separate management divisions to be classified individually and uses the known catches from each division.

An attempt was made to separate the western area into two divisions, the Asian and the remainder west of the line adopted at the June 1977 meeting. The catches of some 2,000 males a year from the Asian component in the late 1950s produced very little change in CPUE, but annual catches of around 1,000 males in the balance of the western area were associated with large density reductions. This inconsistency led the Committee to adopt a division of the North Pacific into only two areas, the Eastern and Western divisions proposed at the June 1977 meeting (*Rep. int. Whal. Commn* 28: 61). This dividing line is shown on p.9.

The POPDYN program gave estimates of mature females and exploitable males for 1947 (original) and for 1978 (current). These were partitioned between the two areas on the basis of relative indices of abundance. The relative index of abundance for the Eastern area was calculated as:

Table 4.
Population estimates ('000s) of exploitable males in the North Pacific

Year	Total Stock			Western Stock			Eastern Stock		
	CHPOP ¹ (CPOP)	CHPOP ² (CNST)	POPDYN ³	CHPOP (CPOP)	CHPOP (CNST)	POPDYN	CHPOP (CPOP)	CHPOP (CNST)	POPDYN
1947	290.7 (13) ⁴	415.2 (15) ⁴	209.2 (15) ⁴	171.6 (13)	190.5 (15)	81.6 (15)	147.7 (13)	3139.3 (15)	203.2 (15)
1962	194.5 (15)	300.5 (15)	166.6 (15)	96.3 (15)	86.5 (15)	47.2 (15)	124.0 (15)	3257.0 (15)	195.0 (15)
1972	107.8 (15)	208.6 (15)	105.4 (15)	50.0 (15)	30.6 (15)	18.4 (15)	100.1 (15)	3261.2 (15)	162.6 (15)
1977	174.8 (13)	—	—	46.3 (13)	—	—	201.8 (13)	—	—

¹CHPOP (CPOP): Estimate of actual exploitable population using annual recruitment obtained from CPOP.
²CHPOP (CNST): Estimate of exploitable population with constant number of recruits equal to mortality rate times original population.
³Estimate using SPDYN population model with parameter values adopted at the meeting.
⁴Numbers in brackets throughout the table indicate the age at recruitment of the population component estimated.

Eastern CPUE × Eastern Relative Area

Eastern CPUE × Eastern Relative Area +

Western CPUE × Western Relative Area

and similarly for the Western area. The relative areas were determined from a chart provided by Ohsumi as 0.39 (East) and 0.61 (West). The CPUE values used for estimating original abundance were for 1954, 1955 and 1957 (the earliest values available) discarding the 1956 value as aberrant (due to a weather factor) and for current 1975/1977. The results are shown in Table 5:

females are being caught has been introduced, and the tonnage correction factor has been given a maximum value instead of continuing indefinitely as a proportional relationship. Each of these changes has had the effect of reducing the rate of increase of efficiency in recent years and therefore of the rate of any decline in CPUE for males. This in turn has caused current population estimates to be higher in relation to the original than previously.

The Committee agreed that in view of their recommendations it was not necessary to consider 'step procedures' in relation to the catch limits as proposed at this time. How-

Table 5.
Divisional Partition

			Relative Abundance			Estimated Number	
Year		Estimated Number (Total Area)		Western Division	Eastern Division	Western Division	Eastern Division
1947	Males (13+)	235.3	CPUE ¹	3.17	3.52		
			Relative index of abundance	.585	.415	137.7	97.6
1978	Mature Females	280.8	(As above for males)			164.3	116.5
	Males (13+)	132.7	CPUE ²	1.42	2.29		
			relative index of abundance	.508	.492	65.3	67.4
			Ratio 1978 exploitable males to 1947 exploitable males			.474	.691
			Ratio 1978 mature females to 1947 mature females			.805	.956

¹ from CPUE 1954, 1955, 1957, 1958
² from CPUE 1973–77

11. CLASSIFICATIONS AND CATCH LIMITS, INCLUDING POSSIBLE STEP PROCEDURES

On the basis of the population assessments above, the SPVAP program was used adopting the population parameters defined earlier to give MSY levels and yields. The results were:

MSY Level (Total catch by number both sexes

Exploited Males: 47.5% of original
Mature Females: 79.0% of original

Yields

Males: 202 per 10,000 mature females original
Females: 53 per 10,000 mature females original

The Committee agreed to recommend to the Commission the corresponding stock classifications and catch limits as shown in Table 6 for the two management divisions.

The changes in the recommended catch limits since the June 1977 meeting have resulted mainly from changes in the estimated current population sizes compared to the original and has not been caused by any significant change in the relative MSY population levels in the model. The increased estimated relative populations, particularly for males, have been caused principally by the effect of changes in effort modifiers. The Committee in June 1977 noted the need to examine the effect of many possible modifiers in more detail and this has now been done. Three modifying factors have been appreciably altered as a result. The Asdic correction factor has been reduced, a factor for the effective reduction of effort directed towards males when

ever, it agreed that consideration of the principles involved in step procedures should be included in the Agenda of the June 1978 meeting. It noted that this matter had been considered by Fukuda in SC/SPC/5.

Table 6
North Pacific sperm whales, estimated stock sizes, MSYs and recommended catch limits by Divisions

	Western Division	Eastern Division	Total
1947 Stock ('000s)			
Males (≥ age 13)	137.7	97.6	235.3
Females (Mature)	164.3	116.5	280.8
1978 Stock ('000s)			
Males (> age 13)	65.3	67.4	132.7
Females ≥ (Mature)	132.2	111.4	243.6
% 1978/1947 Males	47.4%	69.1%	
% 1978/1947 Females	80.5%	95.6%	
MSY Male	3,319	2,353	5,672
MSY Females	871	617	1,488
MSY Level, Males (> age 13)	47.5%	47.5%	47.5%
MSY Level, Females (Mature)	79.0%	79.0%	79.0%
1978 % MSYL Males	100	145	—
1978 % MSYL Females	102	121	—
Classification, Males	SMS	IMS	
Classification, Females	SMS	IMS	
Catch Limit, Males	2,987	2,118	5,105
Catch limit, Females	784	555	1,339

12. NEED FOR CLOSED SEASON FOR MALES

The Committee reviewed the need for a closed season applying to North Pacific males. It had no new evidence available to alter the conclusion of the June 1977 meeting, that there is a peak in mating in April–May, implying a four month closed season from March to June inclusive. The Committee recommends that a closed season for bulls greater than 45 ft, south of 40°N, should be imposed for the North Pacific for a four month season from March until June.

13. OTHER BUSINESS

13.1 Bowhead Whales

The Committee noted that the meeting had been called specially to discuss sperm whales and the members present were those particularly involved with work on sperm whales. It felt that inadequate notice was given to allow preparations for substantive discussion on bowhead whales.

The Committee was presented with Documents SC/SPC/13, 14 and 15 dealing with the Alaskan bowhead problem. Document 14 is a management and research plan that includes a proposal for the resumption of the kill of Alaskan bowhead whales, that will be presented by the USA to the Commission at the Special Meeting in Tokyo. In the plan, the USA has attempted to answer the criticisms of the Scientific Committee on the management and capture of bowheads by the Alaskan Eskimos.

Tillman summarised SC/SPC/14 and stated that the new proposals put forward now by the USA would be enforced by their federal agencies. The 1978 catch would be limited to 15 landed or 30 struck whales (whichever occurs first within the season), with appropriate effort limitations and the requirement to make fast to the whale before a shoulder gun is used. Biological data would be collected from the proposed catch and an international observer from Denmark would be arranged within the IWC scheme.

The accompanying research plan is aimed at deriving more precise estimates of population abundance, migration and distribution, as well as assessing recruitment and mortality rates. The plan attempts to provide maximum scientific use of any animals which are harvested or recovered. The Committee emphasised that it supports the idea of research being carried out on this very depleted stock. However, the Committee points out that it may be very many years before the information gathered could contribute to developing appropriate management policies, based upon biological data and their use in models; but emphasises that direct counts would be of immediate value.

In document SC/SPC/13 the present population is estimated at about 1,300 whales, compared with an estimate of original abundance of about 18,000 (Mitchell, paper SC/29/Doc 33, submitted to the Scientific Committee meeting, Canberra, 1977). Some consequences of any kill are noted for possible alternative net recruitment rates. For example, if $M = 0.04$ and $r - M = 0.01$, with no kill, the population would rebuild from 1,000 to 10,000 whales in 372 years; an annual kill of 15 whales would lead to extinction. With $r - M = 0.05$ and no kill, the time required to rebuild from 1,000 to 10,000 is 75 years, but 99 years with a continuing annual kill of 30 whales.

Information on the bowhead whale is inadequate to provide any satisfactory guide to management of this population with a non zero quota.

The Committee reiterates its statement of June 1977

that taking of any bowhead whales could adversely affect the stock and contribute to preventing its eventual recovery, if in fact such recovery is still possible.

The Committee re-emphasises the serious consequences of a high rate of exploitation on a small stock which may suffer environmental perturbations. Mitchell pointed out the possibilities and the significance of events such as ice entrapment and resulting mass mortality (SC/29/Doc 33).

The Committee recognises that the Commission may wish to discuss other considerations (subsistence and cultural needs, etc.). These are beyond the expertise of the Scientific Committee.

13.2 Availability of basic data

The Committee emphasised the importance of having access to original data in addition to the derived statistics available in the analyses presented as background documents, particularly when constituted as working group at special meetings. It recognised that examination of such material would be difficult at annual meetings because of the many matters which have to be considered, but accepted that in certain circumstances this would be necessary. Particular attention was drawn to the need for the background data used in deriving the estimates of effort modifiers to be available for the June 1978 Meeting.

13.3 Computer facilities

The Committee considered further the need for computer facilities to be available at its June 1978 Meeting. It noted the tentative arrangements so far discussed by the Secretary with the Cambridge Computer Laboratory, and recommended that the Government of Australia be asked to make the services of Kirkwood available for four weeks before the Meeting to arrange for the storage and operation of the data banks and programmes, and to carry out analyses required for the Meeting.

14. RECOMMENDATIONS

The Scientific Committee recommends:

1. The management of the North Pacific sperm whale stocks based on two Divisions divided by a line specified in the June 1977 Scientific Committee Report (*Rep. int. Whal. Commn* 28:61).
2. Stocks classifications and catch limits:

West Male	SMS	2,987
Female	SMS	784
East Male	IMS	2,118
Female	IMS	555
3. A closed season for males over 45 ft, south of 40°N, for four months, March until June.
4. For the Bering Sea stock of bowhead whales, the Committee reiterates its statement of June 1977 that any take could adversely affect the stock and contribute to preventing its eventual recovery.

ACKNOWLEDGEMENTS

The Committee wishes to record its appreciation of the assistance provided during its meeting by the CSIRO Division of Fisheries and Oceanography, particularly its Chief, Mr D. J. Rochford, and the secretariat provided by members of the Department of Primary Industry.

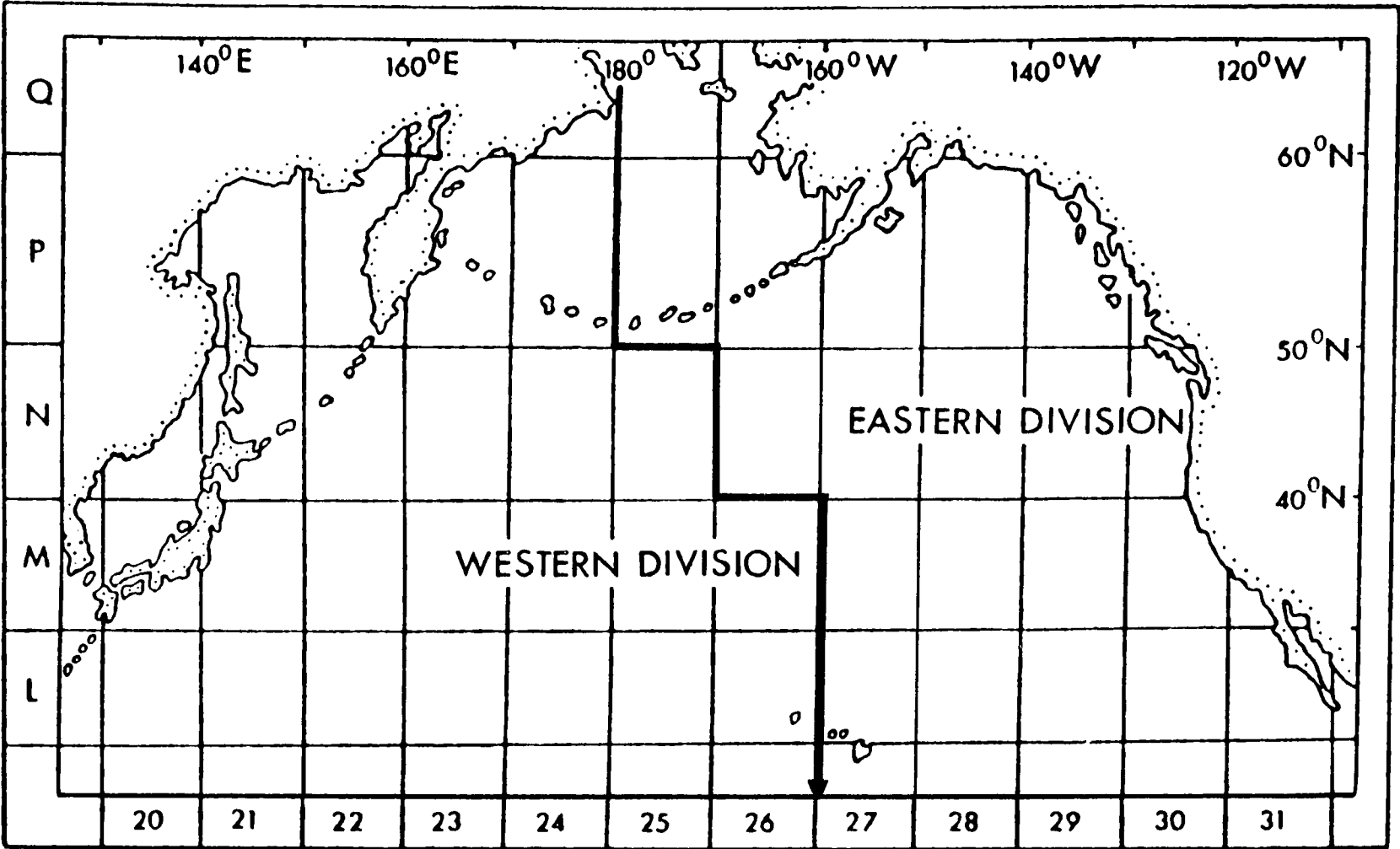


Fig. 1. Sperm whale Divisions in the North Pacific.

Annex A
AGENDA

1. Opening Remarks.
2. Election of Chairman.
3. Appointment of Rapporteurs
4. Adoption of Agenda
5. Review of Documents and Statistical Material
6. Effort Modifiers —
 especially Asdic, other efficiency factors, redirection of effort to females, and changes in distribution of effort.
7. Stock Identity
8. Biological Parameters —
 especially ages at recruitment, pregnancy rates, and changes over time.
9. Population Models
10. Estimates of Initial and Present Population Sizes, and MSY.
11. Classification and Catch limits (including possible 'step' procedures)
12. Need for Closed Season for Males
13. Any Other Business
14. Recommendations for the Commission

Annex B

DOCUMENTS SUBMITTED TO THE MEETING

SC/SPC/

- 1 OHSUMI, S. Catches of sperm whales by modern whaling in the North Pacific.
- 2 OHSUMI, S. Review of Japanese fishing effort on sperm whales in the North Pacific.
- 3 OHSUMI, S. Population assessment of the sperm whale in the North Pacific.
- 4 MASAKI, Y. On the pregnancy rate of the North Pacific sperm whales.
- 5 FUKUDA, Y. A consideration towards possible step procedures.
- 6 ANON, (USSR) Sperm whale catch data in the North Pacific in 1977 (preliminary data, USSR).
- 7 ANON, (USSR) Age-length key for male sperm whales from the North Pacific caught by the USSR fleet in 1977.
- 8 ANON, (USSR) Age-length key for female sperm whales from the North Pacific caught by the USSR fleet in 1977.
- 9 ALLEN, K. R. Size distribution of male sperm whales in the pelagic catches.
- 10 BEDDINGTON, J. R. and KIRKWOOD, G. P. On the mathematical structure of possible sperm whale models.
- 11 KIRKWOOD, G. P. Catch and effort data by 10° square for North Pacific sperm whales.
- 12 FORTOM-GOUIN, J. P. Pregnancy rate of female *Physeter catodon* appears to decrease with increased exploitation.
- 13 BREIWICK, J. M. and CHAPMAN, D. G. Population analysis of the Alaska bowhead whale stock. (Preliminary report).
- 14 ANON, (USA). The United States' conservation program for the bowhead whale (*Balaena mysticetus*) in the Bering, Chuckchi and Beaufort Seas. (Incorporating National Marine Fisheries Service plan for an expanded bowhead whale research program (October 1, 1977 through September 30, 1980).
- 15 ANON, (USA). Taking of bowhead whales by Indians, Aleuts, or Eskimos for subsistence purposes.
- 16 IVASHIN, M. V. and BORODIN, R. G. A note on catch per unit effort trends in USSR North Pacific sperm whale operations.
- 17 CHAPMAN, D. G. Estimates of pregnancy rates – North Pacific.
- 18 CHAPMAN, D. G. Natural mortality rate – males
- 19 BEDDINGTON, J. R. Analysis of the pregnancy rates of sperm whales in the North Pacific.
- 20 MITCHELL, E. D. Alternative interpretations of three stocks of North Pacific sperm whales, *Physeter catodon*.

Catches of Sperm Whales by Modern Whaling in the North Pacific

Seiji Ohsumi

Far Seas Fisheries Research Laboratory

INTRODUCTION

The North Pacific has been recognised as one of the world's major whaling grounds for sperm whales since the 19th century. Even since prehistoric times native peoples living on the coast must have caught and used sperm whales when they stranded or approached the beach, but these catches would have been negligible.

Organised traditional whaling started in Japan in the 16th century, but the sperm whale was not a target of these whaling operations (although they were occasionally caught) because the whaling grounds were close to the coast and the sperm whale is a deep-sea animal. Japanese traditional whaling had ceased by the beginning of the 20th century.

The open boat sperm whale fishery on the high seas which started in New England in the early 18th century, expanded from the Atlantic after 1783. The whaling ground developed in the central Pacific in 1818, and the Coast of Japan ground was opened up in 1820, after which American and European whaling vessels actively took sperm whales in the North Pacific. This type of whaling flourished from 1840–69, but declined rapidly after that period, and had essentially ceased by the beginning of this century. This whaling must have had some effect on the North Pacific sperm whale stocks but no comprehensive catch figures are available for population analysis. According to Best (1976), an estimated 60,842 sperm whales were caught in the North Pacific in the period 1800–1909.

Modern whaling using an explosive harpoon and cannon mounted on a motor boat is generally taken as starting with Svend Foyn's invention in 1864. This type of whaling spread rapidly to many places in the world and was introduced to the North Pacific in 1890.

This paper deals with the catch history of the sperm whale by modern whaling in the North Pacific as a means of assessing its population.

HISTORY OF MODERN WHALING IN THE NORTH PACIFIC

A modern whaling catcher boat was ordered to be built in Norway by a Russian company in 1887. The boat was brought to Vladivostok, and operated in the waters along the east coast of Korea in 1890, but was lost in a storm in January 1891 (Kleinenberg and Makarov, 1955). This is considered to be the first incidence of modern whaling in the North Pacific. In 1894 a second Russian whaling company was established in the Far East with two catcher boats and a floating factory ship, and it engaged in whaling along the coasts of the Sea of Japan from several land stations until 1904 (Kleinenberg and Makarov, 1955).

Modern whaling was introduced to Japan in 1897 and developed rapidly. The whaling ground was limited to the east coast of Korea and western Kyushu for several years, and the sperm whale is not considered to have been caught

by modern whaling until the beginning of this century, as it is not found in those waters. The Japanese coastal whaling ground spread considerably after 1905, and by 1908, 12 whaling companies and 28 catcher boats were engaged in coastal whaling in Japan. (Omura, Matsuura and Miyazaki, 1942).

Kasahara (1950) examined the changes in the Japanese coastal whaling grounds in detail. The grounds were on the east coast of Korea, west Kyushu, Tsushima, Shikoku, Wakayama, Sanriku, Hokuriku and South Sghalien in 1911, and the following grounds then opened: Amami Ohshima in 1913, Hokkaido in 1914, South Kuril, Kwantung and west Korea in 1915, Taiwan in 1920, Bonin Islands in 1923, Middle Kuril in 1928 and North Kuril in 1941. Among these whaling grounds, sperm whales were caught mainly in the Kuril Islands, the Pacific side of Hokkaido, Sanriku, Wakayama, Shikoku and Bonin Islands, and they were occasionally caught in the Okhotsk Sea, East China Sea, Sea of Japan and Taiwan. Japanese coastal whaling lost all land stations in the external territories in 1945, and since then has been limited to the Kyushyu, Hokkaido and Honshyu.

Modern whaling was introduced to the west coast of North America in 1905 (Rice and Wolman, 1971), and at most ten land stations were built along the coasts of California, Oregon, Washington, British Columbia and Alaska (Kasahara, 1950). Land stations in Alaska operated until 1939, British Columbian whaling lasted until 1967, land stations in Washington closed in 1926, a land station in Oregon operated from 1961 to 1965 and the Californian land station closed in 1972. The USSR reopened land stations on the Kuril Islands which were built by Japanese whalers before the Second World War, in 1948, and engaged in coastal whaling until 1964.

Floating factory ships were used from the early stages of modern whaling in the North Pacific. These early floating factories could only operate in sheltered anchorages, because the whales were flensed while floating alongside the ship. A floating factory ship, *Mihael*, which belonged to a Russian whaling company operated along the east coast of Korea in 1903 and 1904 (Kleinenberg and Makarov, 1955). According to Kellogg (1931, cited by Kasahara, 1950), two floating factories operated along the Pacific coast of North America in 1912. A Norwegian factory ship *Capella I* engaged in whaling off Baja California (Rice and Wolman, 1971) in 1914. Norwegian whaling interests operated three factory ships along the coast of Baja California from 1925 to 1929: *Kommandoren I* 1925–27, *Mexico* 1925–26 and *Esperanza* 1927–29. *Kommandoren I* also engaged in whaling off Kamchatka in 1925 and 1926. An American floating factory, *Lansing*, operated in California from 1927–30, when she was replaced by *California*, which operated until 1937 (Rice and Wolman, 1971).

The appearance in 1925, of a new type of floating factory ship with a stern slipway, permitted whalers to

operate on the high seas. The Soviet factory ship *Aleut* was the first example of this new type of floating factory to operate in the North Pacific. After operating in the tropical waters of the North Pacific in 1932, *Aleut* engaged in pelagic whaling in the northern part of the North Pacific until 1967. The Japanese factory ship *Tonanmaru* and her whaling fleet operated in the waters off Kamchatka and the west Bering Sea in 1940 and 1941. Even during the Second World War, the *Aleut* whaling fleet continued pelagic whaling, although *Tonanmaru* had ceased operations by the beginning of the Pacific War.

Japanese whaling was seriously damaged by the War, and all six factory ships and many catcher boats were lost. In 1946 the General Headquarters of the Allied Powers allowed a whaling fleet to operate in the waters around the Bonin Islands which were occupied by United States Forces. A small transport vessel operated in these grounds in 1947 and 1948, and Bonin Islands pelagic whaling was continued by one or two floating factory ships for four years until 1952.

A Japanese factory ship *Baikarumaru* reopened pelagic whaling in the northern part of the North Pacific in 1952 after operating around the Bonin Islands in the same year. A further Japanese whaling fleet was added in 1954, and another in 1962 and three fleets continued pelagic whaling in the North Pacific from 1962 to 1975. Since 1976 only one Japanese fleet has been operating.

The Soviet whaling fleets increased rapidly after 1962, although only the *Aleut* fleet had operated until 1961, and four Soviet whaling fleets engaged in pelagic whaling in the North Pacific from 1963 to 1967. Two Soviet whaling fleets have been operating since 1970 except in 1974 when three fleets operated.

Table 1 shows the yearly change in number of land stations, whaling fleets and catcher boats engaged in modern whaling in the North Pacific from 1911 to 1976. Information was obtained from Tables by Kasahara (1950) and the International Whaling Statistics, and some were corrected by other data. Land stations reached a maximum of 39 in 1914, and gradually decreased until the end of the Second World War. After the War land stations slowly recovered in number until 1958 when there were 32, but have been rapidly decreasing since then and there were only 5 in 1976. The number of catcher boats which engaged in coastal whaling was about 40 before the War, although there were yearly fluctuations. It decreased during the War to 22, and then gradually recovered until 1958, when 72 boats operated. The number of boats has been decreasing since then, and there were 12 in 1976. Whaling fleets numbered three or less until 1961, and increased to seven in 1963. Since 1968 the number of whaling fleets has been decreasing and there were three in 1976. Catcher boats belonging to whaling fleets numbered less than 12 until 1953, but had increased to 74 in 1965 and 1966. They have been decreasing since then, and there were 26 in 1976.

It must be recognised that all land stations or whaling fleets did not always take sperm whales. There were land stations in areas where sperm whales were not found and some Japanese fleets only took baleen whales.

CATCHES

As noted above, sperm whales are thought to have first been taken by modern whaling in the North Pacific at the earliest in 1905. Some catch statistics are available since 1910 as shown in Appendix Tables I and II, but they are incomplete

before 1946. The figures in the Tables are based on Kasahara (1950) for the period before 1946, and the International Whaling Statistics for the latter period. The number of

Table 1.
Numbers of land stations, fleets and catcher boats for modern whaling in the North Pacific.

Year	Coastal		Pelagic		Total Boats
	Stations	Boats	Fleets	Boats	
1911	30+	32+	—	—	32+
1912	32?	35?	2	2?	37?
1913	31?	35?	—	—	35?
1914	39	48?	1	4?	52
1915	36?	43?	—	—	43?
1916	37?	45?	—	—	45?
1917	?	?	—	—	?
1918	37?	45?	—	—	45?
1919	36	45	—	—	45
1920	37?	45?	—	—	45?
1921	28	27	—	—	27
1922	31	46?	—	—	46?
1923	32	46?	—	—	46?
1924	32	44?	—	—	44?
1925	32	44?	3	9?	53?
1926	33	40?	3	9?	49?
1927	33	45?	3	9?	54?
1928	29	41?	2	7?	48?
1929	27	41?	2	7?	48
1930	29	44?	1	3?	47
1931	24	26	—	—	26
1932	24	30?	2	5?	35
1933	23	29?	2	5?	34
1934	28	34?	2	5?	39
1935	24	35?	3	7?	42
1936	20	38?	2	7?	45
1937	21	36?	2	7?	43
1938	18	55	1	3	58
1940	20?	48?	2	7	55?
1941	22	53	2	10	63
1942	19	22	1	3	25
1943	22	25	1	3	28
1944	25	25	1	3	28
1945	16	26	1	3	29
1946	23	25	2	5	30
1947	20	27	3	10	37
1948	27	41	3	9	50
1949	24	40	2	8	48
1950	22	41	2	8	49
1951	24	46	2	8	54
1952	24	42	2	11	53
1953	24	43	2	9	52
1954	24	44	3	15	59
1955	25	44	3	18	62
1956	26	48	3	20	68
1957	24	50	3	22	72
1958	32	72	3	22	94
1959	28	61	3	26	87
1960	28	57	3	24	81
1961	27	58	3	30	88
1962	24	53	5	49	102
1963	20	38	7	67	105
1964	19	37	7	67	104
1965	12	28	7	74	102
1966	12	29	7	74	103
1967	11	26	7	61	87
1968	9	17	6	64	81
1969	8	17	6	58	75
1970	8	17	5	57	74
1971	7	15	5	54	69
1972	8	12	5	44	56
1973	8	12	5	68	80
1974	7	12	6	50	62
1975	5	12	5	44	56
1976	5	12	3	26	38

sperm whales which were caught but lost is included in the total number, so that the sum of males and females does not always coincide with the total figure.

Complete catch statistics for Japanese and Kuril coastal whaling were reported by Japanese whalers, but most of the pre-War data were burned during the War. Kasahara (1950) reported detailed statistics on 16 sub-areas (including the external territory) for Japanese coastal whaling until 1949. Detailed catch statistics have been reported from the Japan Whaling Association every year.

The catches of sperm whales in the coastal waters of Japan increased gradually from 102 in 1910 to 839 in 1940. Although they decreased during the Pacific War, they again increased after the War, and reached 2,588 in 1958. The Japanese Government began to set national quotas in 1959 in order to prevent any further increase in catches by coastal whaling. Since 1971 the IWC has set quotas for North Pacific sperm whales and the catch in 1976 was 2,487.

Sperm whales began to be caught in the Kuril Islands in 1919 by Japanese whalers and catches increased gradually but these land stations were abandoned after the defeat. The USSR reopened some of these land stations, and began coastal whaling in 1948. The catch reached 2,184 in 1958, but stopped in 1965.

Land stations worked from 1905 to 1939 in Alaska, but the sperm whale catches were not large (with a maximum of 95). Coastal whaling in British Columbia, Canada, began at the beginning of this century, but the catch statistics are not clear in the early period. Although whaling was suspended at these land stations several times, coastal whaling continued until 1967. The maximum catch of sperm whales was 320. Coastal whaling along the west coast of the USA operated in Washington, Oregon and California from the beginning of this century. Pelagic whaling by the old-type floating factory also operated along the coast of California and Baja California until 1937. Catches of sperm whales ceased by 1937, but they are estimated to be less than 30 during these periods. Coastal whaling in this area was suspended several times, but continued until 1971. The maximum catch was 104. The catches by floating factory fleets are included in the figures in Appendix Table II.

Japan started pelagic whaling in the northern part of the North Pacific in 1940, but Japanese pelagic whaling was suspended by the outbreak of the Pacific War in 1941. Pelagic whaling around the Bonin Islands operated from 1946 to 1952, but the maximum sperm whale catch was only 201 there. The catch of sperm whales by pelagic whaling in the northern part of the North Pacific reopened in 1954. The Japanese Government began to set national quotas for pelagic whaling in 1957 to regulate the fishery (see later) so that catches were not greatly increased by Japanese pelagic whaling, and were 3,000 at maximum.

A Norwegian floating factory operated along the coast of Kamchatka in 1925 and 1926, but the catches of sperm whales were only 17 and 35 respectively.

The USSR has continued pelagic whaling since 1932 in the North Pacific, and even during the War it was not suspended. The catches of sperm whales gradually increased, and they became very large from 1963, reaching 9,542 in 1968. The North Pacific Commissioners Meeting was established in 1966, and continued to discuss the methods of regulation of the whale stocks of the North Pacific until the Meeting reached agreement in 1969 to reduce catches of pelagic whaling in 1970, and the catch in 1976 was 3,671.

The accumulated total catches of sperm whales by

modern whaling from 1910 to 1976 is 268,972 according to Appendix Table II. Some other sperm whales must have been caught during the period, but the numbers are not thought to have been significant. Catch figures by sex were incomplete until 1947. The recorded total catches of males and females are 188,932 and 60,473 respectively.

Fig. 1 shows the yearly change in the catch of sperm whales by modern whaling in the North Pacific. The sperm whale catch increased slowly until the beginning of the Pacific War, but at its maximum was only 1,890 in 1941 and had decreased by the end of the War. After the War it increased very rapidly, and reached 16,320 in 1968. Since the setting of catch limits in 1970, the catch has been rapidly reduced and was 7,211 in 1976.

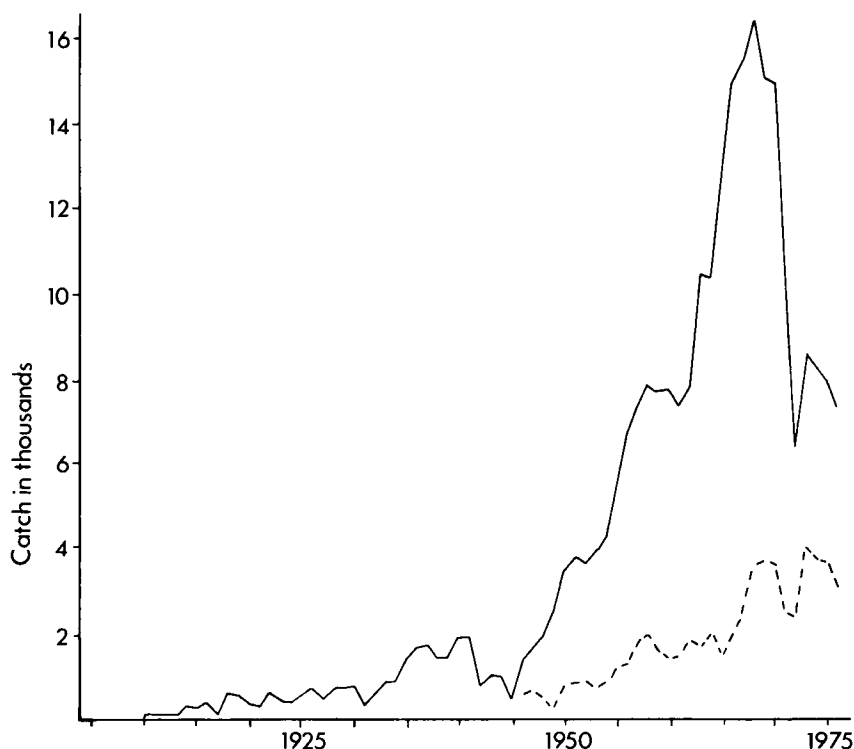


Fig. 1. Yearly change in catch of sperm whales by modern whaling in the North Pacific, 1910–1976.

Solid line: Total catches, Broken line: Female catches.

The catch of female sperm whales before the end of the War is uncertain, but the annual catch is estimated at less than 600 at maximum during the period. It increased gradually after the War, but the rate was not as high as for males. The female catch reached 3,962 in 1973, when catch limits were set by sex and the legal size limit was reduced. In 1976 it was 3,011.

CHANGE IN THE PELAGIC WHALING GROUND

Coastal whaling is passive and the whaling ground is limited to within 300 miles of a land station at most whereas pelagic whaling, especially using a factory ship with a stern slipway, can operate in any waters.

The operations with old-type floating factory ships were limited to along the coasts of Baja California, California and Kamtchatka. The first new-type factory ship *Aleut* operated in the tropical waters of the North Pacific in 1932, but her whaling ground was limited to along the coasts of the Kuril Islands, Kamtchatka and Komandor Islands until 1954. The operation of *Tonanmaru* in 1940 and 1941 was also in similar grounds. Japanese pelagic whaling in 1946/52 operated in the very narrow waters around the Bonin Islands.

Fig. 2 shows the 10° squares which have been used by the IWC Scientific Committee and Fig. 3 shows the records of operations to take sperm whales in each 10° square from 1954 to 1976. Data are based on the CDWs of Japanese and

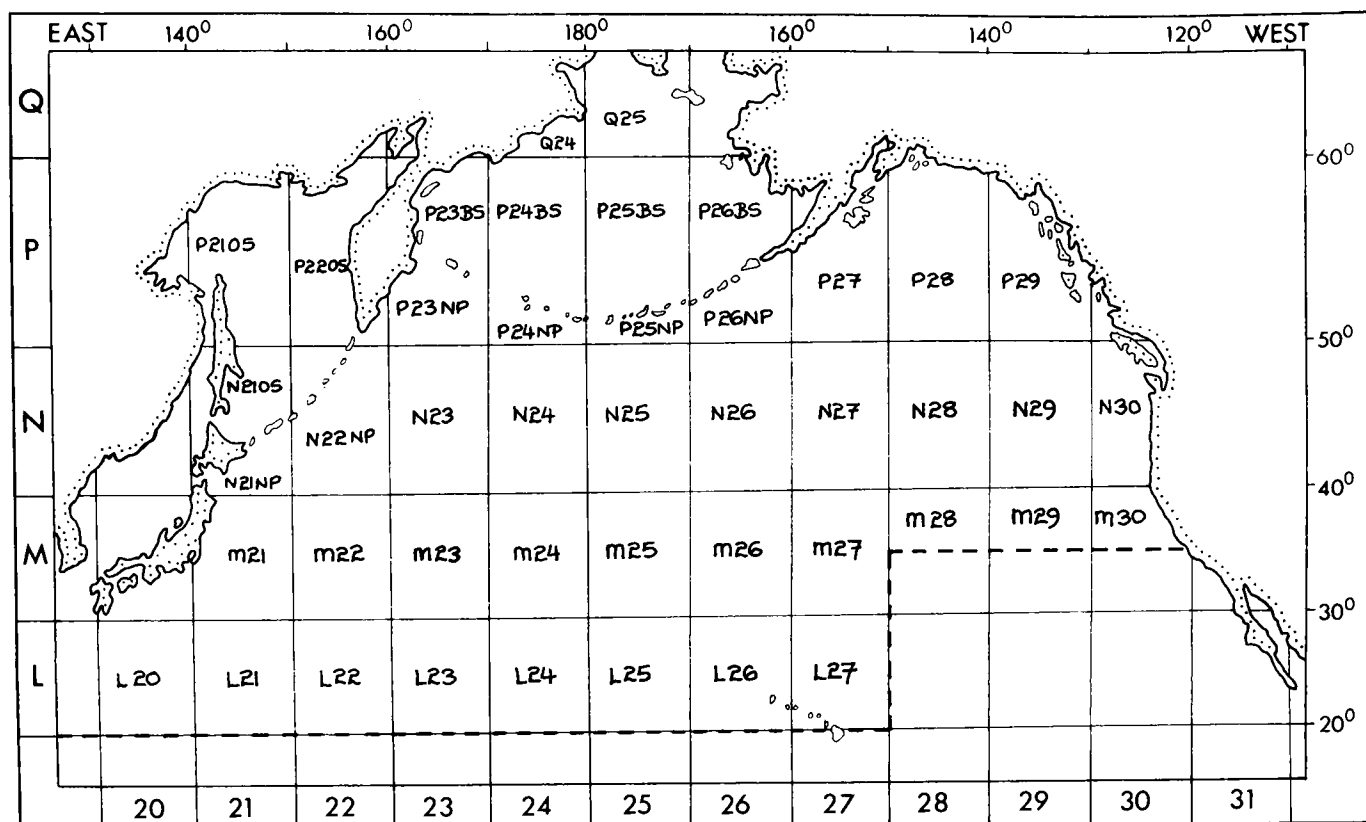


Fig. 2. Map of the North Pacific and positions of 10° Squares for Fig. 3.

Soviet fleets. These data have been exchanged among the four countries with an interest in the North Pacific for the North Pacific Working Group of the Scientific Committee.

Until 1960 the pelagic whaling ground of Japanese fleets was around the Aleutian Islands, but it developed into the Gulf of Alaska in 1961. It was further extended to the waters south of 50°N in 1967, and the main whaling ground moved gradually to the southern waters. Japanese whaling fleets have not operated in the waters around the Aleutian Islands since 1973. They began to operate in Zone M (30°–60°N) in 1972, and they have even been operating in Zone L (20°–30°N) since 1973.

Soviet fleets also developed their whaling ground eastward in the waters of Zone P (50°–60°N), and reached the Gulf of Alaska in 1962. They also developed their whaling ground southwards earlier than the Japanese fleets. They operated widely in Zone N in 1963, in Zone M in 1966, and Zone L in 1973. Their main whaling ground moved southwards accordingly and since 1970 they have essentially not operated in Zone P.

The changes in the sperm whaling grounds are closely linked with the change in the main target species of baleen whaling. The fin whale was the main object of pelagic whaling until the early half of the 1960s, and it is mainly found north of 50°N in the whaling season. However, it was succeeded by the sei whale in the latter half of the 1960s, which is found mainly in Zone N in the summer. Bryde's whales began to be caught by pelagic whaling in 1970, and they are found in Zones M and L. Baleen whales are the main object of Japanese pelagic whaling and the sperm whale catch and whaling ground is affected by the whaling ground of baleen whales.

REGULATION OF WHALING FOR THE SPERM WHALE

In view of the rapid expansion of modern whaling, the Japanese Government promulgated regulations on whaling in 1909 which placed whaling enterprises under a license system, and it has been controlled by limiting catch effort and other methods.

The International Whaling Agreement in Geneva in 1931 did not include items on the regulation of sperm whaling, although it became the basis for later Conventions on

whaling. The International Whaling Treaty was signed in 1937 to regulate the world's whale resources, and a Protocol was signed in 1938. In 1939 a Resolution was formulated and signed. The present International Convention for the Regulation of Whaling was signed in Washington DC in 1946, and the International Whaling Commission was established in 1948.

There have been many methods of regulating whaling both internationally and nationally. The following are main methods used concerning with the regulation of sperm whaling in the North Pacific.

Fishing effort

The Japanese Government has been regulating fishing effort under a license system. The number of catcher boats used in coastal whaling was limited to 30 and less in 1909, and it has been reduced gradually since then. Twelve catcher boats were licensed in 1976. The size and number of catcher boats attached to a whaling fleet has also been regulated by the Government.

There has been no international effort regulation for the North Pacific sperm whale.

Size limit

The legal minimum size limit for the sperm whale was set at 35 feet in the International Whaling Treaty in 1937, and was amended to 30 feet for coastal whaling in 1938. Although Japan did not adhere to the Treaty, the Government adopted this regulatory measure in 1938. With the coming into effect of the International Convention for Regulation of Whaling, the minimum size limit became 35 feet for both coastal and pelagic whaling in 1949. It was later amended to 38 feet for pelagic whaling from 1952. The minimum size limit was changed to 30 feet for both coastal and pelagic whaling along with the setting of catch limits by sex in 1973.

Whaling season

The IWC decided to regulate the length of the coastal whaling season to take sperm whales at the 1951 Annual Meeting, and it has been limited to eight successive months since February 1952. The Japanese Government set it from April–November until 1965, and then to May–December

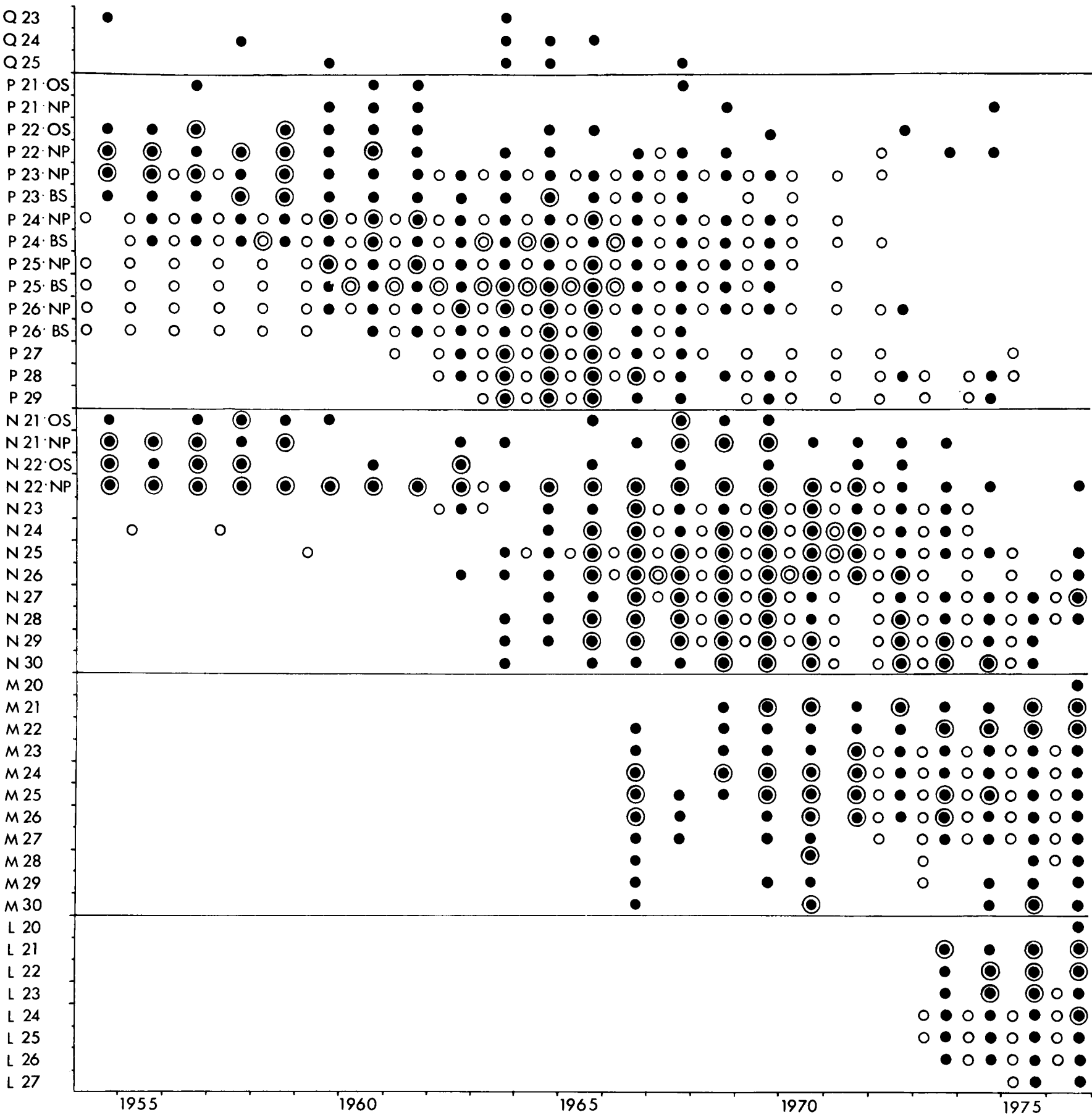


Fig. 3 Yearly change in the pelagic whaling grounds of the Japanese and Soviet whaling fleets in the North Pacific.
○,◐: Japanese fleets; ●,◑: Soviet fleets; ○,●: ≤200 CDW; ◐,◑: >200 CDW.

from 1966. It was further changed to August–March from 1976.

The limitation of the pelagic sperm whaling season to eight successive months was adopted in 1952 and this was amended to any eight months in 1975.

Whaling ground

Pelagic whaling to take baleen whales has been permitted in the North Pacific since the 1937 Treaty. The IWC amended the Schedule so that it was forbidden to use a whale catcher attached to a factory ship for the purpose of killing or attempting to kill sperm whales in the waters between 40°S and 40°N at the 1965 Annual Meeting, but Japan, Norway and the USSR objected to this amendment. This subparagraph of the Schedule was deleted in 1973.

The Japanese Government limited the pelagic whaling

ground to 45°N in 1952. This was changed in 1967 and 1972 (Ohsumi, 1978), and it is now limited to the waters east of 159°E to prevent competition with coastal whaling.

Catch quota

The catch quota system is the best way to regulate whaling, but it should be based on the proper assessment of populations. The North Pacific Working Group was established among the members of the Scientific Committee of the IWC to assess whale populations in the North Pacific in 1961, and it had several meetings in 1968. The sperm whale sub-committee was also established in the Scientific Committee in 1962, and it has been continuing its work.

The Japanese Government set catch limits for the sperm whale to control the increase in the catch by pelagic whaling in 1957, and it continued this system until the

international agreement on the setting of catch limits in 1969. The Government also set sperm whale catch limits for coastal whaling in 1959, but this stopped in 1967.

The Commissioners of four countries which were concerned with North Pacific whaling began to examine rational regulation measures at a meeting in 1966, and they finally reached an agreement to reduce the catch of sperm whales by pelagic whaling in 1969. Thus, the catch limits for pelagic sperm whaling by Japan and the USSR in 1970 were agreed to be a reduction of 10% on the 1968 catches. The Commissioners agreed to set a limit for coastal whaling as well as pelagic whaling in the next year. It was accepted at the 23rd Annual Meeting of the IWC in 1971 that the total catch limit should be included in the Schedule.

Catch limits by sex have been set for the sperm whale in the North Pacific since 1973.

Table 2 shows the values of national and international sperm whale catch limits in the North Pacific for each year. The quotas of coastal and pelagic whaling have been exchangeable in Japan.

International Observer Scheme

The International Observer Scheme which began to be discussed in the IWC in 1955 (Shigeta, 1964) was finally agreed upon at the 1971 Annual Meeting and has been

continuing since 1972 in the North Pacific. Japan and USSR exchange observers on their whaling fleets, and US observers work in the land stations in Japan.

REFERENCES

- Best, P. B. 1976. A review of world sperm whale stocks. Paper FAO/ACMRR/MM/SC8, Rev. 1 (limited), FAO Consultation on Marine Mammals, Bergen, 126pp.
- Committee for International Whaling Statistics. 1930–1976. *International Whaling Statistics*, I–LIVIII.
- Kasahara, A. 1950. Whaling and its resources in the waters adjacent to Japan. *Rep. Lab. Nippon Suisan Co. Ltd.* 4: 1–103 with attached figures (in Japanese).
- Kellogg, R. 1931. Whaling statistics for the Pacific coast of the North Pacific. *J. Mamm.* 12: 73–77.
- Kleinenberg, S. E. and Makarov, T. I. 1955. *Whaling in USSR* (in Russian, translated by Sakiura, Y. into Japanese in 1956). 101 pp.
- Ohsumi, S. 1978 New whaling ground in the North Pacific and some problems on management of whale resources. *J. Fish. Ocean Soc.* 22: 41–45 (in Japanese).
- Omura, H. Matsuura, Y. and Miyazaki, I. 1942. *Whales – Their science and practice of whaling*. 319 pp. Suisan-Sha (in Japanese).
- Rice, D. W. and Wolman, A. A. 1971. The Life History and Ecology of the Gray Whale (*Eschrichtius robustus*). *Amer. Soc. Mammalogists Special Pub.*, No. 3, 142 pp.
- Shigeta, Y. 1964. *Progress of Whaling after the War*. Ministry of Foreign Affairs. 159 pp. (in Japanese).

Appendix Table 1
Catches of sperm whales in the North Pacific – I.

	Japan, coastal			Kuril, coastal			Japan, pelagic			USSR, pelagic		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
1910	51	51	102	—	—	—	—	—	—	—	—	—
1911	61	93	162	—	—	—	—	—	—	—	—	—
1912	—	—	107	—	—	—	—	—	—	—	—	—
1913	—	—	77	—	—	—	—	—	—	—	—	—
1914	191	113	304	—	—	—	—	—	—	—	—	—
1915	—	—	252	—	—	—	—	—	—	—	—	—
1916	—	—	389	—	—	—	—	—	—	—	—	—
1917	—	—	40	—	—	—	—	—	—	—	—	—
1918	—	—	576	—	—	—	—	—	—	—	—	—
1919	246	214	460	1	—	1	—	—	—	—	—	—
1920	—	—	245	—	—	—	—	—	—	—	—	—
1921	138	161	299	2	—	2	—	—	—	—	—	—
1922	238	312	550	17	—	17	—	—	—	—	—	—
1923	—	—	332	—	—	32	—	—	—	—	—	—
1924	—	—	318	—	—	18	—	—	—	—	—	—
1925	—	—	432	—	—	47	—	—	—	—	—	17*
1926	366	205	571	55	—	55	—	—	—	—	—	35*
1927	—	—	441	—	—	9	—	—	—	—	—	—
1928	—	—	516	—	—	101	—	—	—	—	—	—
1929	—	—	504	—	—	102	—	—	—	—	—	—
1930	—	—	618	—	—	135	—	—	—	—	—	—
1931	—	—	289	—	—	70	—	—	—	—	—	—
1932	248	228	476	91	—	91	—	—	—	—	—	14
1933	—	—	429	—	—	189	—	—	—	—	—	57
1934	281	286	567	221	5	226	—	—	—	—	—	74
1935	—	—	793	—	—	212	—	—	—	—	—	94
1936	—	—	768	—	—	367	—	—	—	—	—	113
1937	—	—	659	—	—	554	—	—	—	—	—	198
1938	—	—	433	—	—	625	—	—	—	—	—	64
1939	—	—	682	—	—	601	—	—	—	—	—	156
1940	—	—	839	—	—	467	—	—	213	—	—	213
1941	396	442	838	393	67	460	—	—	164	—	—	194
1942	137	34	171	255	1	256	—	—	—	—	—	215
1943	162	212	374	325	28	353	—	—	—	—	—	216
1944	391	299	690	235	65	300	—	—	—	—	—	50
1945	—	—	240	—	—	26	—	—	—	—	—	206
1946	482	475	957	—	—	—	25	47	72	—	—	316
1947	450	514	964	—	—	—	58	137	201	457	15	472
1948	429	394	823	370	20	394	49	82	131	561	9	570
1949	436	63	501	867	119	986	72	13	85	731	43	774
1950	820	423	1,249	1,166	305	1,471	58	5	63	530	57	587
1951	923	360	1,283	1,064	398	1,462	59	1	60	702	62	765
1952	686	382	1,071	1,154	474	1,641	18	—	18	721	10	731
1953	812	373	1,186	1,165	329	1,521	—	—	—	833	20	865
1954	942	542	1,487	956	191	1,192	490	—	490	749	65	817
1955	867	639	1,506	989	464	1,494	1,080	—	1,084	932	52	996
1956	1,224	901	2,125	1,409	280	1,693	1,593	—	1,598	973	22	998
1957	1,048	1,313	2,361	1,457	346	1,821	1,699	—	1,700	1,125	46	1,174
1958	1,210	1,366	2,588	1,579	562	2,184	1,499	—	1,500	1,430	—	1,430
1959	926	1,184	2,111	1,561	308	1,878	1,798	2	1,800	1,540	18	1,560
1960	1,008	1,113	2,121	1,241	244	1,487	1,798	1	1,800	2,188	40	2,228
1961	986	1,124	2,110	1,142	244	1,401	1,765	35	1,800	1,861	5	1,868
1962	614	1,071	1,685	1,048	261	1,347	2,546	3	2,549	1,593	358	1,955
1963	761	954	1,715	589	66	659	2,692	7	2,700	4,547	570	5,125
1964	949	850	1,800	260	190	452	2,442	17	2,460	4,580	842	5,432
1965	996	804	1,800	—	—	—	2,434	26	2,460	7,652	519	8,196
1966	994	1,107	2,101	—	—	—	2,834	166	3,000	8,968	468	9,476
1967	1,198	1,437	2,635	—	—	—	2,665	335	3,000	8,929	453	9,430
1968	1,254	2,493	3,747	—	—	—	2,414	586	3,000	9,081	445	9,542
1969	1,855	1,812	3,667	—	—	—	2,015	985	3,000	7,424	774	8,198
1970	1,613	1,871	3,484	—	—	—	2,353	347	2,700	7,236	1,331	8,567
1971	1,653	1,673	3,326	—	—	—	1,517	286	1,803	5,052	460	5,512
1972	1,379	1,641	3,020	—	—	—	1,342	225	1,567	1,311	425	1,736
1973	1,117	1,319	2,436	—	—	—	1,442	360	1,802	2,046	2,283	4,329
1974	1,194	1,167	2,361	—	—	—	1,342	461	1,803	1,883	2,080	3,963
1975	1,271	1,035	2,307	—	—	—	1,222	581	1,803	1,768	1,982	3,750
1976	1,737	750	2,487	—	—	—	483	570	1,053	1,980	1,691	3,671

* Norwegian fleet.

Appendix Table 2
Catches of sperm whales in the North Pacific – H.

	Alaska, coastal			Canada, coastal			USA, coastal			Grand total		
	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total		
1910	?	—	—	?	—	—	?	51	51	102		
1911	?	—	—	?	—	—	?	69	93	162		
1912	(30)	—	—	?	—	—	?	—	—	137		
1913	(52)	—	—	?	—	—	?	—	—	129		
1914	43	—	—	?	—	—	?	191	113	347		
1915	25	—	—	(23)	—	—	?	—	—	300		
1916	20	—	—	(6)	—	—	?	—	—	415		
1917	51	—	—	(36)	—	—	?	—	—	127		
1918	?	—	—	(69)	—	—	?	—	—	645		
1919	95	—	—	35	—	—	22	247	214	613		
1920	90	—	—	56	—	—	15	—	—	406		
1921	1	—	—	—	—	—	—	140	161	303		
1922	69	—	—	38	—	—	10	255	312	684		
1923	16	—	—	94	—	—	15	—	—	489		
1924	17	—	—	83	—	—	5	—	—	441		
1925	33	—	—	76	—	—	6	—	—	611		
1926	1	—	—	80	—	—	4	421	205	746		
1927	3	—	—	82	—	—	3	—	—	538		
1928	24	—	—	83	—	—	2	—	—	726		
1929	12	—	—	146	—	—	—	—	—	764		
1930	36	—	—	?	—	—	?	—	—	789		
1931	—	—	—	—	—	—	—	—	—	359		
1932	2	—	—	?	—	—	?	339	228	583		
1933	3	—	—	(190)	—	—	?	—	—	868		
1934	21	—	—	?	—	—	?	502	291	888		
1935	70	—	—	175	—	—	?	—	—	1,344		
1936	66	—	—	311	—	—	?	—	—	1,625		
1937	56	—	—	265	—	—	—	—	—	1,732		
1938	63	—	—	252	—	—	—	—	—	1,437		
1939	49	—	—	—	—	—	—	—	—	1,488		
1940	—	—	—	126	—	—	4	261	261	1,862		
1941	—	—	—	233	—	—	1	789	509	1,890		
1942	—	—	—	130	—	—	3	392	35	775		
1943	—	—	—	69	—	—	3	487	240	1,015		
1944	—	—	—	—	—	—	1	625	361	1,041		
1945	—	—	—	—	—	—	—	157	109	472		
1946	—	—	—	—	—	—	—	507	522	1,345		
1947	—	—	—	—	5	—	5	970	666	1,642		
1948	—	28	—	28	31	—	31	1,468	505	1,977		
1949	—	69	—	69	28	—	28	2,203	238	2,443		
1950	—	40	—	40	—	—	—	2,614	790	3,410		
1951	—	136	17	153	26	—	26	2,899	838	3,739		
1952	—	122	4	126	—	—	—	2,701	870	3,587		
1953	—	267	8	275	—	—	—	3,077	730	3,847		
1954	—	215	11	226	—	—	—	3,352	809	4,212		
1955	—	304	16	320	—	—	—	4,172	1,171	5,400		
1956	—	107	20	127	9	—	9	5,315	1,223	6,550		
1957	—	146	44	190	14	—	14	5,489	1,749	7,260		
1958	—	76	36	112	8	—	8	5,802	1,964	7,822		
1959	—	215	45	260	16	1	17	6,056	1,558	7,626		
1960	—	—	—	—	14	2	16	6,249	1,400	7,652		
1961	—	—	—	—	61	43	104	5,815	1,451	7,283		
1962	—	108	64	172	46	14	60	5,955	1,771	7,768		
1963	—	96	51	147	75	2	77	8,760	1,650	10,432		
1964	—	60	45	105	55	9	64	8,346	1,953	10,314		
1965	—	72	78	151	82	15	97	11,236	1,442	12,704		
1966	—	132	97	229	37	9	46	12,965	1,847	14,852		
1967	—	140	164	304	28	22	100	12,960	2,411	15,419		
1968	—	—	—	—	37	47	84	12,772	3,532	16,320		
1969	—	—	—	—	28	40	68	11,322	3,611	14,933		
1970	—	—	—	—	32	32	64	11,234	3,581	14,815		
1971	—	—	—	—	28	19	47	8,250	2,438	10,688		
1972	—	—	—	—	—	—	—	4,032	2,291	6,323		
1973	—	—	—	—	—	—	—	4,605	3,962	8,567		
1974	—	—	—	—	—	—	—	4,419	3,708	8,127		
1975	—	—	—	—	—	—	—	4,261	3,598	7,860		
1976	—	—	—	—	—	—	—	4,200	3,011	7,211		

Criticism on Japanese Fishing Effort for Sperm Whales in the North Pacific

Seiji Ohsumi

Far Seas Fisheries Research Laboratory

INTRODUCTION

Catch per unit effort (CPUE) has been regarded as an index of density of whale populations and catch and fishing effort data are needed for its calculation. Catcher's days' work (CDW) has been used to represent the fishing effort of whaling, but it is very difficult in practice to obtain real fishing effort data because whaling operations are conducted in a complex manner, and CDW is too simple an index of fishing effort. Since the Committee of Three, the IWC Scientific Committee has been trying to obtain more reasonable fishing effort data and hence CPUE, because the latter has been of fundamental importance in the assessment of whale populations. Nevertheless, a thorough criticism has not yet been carried out for each whale stock.

The Scientific Committee has tried to correct raw and apparent CDW with efficiency of catcher boat, weather factors, etc., but I think an analysis of actual whaling operations is fundamental to understanding the real fishing effort of whaling. In this paper I examine the operational processes of catcher boats in order to better understand the meaning of CDW, correction factors such as the efficiency of catcher boats and weather conditions and finally the change in whaling grounds and the sex composition of the catch, to help in appreciating the problems of adopting CPUE for population assessment. All of the criticism is based on the catch data of sperm whales in the North Pacific by Japanese coastal and pelagic whaling.

MEASUREMENT OF CDW FOR SPERM WHALES

The CDW (accumulated catcher days for all catcher boats) has been used as an index of fishing effort in Japanese whaling, although detailed operation times have been recorded in pelagic whaling since 1977. The catch and effort statistics since 1949 have been circulated to the four countries of the North Pacific Working Group which was established in 1961. The measurement of CDW for the sperm whale in Japan is complicated, and is explained here in order to better understand Japanese fishing effort data.

Coastal whaling

There was no limit to the length of the coastal whaling season for sperm whales in Japan until 1952. Since then the whaling season has been limited to six months for baleen whales and eight months for sperm whales. The first six months, which started in April from 1953 to 1965 and in May from 1966 to 1975, were used for baleen and sperm whales (the baleen whaling season), and the later two months were only used for sperm whales (the sperm whaling season). Sperm whales have been caught from August to March of the next year since 1976. As the baleen whaling season lasts from April to September, sperm whales are now only caught during two months of the baleen whaling season.

The CDW of sperm whales in Japanese coastal whaling is measured as gross catcher days (all days from the start of operations until the end of operations, including no catch days, resting, navigating and towing times as well as searching, chasing and handling times, but excluding holidays during operation) for both the baleen and sperm whaling seasons.

Pelagic whaling

One or two scouting boats have been used for searching for the whaling ground in Japanese pelagic whaling in most years, and towing boats were also used in some years. The work of these kinds of boats is included in the measurement of CDW in pelagic whaling. The problem of whether the work of scouting boats has the same effect on efficiency as that of the operating catcher boats will be examined later.

As will be seen, sperm whales were only caught after the attainment of the catch quota for baleen whales in the early period, although the catch of sperm whales in the baleen whale season increased gradually each year. However, the main objective remained baleen whales and sperm whales were not taken on most days in the baleen whaling season even if they were found in the whaling ground. Therefore, net catch days (the days when one or more sperm whales were taken) are used for the baleen whaling season.

Sperm whales are taken after or occasionally before the baleen whaling season and whaling fleets which only took sperm whales operated in several years. The gross catch days are used for the measurement of CDW in these two cases.

OPERATIONAL PROCESSES OF CATCHER BOATS

Whaling operations are very complicated, and whaling equipment and methods have been gradually changing, so that it is difficult to explain the operational processes of catcher boats in detail historically, and I only want to explain the standard mode of operation of a catcher boat here.

Pelagic whaling

When a catch quota is allocated to a whaling fleet, a manager and his fleet staff begin to plan and prepare the operation for the coming season. As the crew and most of the workers are permanent employees, the short whaling season is not a major factor in the planning of operations. In order to maximise products from the limited quota, the whale carcasses should be as fresh as possible, and careful flensing and processing are required of the workers. Thus the upper limit of catches per day is determined, and the processing capacity (such as the refrigeration plant) is prepared so as to be suitable for the daily catch limit. The

number of catcher boats attached to the fleet is also calculated on the basis of the daily catch limit. Other vessels and special equipment are prepared accordingly. When the fleet arrives on the whaling ground, operations start. The Japanese fleet has a control room in the factory ship from which the manager and staff examine the operation plans for the next day.

They consider this in the light of the catch data from previous seasons, information on whale sightings and oceanographic conditions from scouting boats, the weather forecast made by staff in the weather room, the processing condition of the whale carcasses etc. and the manager relays the operations schedule to the catcher boats and other vessels.

Catcher boats usually begin operations arranged linearly, separated 10–20 miles from each other, to search for the target species under the instructions of the manager. When a catcher boat finds a school of whales, the boat approaches the school to confirm the whale species, size and if there are any cows and calves. If the school is not suitable for catching the boat continues searching, but if it is suitable, the boat starts to chase a whale and informs the other catcher boats and the steering room on the factory ship. The other boats usually gather at the position the school is found and chase whales co-operatively.

When a harpoon is fired into a whale, the boat manoeuvres the whale in order to be able to pump compressed air into the belly and to tie up the tail with wire. If there is enough time to take further whales, a radio buoy,

flag, radar reflector, floating buoy, etc. are attached to the carcass, and the boat leaves the carcass to search for or to chase other whales. After the catching operation ends, the catcher boat collects any left whale carcasses and tows them to the factory ship. In some years one or two catcher boats engaged solely in towing and in some cases the factory ship moves to the area and the floating carcasses are collected by a small boat. Catcher boats sometimes tow the carcasses to the factory ship during operation time, and then return to the whaling ground. When enough whales have been caught for processing, the manager orders the catcher boats to stop operations and rest for a while even during daylight.

Usually the catching operations of catcher boats end by sunset, while handling and towing often continues after sunset. At the end of operations, the catcher boat can rest and sometimes obtains fuel, fishing equipment, food, water, etc. from the factory ship. The manager could also order a catcher boat to engage in whale sighting, and furthermore, the fleet may move to another whaling ground after the end of a day's operation.

Coastal whaling

Operations of catcher boats in coastal whaling are somewhat different from those in pelagic whaling. The whaling ground is usually a long way from the land station, especially for sperm whales, and thus catcher boats have to sail long distances (100–300 miles) to the whaling ground, and similarly it takes a long time to tow whale carcasses back to the land station. On days when no whales are taken

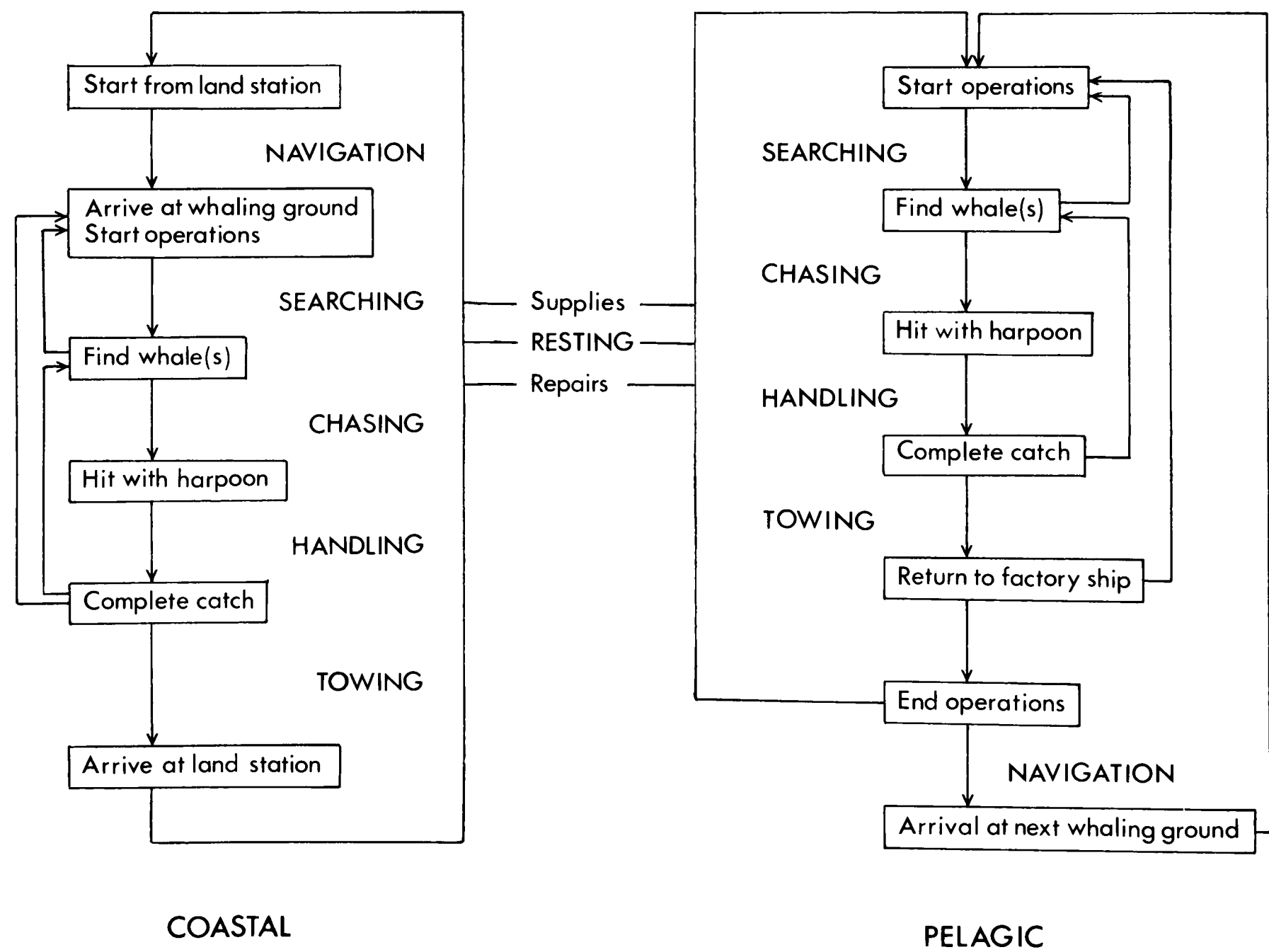


Fig. 1. Catcher boat operations in Japanese whaling.

the catcher boat drifts in the whaling ground during the night. The operational cycle of catcher boats in pelagic whaling is one day, but as we shall see, it is longer than that in coastal whaling.

As there are long towing times in coastal whaling, keeping the carcasses fresh is a major problem. Several slits are made into the blubber to chill the body, but this is laborious work for the crew of a catcher boat. Furthermore, large floating buoys are used when leaving a carcass to chase other whales, because compressed air cannot be used to keep the carcass fresh. Scouting boats are not used in coastal whaling, and catcher boats must tow the carcasses by themselves.

Fig. 1 shows a summary of the operational processes of catcher boats in coastal and pelagic whaling. Operations of catcher boats can be classified into navigation, searching, chasing, handling, towing, resting and other. As would be expected, chasing, handling and towing are not included in no catch days, and navigation is rare in pelagic whaling.

DETAILED OPERATION TIMES OF CATCHER BOATS

As explained above, all the operational processes are included in the CDW. Some of these processes depend on the population density and some do not. To understand the meaning of CDW those factors concerned with each operational process of the catcher boats should be examined and the length of time involved in each process is needed to assess the relative importance of each process in the CDW.

We really need data on the operational times of each process for past years, but unfortunately these data are not available. Ohsumi and Satake (1977) reported operational process times for coastal whaling, but the data came from experimental catches under a special permit, and they are somewhat different from ordinary operations. Detailed data collection was made for pelagic whaling in the North Pacific in 1977 and based on these data, operation process times and related factors are analysed in this section.

Operation times in pelagic whaling

Table 1 shows the average operation times of seven catcher boats attached to the *Kyokuyomaru No. 3* fleet for the 1977 North Pacific sperm whaling season.

There are some individual variations among catcher boats for each item, and average values are used in the following examination. The average searching time is 11.61 hours, if no catch day's operations are included. As catcher boats are searching all day on no catch days, including these days increases the average time for this item. Searching

occupies 49.3% of the CDW, or 83.7% of the total operation time excluding resting and others. The average time to find one sperm whale is 5.83 hrs.

On average 1.19 hrs a day are spent chasing. This is only 5.0% of CDW, or 8.4% of the total operation time. The average chasing time per whale is calculated to be 0.59 hrs (35 minutes) including the time taken if a catcher boat tries to take a whale but abandons the chase without catching it. Fig. 2 shows the relationship between the estimated size of sperm whales caught and the average chasing time. There are large variations in the chasing time, but the average chasing time increases with increasing size of whale. Thus it takes about 22 minutes for 30–35 feet long whales, and 35 minutes for 50–55 feet long whales.

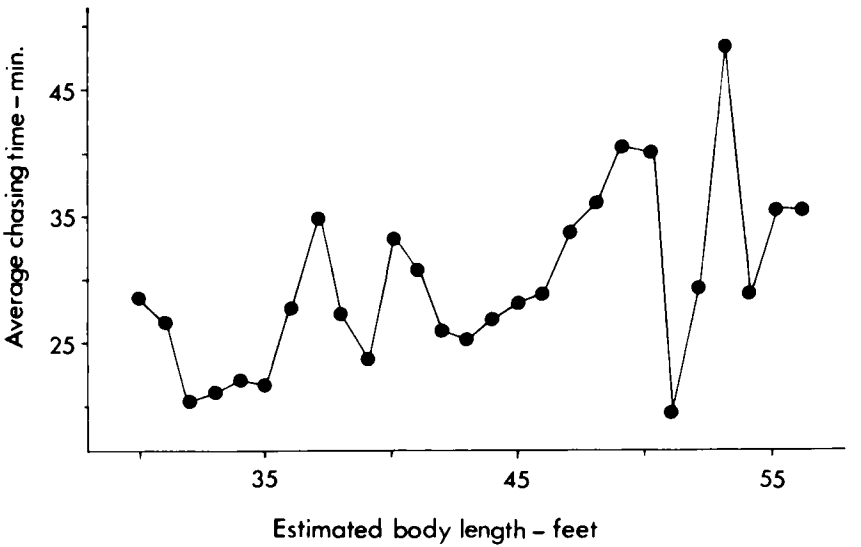


Fig. 2. Relationship between the estimated body length of sperm whales and the average chasing time per whale in pelagic whaling.

The average handling time is 0.66 hrs (40 minutes) which is 2.8% of CDW, or 4.7% of the total operation time. Although handling time changes with the operational conditions, the average time per whale is 0.33 hrs (20 minutes). The handling time becomes shorter, when the carcasses are towed until the end of catching operations.

The towing time is 0.45 hours per day on average which is 1.9% of CDW or 3.4% of the total operation time. There were many cases when the towing time after the cessation of catching was not recorded. Therefore, the actual towing time will be longer than the above value. There were records of 108 towing times and the total time was 180.96 hours, so that the average towing time is 1.68 hours.

Time used for resting, obtaining supplies and other activities totalled 9.87 hours on average, but some towing times after the end of operations are included in this value. Therefore, the actual time for resting etc. is less than this figure. Resting time occupies 41.1% of CDW.

Table 1.

Average operation times (hours per day) of catcher boats in a whaling fleet for the 1977 sperm whaling season in the North Pacific.

Name of boat	<i>Toshi 18</i>	<i>Toshi 25</i>	<i>Kyo 1</i>	<i>Kyo 11</i>	<i>Kyo 27</i>	<i>Shonan</i>	<i>Shonan 2</i>	Total
Catch (sperm)	145	56	132	110	140	118	117	818
Total days	61	36	61	61	61	61	61	402
Searching	11.64	12.24	11.90	11.86	11.67	11.65	12.12	11.83
Chasing	1.23	1.04	1.00	0.98	1.85	1.33	0.83	1.19
Handling	0.50	0.63	0.73	0.65	0.57	0.63	0.93	0.66
Towing	0.53	0.27	0.52	0.54	0.58	0.40	0.24	0.45
Resting etc.	11.10	9.82	9.85	9.97	9.33	9.59	9.88	9.87
Total	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
Catch per day	2.38	1.55	2.16	1.80	2.30	1.93	1.92	2.03

Table 2.
Average operation times (hours) of catcher boats in Japanese coastal whaling.

	Ohsumi & Satake (1977) ¹			Present data ²		
	Per cycle	Per day	Ratio (%)	Per cycle	Per day	Ratio (%)
Cycles	19					
Catch	4.2	1.56		5.8	2.29	
Anchorage	3.36	1.24	5.2	22.6	8.93	37.2
Drifting	11.42	4.23	17.6			
Navigating	12.20	4.52	18.8			
Searching	9.00	3.33	13.8			
Chasing	1.76	1.29	5.3	1.3	0.51	2.1
Handling	1.00			3.1	1.22	5.1
Towing	21.04	7.79	32.4	12.5	4.94	20.6
Whale sighting	4.52	1.67	7.0	—	—	—

¹ January–February, 1976. ² December, 1976–February, 1977.

Operation times in coastal whaling

Ohsumi and Satake (1977) reported operational times for two catcher boats taking sperm whales under a special permit in 1976. I have also obtained data from a coastal whaling. The operational cycle in pelagic whaling is approximately one day whereas it is usually more than this in coastal whaling and frequently varies. In the two cases shown in Table 2, the lengths of cycle were 65.01 hours (2.7 days) and 60.8 hours (2.5 days). As the first example was an experimental operation, sighting was conducted independently of the ordinary operation. The differences between the navigation and towing times between the two operations are due to the whaling ground in the experimental operation being 100–240 miles from the land station, whereas it was 106 miles on average in the commercial operation.

The anchorage and drifting times were not separated in the second example, but the anchorage time is estimated to have been longer than in the experimental operation where the drifting time was 11.42 hours. This is longer than the resting time in pelagic whaling because the pelagic whaling season was from June to September, with short nights, whereas the coastal whaling season was in winter, when the nights are long. Anchorage and drifting times take up 22–37% of CDW which is relatively low compared to pelagic whaling.

Navigating is one of the characteristics of coastal whaling. Moving from one whaling ground to another is usually conducted during resting time in pelagic whaling and is included in the resting time. It was 9–12 hours in the coastal whaling examples and took up 15–19% of CDW.

Searching time also took about 9–12 hours (14–20% of CDW) and thus takes up a relatively small part of CDW compared with pelagic whaling. The average time to find one sperm whale was 2.1 hours in both cases, which is less than half that for pelagic whaling. This means that density or availability of sperm whales is higher in the coastal whaling grounds than the pelagic whaling grounds.

The chasing time per cycle was 1.76 hours for one catcher boat of the experimental operation, although chasing and handling times were combined for the other boat. In the commercial operation the average was 1.3 hours per cycle (only 2.1% of CDW) with an average chasing time per sperm whale of only 13 minutes. This may be because females and small sperm whales are more abundant in the coastal whaling grounds and because large schools are more easily caught.

The handling time in the commercial operation was 3.1

hours longer than both the experimental operation and pelagic whaling. This is because the blubber cutting process is ordinarily conducted in coastal whaling, but was not in the experimental catch or in pelagic whaling.

A long towing time is another characteristic of coastal whaling, and the average time was 21.4 hours in the experimental operation and 12.5 hours in the commercial operation and took up 21–32% of CDW.

Factors influencing operational processes of catcher boats Searching is one of the fundamental operational processes of a catcher boat, and it is still dependent on the human eye. The searching time is related to the density or availability of whales – the more whales found in an area, the more easily and quickly they will be seen by the crew. The weather and sea conditions greatly influence the rate of finding whales. Of these, visibility directly affects searching, and the wind force which determines the wave height also affects the rate of finding whales. These factors also affect catcher boat operations, as small boats are rather difficult to handle in bad weather and therefore the size of the boat is also concerned with searching activity. Furthermore, large boats have taller crow's nests and therefore better visibility. Asdic is not used in the searching operations because it is only effective within a one mile range and it is not very efficient to only use Asdic. Although there have been very rare occasions when whales have been found by picking up their calls on the Asdic receiver while drifting in fog, whales are usually detected by their blow. Thus the searching time is related to the size of the school, the body length, the air temperature, the direction of sun, etc.

Although the searching time per whale will be inversely proportional to the density of the population, and the difference in the searching times per whale caught suggest that this would be useful in population estimation, data from the same area must be compared because the distribution pattern of the whales differs by whaling ground. Unfortunately data from past years are not available.

The chasing time of whales will be proportional to the number of whales caught, although sometimes the chase is abandoned in the middle. As we have seen, the chasing time per whale is related to the size of the whale, but not directly with the density. Weather conditions affect the chasing time, which will be prolonged in bad weather conditions and thus the size of the catcher boat will also affect the chasing time. This is the only process in which Asdic increases the efficiency. Despite the obvious importance of chasing as part of the catching operations it only occupies 2% of CDW in coastal whaling and 5% of CDW in pelagic

Table 3.
Estimation of factors concerned with each operational process of a catcher.

Process	Population density	Number caught	Weather conditions	Size of boat	Asdic
Searching	++	+	++	+	
Chasing		+	+	+	++
Handling		+			
Towing	+	+	+	+	
Resting					
Navigating	+		+		

whaling in these examples. The chasing time per whale caught may have changed with the change in fishing efficiency of catcher boats, but past data are not available.

The handling time will be also be proportional to the number of whales caught, but it differs per whale in pelagic and coastal whaling. It is longer (32 minutes) in coastal whaling than pelagic whaling (20 minutes) because it is only in the former that the blubber needs to be cut. Weather conditions and boat size are not so important to the handling time.

Although the towing time, which is related to the distance between the whaling ground and the factory ship or land station, takes up only about 2% of CDW in pelagic whaling, it takes up a significant proportion (21–32%) in coastal whaling. When the density of the whale population decreases, the whaling ground will be expanded and therefore be further away. Thus towing time is related to population density. Larger catcher boats can operate further afield and have a greater towing capacity. Weather conditions will also affect the towing time.

Resting time (including obtaining supplies, making repairs etc.) is not directly related to the density of the population, the number of whales caught, efficiency of the boat or weather conditions but is concerned with day length and the processing capacity of the factory ship or land station. In recent years it has increased in association with improvements in the working conditions of the crews. Resting time has been about 41% of CDW in pelagic whaling, and 37% of CDW in coastal whaling in recent years.

Navigating time (included in the resting time in pelagic whaling where it is negligible) occupies 15–19% of CDW in coastal whaling. It is affected by the same factors as the towing time.

Table 3 shows a summary of the factors associated with each operational process of the catcher boats. Population density of availability is concerned with searching time, towing time and navigation time. The number of whales caught is related to the searching, chasing, handling and towing times; weather conditions affect the searching, chasing, towing and navigating times; the size of the catcher boat is related to the searching, chasing, towing and navigating times; and Asdic only affects the chasing time.

As we have seen, the searching time per whale will be proportional to the population density and the total searching time will be proportional to the number of whales caught. The chasing time per whale will be approximately constant at each population level, although it may be somewhat shorter at the lower population level as the average body length will be smaller at such a population level. The total chasing time is proportional to the number of whales caught. The handling time per whale will also be constant at each population level, and the total handling time will be proportional to the number of whales caught. The resting time is not affected by any of these factors.

Based on the above considerations, the number of sperm whales caught was estimated for three population levels. For this calculation, the searching time per whale at the original population level was assumed to be 3.0 hours. Thus it becomes 6.0 hours at half the original population level and 9.0 hours at one third the original population level. The chasing time per whale was assumed to be 1.2 hrs and remains constant at the three population levels. The handling time per whale is also constant, and it was assumed to be 0.3 hours. It is difficult to say whether the towing time is proportional to the number of whales caught but in this examination it was assumed to be so. The towing time per whale will be related to the population density but it will be not exactly inversely proportional to it. It was assumed to be 0.2 hours, 0.3 hours and 0.4 hours at the original, half and one third population levels respectively. The resting time was assumed to be 9 hours.

Table 4 shows the result of these calculations for the three population levels. The searching time gradually increases with a decrease in population. The chasing and handling times both decrease with a decrease in population. The total towing time remains almost constant. The number of whales caught per CDW (CPUE) was calculated to be 3.19, 1.92 and 1.38 at the three population levels, respectively. The ratio of catches at one half and one third of the population level to the original one are 0.60 and 0.43. This means that the apparent CPUE does not represent an actual index of population density.

Table 4.

Estimated operation times and number of sperm whales caught for three population levels for pelagic whaling with the same boat efficiency.

Population	P1	P2	P3
Population level	1.0	0.50	0.33
Searching	3.0x = 9.6	6.0y = 11.5	9.0z = 12.4
Chasing	1.2x = 3.8	1.2y = 2.3	1.2z = 1.7
Handling	0.3x = 1.0	0.3y = 0.6	0.3z = 0.4
Towing	0.2x = 0.6	0.3y = 0.6	0.4z = 0.6
Resting	9.0	9.0	9.0
Total	24.0	24.0	24.0
Catch (x,y,z,)	3.19	1.92	1.38
Ratio of catch to P1	1.00	0.60	0.43

Examination of the effect of some factors concerned with operation times

We have seen that several factors affect the time spent in each operational process of the catcher boats and as the fishing effort is obtained from these times, the quantitative effect of each factor should be investigated.

The effect of some of these factors on the CPUE for sperm whales taken by pelagic whaling is examined below.

The operational process of catcher boats in pelagic whaling are searching, chasing, handling, towing and resting.

The CPUE will change with a change in the efficiency of the catcher boat. The size of boat is thought to be related to the searching, chasing and towing times. If the efficiency of the size of boat is assumed to be 1.5, the searching, chasing and towing times per whale will be changed to 4.0, 0.8 and 0.2 hours, respectively, at half the original population level. Asdic only affects the chasing time and thus if the efficiency of a boat with Asdic is assumed to be four times that of non-Asdic boat then the chasing time per whale becomes 0.2 hours at half the original population level. Recently there has tended to be an increase in resting time and if it changes from 9 hours to 10 hours, at the same population level, the apparent CPUE will be changed.

Table 5 shows the effect of the efficiency of the catcher boat and changes in resting time at the same population level. The apparent CPUE changes with the change in efficiency of the boat. The efficiency of boat size is almost directly reflected in the apparent CPUE:— when the efficiency is 4x, the apparent CPUE becomes 1.47 times that of a boat with an efficiency of 1.0. If Asdic is introduced to a boat with an efficiency of 1.5, the apparent CPUE becomes 3.19, which is only 1.13 times of the boat without Asdic. With an increase in resting time, the apparent CPUE becomes smaller:— when it increases by one hour the apparent CPUE becomes 0.93 times the original.

Although the above examination contained many assumptions it helps in understanding the behaviour of CDW and CPUE. Further study is needed based on actual data from catcher boat operations.

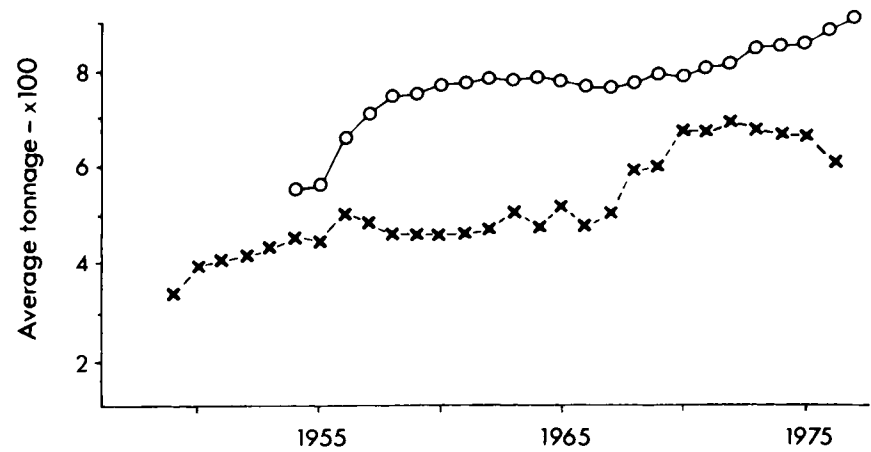


Fig. 3. Yearly change in the average tonnage of catching boats. o—o Pelagic whaling. x—x Coastal whaling.

Comparison of tonnage and horse power in catch efficiency
Tonnage and horse power have been used as two indices of boat size but a better index of catcher boat size is needed to represent catch efficiency more reasonably.

Because the density or availability of whales differs by whaling ground and by year, catch efficiencies should be compared from the same whaling ground and in the same year. The relationship between tonnage or horse power and CPUE for each catcher boat in the same whaling fleet or the same whaling ground in the same year should be examined, and the catch efficiency chosen by comparing the size of the correlation for the relationships.

Table 6 shows the correlation coefficients for catcher boats in the Sanriku Ground in 1956 and 1957 (coastal whaling) and for pelagic whaling fleets which only took

Table 5.

Estimated operation times and number of sperm whales caught at the same population level with changing boat efficiency and resting time for pelagic whaling.

Population Efficiency	P2 1.0	P2 A	P2 AB	P2 ABc
Searching	6.0y = 11.5	4.0a = 11.3	4.0b = 12.8	4.0c = 11.9
Chasing	1.2y = 2.3	0.8a = 2.3	0.2b = 0.6	0.2c = 0.6
Handling	0.3y = 1.0	0.3a = 0.8	0.3b = 1.0	0.3c = 0.9
Towing	0.3y = 0.6	0.2a = 0.6	0.2b = 0.6	0.2c = 0.6
Resting	9.0	9.0	9.0	10.0
Total	24.0	24.0	24.0	24.0
Catch (y,a,b,c,)	1.92	2.83	3.19	2.98
Ratio of catch of P2A to P2		1.47		
Ratio of catch of P2AB to P2A			1.13	
Ratio of catch of P2ABc to P2AB				0.93

A : Efficiency of size of boat, 1.5; B: Efficiency of Asdic, 4.0.

CATCH EFFICIENCY AND THE SIZE OF CATCHER BOAT

Fig. 3 shows the yearly change in average tonnage of catcher boats for Japanese pelagic and coastal whaling. In pelagic whaling, tonnage increased rapidly from 1954 to 1958, remained almost constant until 1972, and has been gradually increasing in recent years. The boats in coastal whaling are smaller on average than those in pelagic whaling. They increased slowly in size until 1972, but the average size has been gradually decreasing since then.

If the catch efficiency is different for different sized catcher boats, some correction of fishing effort should be made, as this factor has not been constant.

Table 6.

Comparison of catcher boat efficiency by tonnage and horse power.

	1956		1957	
	Number of boats	Correlation coefficient	Number of boats	Correlation coefficient
A. Coastal whaling				
Tonnage	23	0.132	24	0.222
Horse power	23	0.151	24	0.488
B. Pelagic whaling				
Tonnage	5	0.351	6	0.263
Horse power	5	0.164	6	0.159

sperm whales in 1956 and 1957. In neither year were any catcher boats fitted with Asdic and so there is no need to consider this factor in the examination.

Although there are few data and the correlation coefficients are statistically low, the correlation coefficients for horse power are higher than those for tonnage in coastal whaling, and thus horse power should be used as an index of boat size in coastal whaling. As we have seen, the towing time occupies 21–32% of CDW in coastal whaling, and the effect of a considerable pulling power will be to shorten the towing time. On the other hand, tonnage shows a better correlation with CPUE than horse power in pelagic whaling, and therefore should be used as an index of boat size in pelagic whaling. This may be because the towing time is much shorter in pelagic whaling than in coastal whaling, and tonnage may affect searching or chasing more than horse power.

Catch efficiency by horse power in coastal whaling

Table 7 shows the relationship between horse power and CPUE for sperm whales in the Sanriku ground in the years 1955–1959. There are two cases in which the correlation coefficient was negative and it is generally low except in 1957, when it was statistically significant at the 5% level. Furthermore, if the catch efficiency is proportional to the horse power of the boat, the values of b in the formula should be zero or nearly zero, but in fact they are 0.34–0.52 even in those cases where the correlation coefficients are positive, e.g. in 1957 the CPUE for 1,000 horse power is calculated to be 0.609, and for 2,000 horse power it is 0.879. The latter is only 1.44 times the former and this means that the catch efficiency of the boats is not directly proportional to the horse power.

Table 7.

Relationship between horse power and CPUE in coastal whaling.¹

Year	Number of boats	Correlation coefficient	a	b
1955	24	0.203	0.052	0.466
1956	23	0.151	0.074	0.518
1957	24	0.488	0.270	0.339
1958	24	−0.116	−0.085	0.872
1959	24	−0.412	−0.199	1.020

¹ : $Y = a \frac{H}{1000} + b$ where, Y = CPUE, H = Horse power, a,b = Constants.

Catch efficiency by tonnage in pelagic whaling

Table 8 shows the relationship between tonnage and CPUE for sperm whales in pelagic whaling in the years 1955–1957. The correlation coefficients are low and there are two negative values. These results may mean that there is no correlation between tonnage and catch efficiency for sperm whales. Furthermore, values of b in the formula do not approximate to zero as they did not in coastal whaling. For the *Matsushimamaru* fleet in 1956 the CPUE for 400 tons is calculated to be 3.34, and for 800 tons it is 5.33. Thus, if the catcher boat tonnage is doubled, the catch efficiency only increases 1.59 times.

Discussion

The bigger the catcher boat, the faster it becomes, and high speed is more efficient for chasing fast swimming whales such as the *Balaenoptera* species. However, the sperm whale is a slower swimmer and dives longer and deeper than the balaenopterids and therefore a high speed catcher boat is

Table 8.

Relationship between tonnage and CPUE in pelagic whaling.

Year	Fleet	Boats	Correlation coefficient	a	b
1955	<i>Kyokuyomaru</i>	8	−0.212	−0.631	2.547
1955	<i>Kinjomaru</i> ¹	5	−0.899	−6.719	5.058
1956	<i>Kyokuyomaru</i>	7	0.194	1.109	2.582
1956	<i>Matsushimamaru</i> ²	5	0.351	4.978	1.344
1957	<i>Kyokuyomaru</i>	10	0.209	1.086	1.260
1957	<i>Matsushimamaru</i> ¹	6	0.263	1.512	3.499

¹ : to take sperm whales only.

² : $Y = a \frac{T}{1000} + b$ where, Y = CPUE, T = Tonnage, a,b = Constants.

not always more efficient for taking sperm whales. Smaller catcher boats can turn more easily, and are therefore more efficient at catching sperm whales. On the other hand, some catcher boats have tall crow's nests, which improves searching and can operate in bad sea conditions which will increase efficiency.

I have discussed with whalers the relationship between the catcher boat size and efficiency with respect to taking sperm whales and they said that catcher boat efficiency increased up to 600 tons although above this it remained almost constant. Japanese catcher boats operate co-operatively and this may explain the poor correlation between boat size and catching efficiency.

The main object of Japanese whaling, especially pelagic whaling, has been baleen whales, and the reason for the increase in catcher boat size is to help in taking baleen whales. However, sperm whales have been a major target for coastal whaling and this may explain why catcher boats have remained smaller here than in pelagic whaling.

CATCH EFFICIENCY AND ASDIC

Fig. 4 shows the yearly change in the ratios of catcher boats with and without Asdic in Japanese pelagic and coastal whaling. Asdic began to be installed into the pelagic catcher boats in 1958, and had been fitted to all of them by 1962. It was introduced in coastal whaling in 1960, but the rate of installation was slower than for pelagic whaling. All boats had Asdic in 1970 and 1971 but one boat without Asdic has been operating in coastal whaling even in recent years.

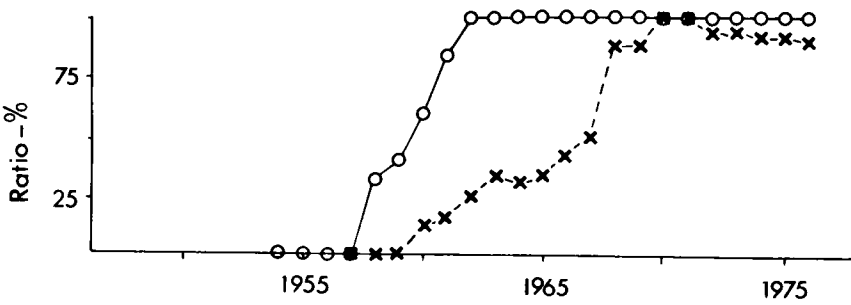


Fig. 4. Yearly change in the ratios of catcher boats with Asdic.
o—o Pelagic whaling.
x—x Coastal whaling.

The catch efficiency of Asdic should be examined as the ratio of the CPUEs of boats with Asdic to boats without Asdic in the same whaling ground in the same year. Table 9 shows the ratios for coastal and pelagic whaling. There are large fluctuations in the ratios, which range from 0.75 to 1.66 (average 1.069) in coastal whaling and 1.01 to 1.20 (average 1.055) in pelagic whaling. Both results suggest the overall efficiency of Asdic in terms of CDW is very low.

Table 9.
Catch efficiency of Asdic.

A. Coastal whaling

Year	Number of boats, Asdic		Horse power uncorrected			Horse power corrected		
	With (a)	Without (b)	CPUE (a)	CPUE (b)	a/b	CPUE (a)	CPUE (b)	a/b
1960	4	20	0.854	0.593	1.440	0.694	0.585	1.185
1961	5	20	0.780	0.668	1.168	0.624	0.626	0.981
1962	6	16	0.782	0.483	1.619	0.623	0.460	1.354
1963	6	14	0.812	0.553	1.468	0.651	0.518	1.257
1964	7	15	0.959	0.509	1.884	0.796	0.481	1.655
1965	7	12	0.741	0.735	1.008	0.597	0.702	0.850
1966	7	11	0.702	0.807	0.876	0.604	0.805	0.750
1967	9	6	1.192	1.290	0.924	0.962	1.198	0.803
1968	14	2	1.452	1.612	0.901	1.136	1.453	0.782

CDWs were corrected with the formula: $Y = 0.270 H/1000 + 0.339$.

B. Pelagic whaling

Year	Fleet	Number of boats, Asdic		CPUE (a)	CPUE (b)	a/b
		With (a)	Without (b)			
1958	<i>Kyokuyo</i>	3	6	2.793	2.772	1.008
1958	<i>Tonan No. 2*</i>	2	4	4.540	4.370	1.039
1959	<i>Kyokuyo</i>	6	3	2.233	2.200	1.015
1959	<i>Kinjo*</i>	1	5	3.789	3.694	1.026
1960	<i>Kyokuyo</i>	6	3	2.463	2.444	1.008
1960	<i>Tonan No. 2*</i>	3	3	3.971	3.637	1.092
1961	<i>Kinjo*</i>	4	3	3.968	3.313	1.198

* : To take sperm whales only.

Asdic has been considered to be very effective in whaling operations but as we have seen it is only used and effective in chasing so that the efficiency of Asdic in terms of the total CDW is only on the component of chasing time. The average chasing time was 35 minutes in pelagic whaling in 1977 (5.0% of CDW) and was 1.3 hours per operational cycle in coastal whaling (2.1% of CDW) in the most recent year.

Table 10 shows that the effect of Asdic on the total CDW is much less than its effect on the chasing time. Although the efficiency is represented as a simple efficiency in Table 10, it should be represented as a time, because CDW is an index of operation time. As we have seen, efficiency should be measured as the shortening of the given operational process per whale caught. The taking of a whale is the result of several operational processes as can be seen in Table 5, and thus the calculation of the catch efficiency of Asdic is more complex than that in Table 10. From Table 5, if the ratio of chasing time to CDW is 0.025, and the Asdic efficiency is 4.0 then the total catch efficiency is 1.13.

To estimate the effect of Asdic on the chasing time, data on the chasing time per whale from boats with Asdic and without Asdic for the same whaling ground in the same

year are needed, but unfortunately these data are not available. There is a very large individual variation in chasing time, but as shown in Fig. 1, the average chasing time of large sperm whales is about 35 minutes in recent years. If the catch efficiency of boats with Asdic is four times that of those without Asdic, the average chasing time of a large sperm whale by a boat without Asdic would be 140 minutes or 2.3 hours, thus if the whale dives for 30 minutes it will be caught within the fourth or fifth time of surfacing.

When Asdic is used, baleen whales swim faster and do not dive, but sperm whales dive for longer and do not swim on the surface, which hinders chasing. According to information from whalers, Asdic is used differently depending on the school size, length of whale, sea conditions, etc. For one or two large whales Asdic is usually used in good sea conditions, but if the wind force is over Beaufort class 5 it becomes less efficient due to the noise of air bubbles. Whalers use Asdic for 30–40% of the chasing time for small schools of over 10 whales. Sperm whale schools tend to divide into two or more sub-schools, when Asdic is used. In order to catch as many whales as possible it is desirable to keep the school together and therefore Asdic is not used for all the whales chased.

Table 10.
Relationship between catch efficiency of Asdic in chasing and CDW.

Ratio of chasing time to total CDW	Efficiency of Asdic on chasing time					
	1.5	2.0	2.5	3.0	3.5	4.0
0.000	1.00	1.00	1.00	1.00	1.00	1.00
0.025	1.04	1.05	1.07	1.18	1.09	1.10
0.050	1.08	1.10	1.13	1.15	1.18	1.20
0.075	1.11	1.15	1.19	1.23	1.26	1.30
0.100	1.15	1.20	1.25	1.30	1.35	1.40
0.125	1.19	1.25	1.31	1.38	1.44	1.50
0.150	1.23	1.30	1.38	1.45	1.53	1.60

The total chasing time depends on the number of whales caught, and therefore as the population level declines the total chasing time becomes shorter (Table 4). If the catch efficiency of Asdic remains the same, the total Asdic effect on CDW will change and become smaller as shown in Table 10.

In the 1950s and early 1960s the main object of pelagic whaling was the fin whale. Large catcher boats with Asdic were efficient in taking this species as Asdic caused it to swim faster and at the surface, and the higher speed was needed to drive and chase it. As shown in Table 9, those whaling fleets whose main object was baleen whales were more rapidly equipped with Asdic than those taking

sperm whales only. All catcher boats in the baleen whaling fleet had been equipped with Asdic by 1961, when the sperm whaling fleet still had 43% of its catcher boats without Asdic. Similarly the installation of Asdic into coastal whaling, where sperm whales formed an important part of the catch, was slower than in pelagic whaling. This feature also suggests that Asdic is not as efficient for the sperm whale as for the baleen whales.

The efficiency of Asdic may vary with the experience and skill of the crew of the catcher boat. A good, experienced crew can successfully chase sperm whales without Asdic, but Asdic is useful for inexperienced crews. In the past a good gunner and boatswain were very efficient at chasing whales, and a skilful gunner tended to gather a good crew in his boat. However, the introduction of Asdic tended to lessen the superiority of a good gunner, and it became easier for a whaling company to change crews around.

It is difficult to determine differences in the efficiency of Asdic by sex for sperm whales. Asdic is used to find the position of sperm whales in the water and two points lead us to suppose that Asdic is more efficient for large males than for small males and females:

- (i) large male sperm whales dive deeper and for longer than females.
- (ii) small males and females are gregarious and Asdic is not used in the early stages of the chase to prevent the division of the school into sub-schools.

EFFECT OF WEATHER CONDITIONS ON CATCHING OPERATIONS

Weather conditions affect the searching, chasing, towing and navigating of a catcher boat. Fig. 5 shows the relationship between the wind force and visibility and the CPUE of sperm whales in pelagic whaling for 1965–1968. Catcher boat operations were not affected very much by winds below Beaufort Class 5 but efficiency decreased rapidly in

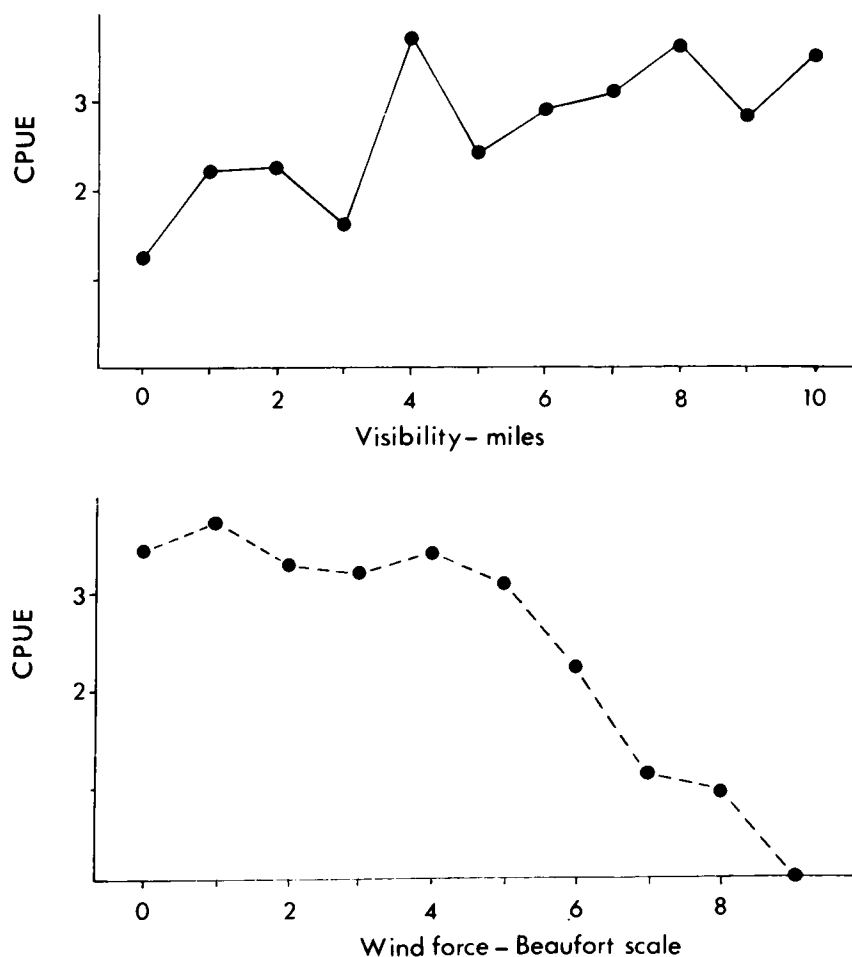


Fig. 5. Relationship between wind force and visibility and CPUE of the sperm whale in pelagic whaling in 1965–1968.

more windy conditions. The efficiency of operations gradually increased with an increase in visibility, but it did not have as large an effect as wind force.

Fig. 6 shows the relationship between wind force and relative values of CPUE for four periods of pelagic whaling to take sperm whales. Efficiency was largely related to wind force in the earliest period when the average size of catcher boats was small, and the efficiency declined at Beaufort Class 3 and over. Efficiency gradually increased even in the high wind force classes in the later periods when boats became larger. However, the pattern of the relationship was not very different in the later three periods when the average boat sizes were 638 tons and over. This suggests that an increase in the size of catcher boats improved operations in windy conditions, but that the size of the boat was not as effective against wind for boats of more than about 600 tons.

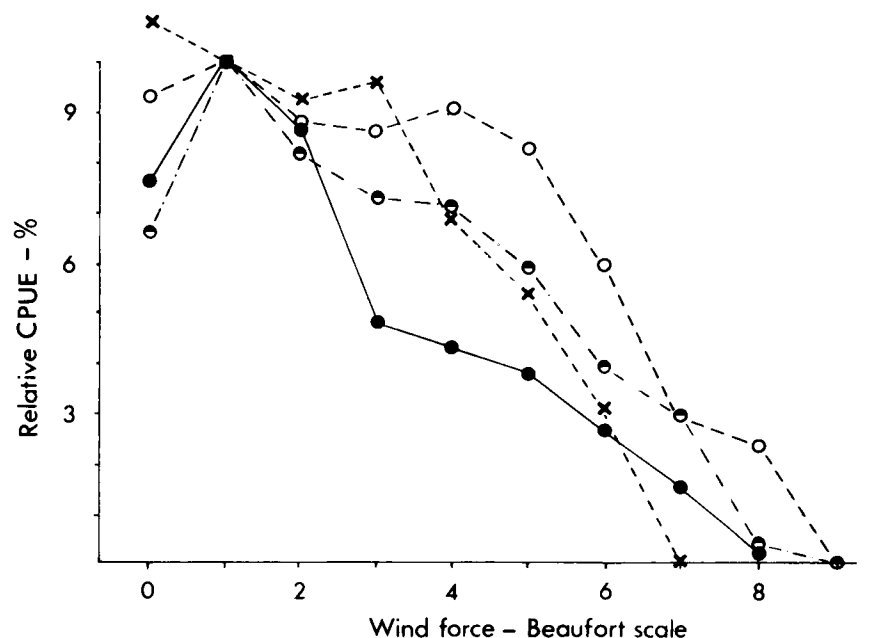


Fig. 6. Relationship between wind force and relative CPUE of the sperm whale. ●—● 1954–1956 (average tonnage, 487.7), ○---○ 1957–1961 (638.0 tons), ○---○ 1965–1968 (676.6 tons), X---X 1972–1976 (740.0 tons).

If the weather factors show any yearly trend the fishing effort should be corrected but the yearly change in average wind force has not been large, although a slightly decreasing trend can be seen in Fig. 7. The change in the effectiveness of weather factors will be represented in the efficiency of the boat size.

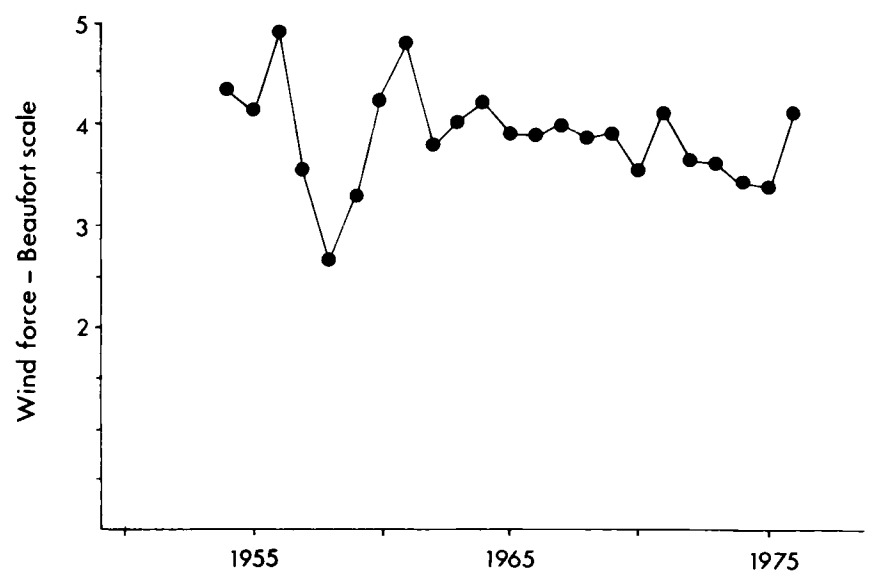


Fig. 7. Yearly change in average wind force on sperm whaling days (pelagic whaling).

CONTRIBUTION OF SCOUTING BOATS TO THE FISHING EFFORT

Scouting boats search the whaling ground independently from the catching operations of the fleet and do not directly engage in catching whales, and thus the operations of scouting boats are very different from ordinary catcher boats. However, the operations days of scouting boats have been included into the total CDW with the same weight as ordinary catcher boats, without examining their contribution to fishing effort in pelagic whaling.

In practice, it is difficult to measure the contribution of a scouting boat to the whaling operation. Table 11 shows the comparison of the CPUE for male sperm whales between whaling fleets with and without a scouting boat.

The ratio represents the contribution of the scouting boat to the operation of the fleet. If the value of the ratio is near to 1.0, the CDW of the scouting boat can be considered to be equal to the operating catcher boats, but if it is not, some correction is needed to evaluate the contribution of the scouting boat in the calculation of CDW. It is difficult to compare the operations of different fleets even in the same whaling year, because the fleets did not always operate in the same whaling ground. As shown in Table 11, the ratio ranged from 0.76 to 1.33 with an average of 1.09. This means that fleets using a scouting boat are more efficient than those without one, but that the efficiency is less than 110%, so that in practice, it is not unreasonable to regard the CDW of a scouting boat with the same weight as an operating catcher boat.

SEPARATION OF FISHING EFFORT FOR EACH SEX

Fig. 8 shows the yearly change in catches of male and female sperm whales in Japanese pelagic whaling, female sex ratios in the catch and apparent CPUEs for males and females. Catches of females were less than 35 until 1965, but have been increasing since 1966. This has been accompanied by a gradual decrease in the number of males caught because Japan has set a national quota for sperm whales since 1957 (Ohsumi, 1980), and therefore the sex ratio of females has been gradually increasing. The apparent CPUE value for females has also been increasing with the increase in the female sex ratio.

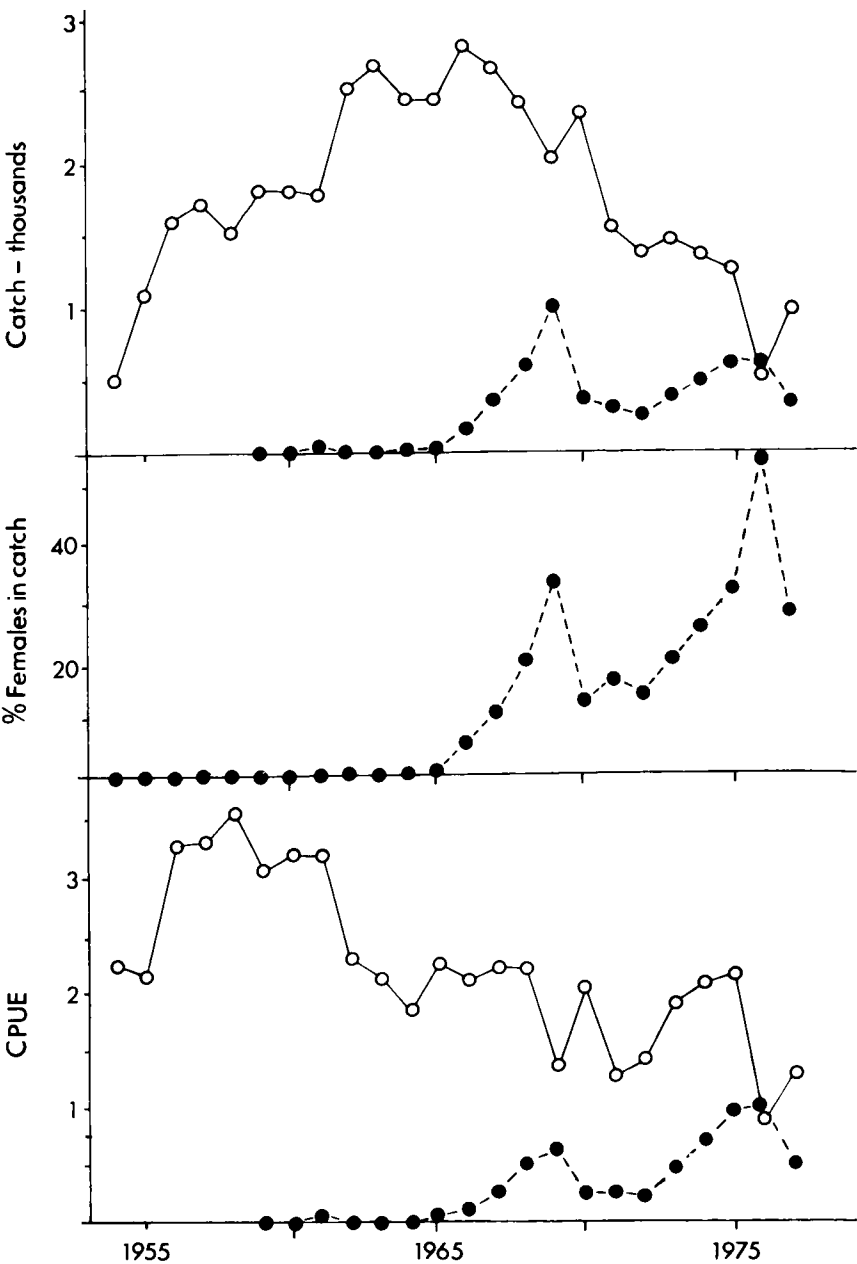


Fig. 8. Yearly change in (a) catch by sex, (b) female sex ratio in the catches and (c) apparent CPUEs by sex in Japanese pelagic whaling in the North Pacific. ●---● females, ○---○ males.

When some females are caught, part of the total fishing effort should be shared for the females, so that the actual fishing effort for males is less than the total effort. The apparent CPUE of males is based on the total effort, and so must be less than the real CPUE value of males.

Table 11.
CPUE of male sperm whales in sperm whaling season for several whaling fleets in different years.

Year	Fleet	Scouting boat	Catcher boat	CDW	Catch	CPUE	Ratio*
1963	Kyokuyo	0	7	427	865	2.03	1.00
1963	Kinjo	1	7	322	865	2.69	1.33
1963	Nitto	1	7	308	803	2.61	1.29
1964	Kyokuyo	0	7	336	762	2.27	1.00
1964	Kinjo	1	6	364	795	2.18	0.96
1964	Nitto	1	6	252	584	2.32	1.02
1969	Tonan	0	9	243	472	1.94	1.00
1969	Kyokuyo No. 3	1	8	153	335	2.19	1.13
1969	Nissin	1	7	224	527	2.35	1.21
1970	Kyokuyo No. 2	0	8	56	125	2.23	1.00
1970	Tonan	0	9	290	632	2.18	
1970	Nissin No. 3	1	7	225	619	2.75	1.25
1973	Kyokuyo No. 3	0	7	70	148	2.11	1.00
1973	Tonan No. 2	1	7	184	331	1.80	0.85
1973	Nissin No. 3	1	6	133	215	1.62	0.76

*: Ratio of the CPUE in fleets with a scouting boat to those without scouting boats in a given year.

Table 12.

An examination of the apparent and real CPUE values of each sex at a given population level.

	Male only	Female only	Male and female combined	
			$y' = 0.33x'$	$y'' = 0.5x''$
Searching	$6.0x = 11.5$	$3.0y = 10.7$	$6.0x' + 3.0y' = 11.4$	$6.0x'' + 3.0y'' = 11.4$
Chasing	$1.2x = 2.3$	$0.6y = 2.1$	$1.2x' + 0.6y' = 2.3$	$1.2x'' + 1.6y'' = 2.3$
Handling	$0.3x = 0.6$	$0.3y = 1.1$	$0.3x' + 0.3y' = 0.7$	$0.3x'' + 0.3y'' = 0.7$
Towing	$0.3x = 0.6$	$0.3y = 1.1$	$0.3x' + 0.3y' = 0.7$	$0.3x'' + 0.3y'' = 0.7$
Resting	9.0	9.0	9.0	9.0
Total	24.0	24.0	24.0	24.0
Catch Males	1.92		1.63	1.52
Females		3.57	0.54	0.76
Total	1.92	3.57	2.17	2.28

A similar analysis to that used for the factors concerned with each operational process of the catcher boats was used to examine this problem. A population level was chosen for males. The searching time per whale is 6.0 hours, the chasing time per whale is 1.2 hours, the handling time per whale is 0.3 hours, and the towing time per whale is 0.3 hours. If the female population level is higher than the male's, the searching time will be shorter than for males and as females are smaller than males, the chasing time per whale will be shorter for females. The handling and towing times per whale are assumed to be the same for both sexes, thus the searching, chasing, handling and towing times per female are 3.0, 0.6, 0.3 and 0.3 hours, respectively. Under these conditions, the catch per day (CPUE) can be calculated to be 1.92 for males and 3.57 for females, if catches are only for one sex. Under the same conditions, but when both sexes are assumed to be caught in a day, the catch number of each sex changes with the sex ratio of the catch. Table 12 shows two examples of female sex ratios: when the female sex ratio is 25%, the catch of males becomes 1.63 i.e. the apparent CPUE becomes less than the real CPUE (1.92); if the female sex ratio is higher (33.3%), the catch of males becomes smaller still (1.52) i.e. the apparent CPUE of males becomes smaller and smaller depending on the increase in the female sex ratio. Clearly the apparent CPUE values of males do not represent the real CPUE, especially as the female sex ratio has been increasing. On the other hand, the real female CPUE is 3.57 but the apparent values are much lower and increase with an increase in the female sex ratio. The phenomenon that the apparent CPUE of the females has been increasing with the increase in the female sex ratio is explained by this examination. As the female sex ratios are still low, the apparent CPUE values do not represent the real density trend of the female sperm whale.

In practice, it is very difficult to correct CPUE by sex. Segregation by sex and by age is very pronounced in the sperm whale, and the density or availability of each sex differs by whaling ground, season and year. No accurate map of the density of sperm whales by sex is available and neither are data on the searching time per whale by sex which would enable us to calculate the real CPUE.

Since the introduction of catch limits for each sex, the problem has become more complex as the whaling fleets must move and regulate more than they used to which results in the accumulation of less efficient operation times.

EFFECT OF CHANGES IN THE PELAGIC WHALING GROUNDS

Ohsumi (1980) shows the yearly change in the sperm whale pelagic whaling ground in the North Pacific since 1954. It

has changed remarkably in the last 24 years, gradually moving southwards. Fig. 9a shows the yearly change in the ratio of CDW for sperm whales in the Aleutian Island area (P23–P26) in the total CDW for sperm whales. Sperm whales were taken by Japanese pelagic whaling only in this area until 1960, but the ratio of the CDW in this area has decreased rapidly since then, and has been less than 10% since 1970.

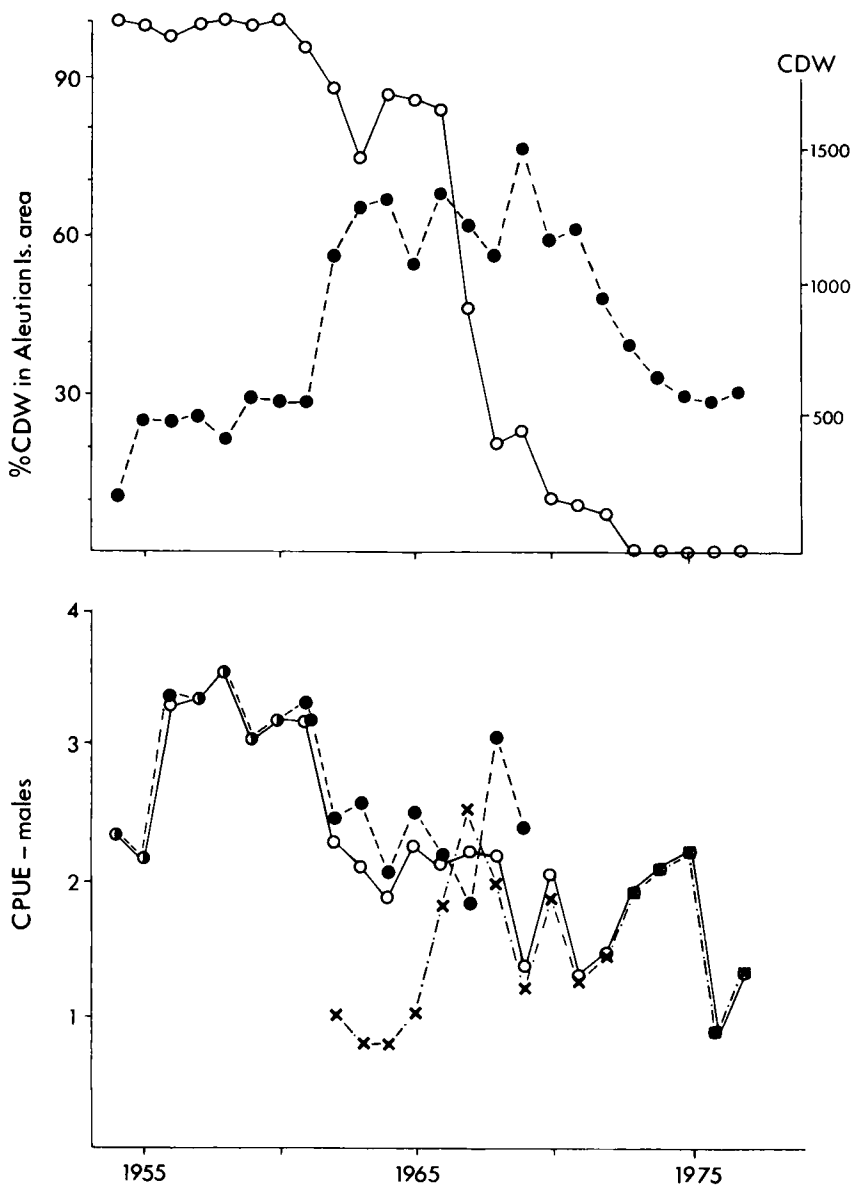


Fig. 9. Yearly change in (a) the ratio of CDW for sperm whales in the Aleutian Islands area (○—○) to total CDW (●—●) and (b) the yearly change in CPUE of male sperm whales in the Aleutian Islands area (●—●), other areas (×—×) and total (○—○).

The density distribution of the sperm whale changes by area, by sex and by age even at the same population level and thus simply an examination of the early change in CPUE as a whole is irrational, remembering the important changes in the whaling ground. Fig. 9b shows the yearly

change in the CPUE of males (fishing efforts were not corrected) for the Aleutian Islands area, other areas and total areas. It is clear that the CPUE in the Aleutian Islands area is higher than the total, and thus it is dangerous to examine the CPUE as a whole. The CPUE in the other areas is less than the Aleutian Islands area, and is increasing.

The second problem is that although the CPUE represents the population density this does not mean it is an index of total population abundance — it represents the relative abundance within a limited area. In the case of the North Pacific sperm whales, the whaling ground has been changing considerably so that it is wrong to use CPUE as an index of total abundance. If the CPUE in lower latitudinal waters is the same as that in the higher latitudinal waters, then the index of abundance should be higher in the former than the latter, as the area of a 10° square, for example, is larger in lower latitudinal waters. Furthermore, the total size of whaling ground has expanded so that the CPUE must be multiplied by the total size of the whaling ground. The greatest problem is that Japanese pelagic whaling has not yet covered all the areas where the North Pacific sperm whale is distributed, and therefore, if any correction or standardisation is made, the corrected index of abundance will not represent the index of total abundance.

The third problem is the segregation of the sperm whale by age and sex. Ohsumi (1966) estimates that the segregation rate of males increases from 10 years of age to 25 years in the higher latitudinal waters, and that 40–60% of mature (9–10 years old and over) males segregate in these waters. Therefore, the greater density in higher latitudinal waters is caused by the segregation and concentration of large males in a smaller area and the CPUE value does not represent the true density of the total population of exploitable males. The average CPUE of exploitable males in their total area of distribution should be less than the value for the Aleutian Islands area. This phenomenon also suggests that it is dangerous to examine the apparent CPUE as a series to estimate the population trend of the North Pacific male sperm whale.

COMPARISON OF CPUE IN BALEEN AND SPERM WHALING SEASONS

The main objects of Japanese pelagic whaling have been baleen whales, and sperm whales were rarely taken before the catch limit for baleen whales had been reached. Therefore in the early period sperm whales were caught after the baleen whaling season had finished and so the baleen and sperm whaling seasons were clearly separated. As shown in Fig. 10a, sperm whales began to be caught during the baleen whaling season in 1962, and the ratio of the catch effort in the sperm whaling season gradually decreased, reaching only 15.7% in 1971. The ratio has been increasing in the last two years, when only Bryde's and sperm whales have been caught in the North Pacific and only one whaling fleet has operated.

As explained above the calculation of CDW for sperm whales taken by Japanese pelagic whaling differs for the baleen and sperm whaling season, although a method to evaluate this has not yet been found. Fig. 10b shows the comparison of the CPUE of sperm whales in the baleen whaling season with that in the sperm whaling season. It remained lower in the baleen whaling season until 1969, and thus the CDW for sperm whales in the baleen whaling season did not represent the real fishing effort for the

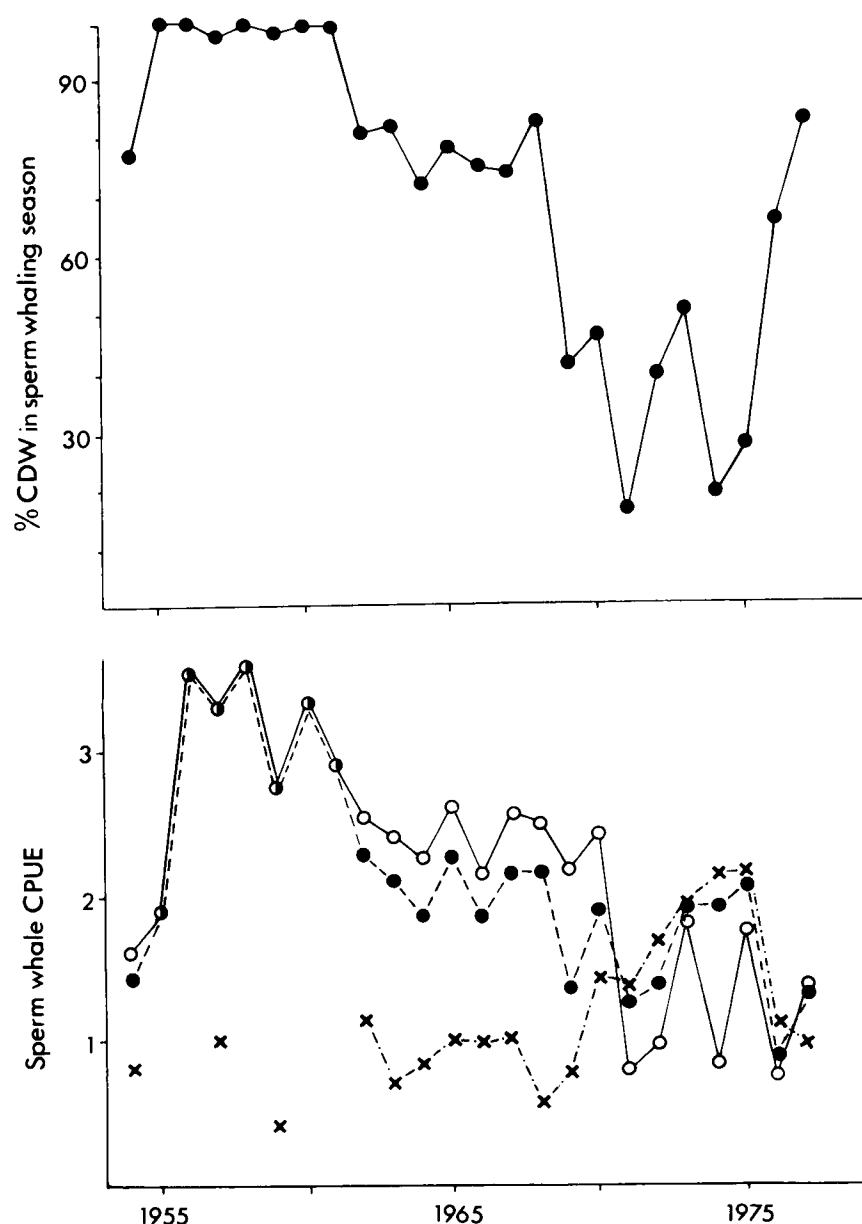


Fig. 10. Yearly change in (a) the ratio of CDW for sperm whales in the sperm whaling season to total CDW (●—●) and (b) comparison of CPUE of sperm whales in the baleen (x—x) and sperm (o—o) whaling seasons and the total (●—●).

sperm whale. This is one of the causes for the reduction in the apparent CPUE figures.

Accompanying this rapid decline in the ratio of fishing effort in the sperm whaling season, the CPUE in the baleen whaling season rapidly increased, i.e. whalers changed their strategy and took sperm whales when they found them even in the baleen whaling season, whereas previously they would not. Since 1971, the CPUE of sperm whales in the baleen whaling season has been higher than in the sperm whaling season, because no catch days for sperm whales are excluded from the fishing effort for sperm whales in the baleen whaling season, but are included in the sperm whaling season.

It can be concluded that the CPUE data from the baleen whaling season should be excluded from the assessment of North Pacific sperm whales, and, as the ratios of fishing effort in the sperm whaling season have been low since 1969, these data may also be unreliable.

REFERENCES

- Ohsumi, S. 1966. Sexual segregation of the sperm whale in the North Pacific. *Sci. Rep. Whales Res. Inst., Tokyo*. 20: 1–16.
- Ohsumi, S. and Satake, Y. 1977. Provisional report on investigation of sperm whales off the coast of Japan under a special permit. *Rep. int. Whal. Commn* 27: 324–32.
- Ohsumi, S. 1980. Catches of sperm whales by modern whaling in the North Pacific. Paper SC/SPC/1 (published in this volume).

Population Assessment of the Sperm Whale in the North Pacific

Seiji Ohsumi

Far Seas Fisheries Research Laboratory

INTRODUCTION

The population of the North Pacific sperm whale has been assessed by many authors since the establishment of the IWC North Pacific Working Group in 1961 and the Sperm Whale sub-committee in 1963. Best (1976) reviewed the results up to 1976.

The Scientific Committee reassessed the population of North Pacific sperm whales at the 29th Annual Meeting of the IWC in 1977 (IWC, 1978). During the meeting, it was recognised that the male sperm whale population of the North Pacific must be assessed as a whole, although two stocks might exist, because of the considerable intermingling of male sperm whales observed in the northern part of the North Pacific (Ohsumi and Masaki, 1977) and because it is impossible to separate the catch and fishing effort data into each stock. Secondly, population sizes and trends had only been assessed using the CHPOP programme of Allen and Kirkwood (1977a), the results of which are very sensitive to correction factors of CDW, and it was recognised that more thorough examinations were needed to obtain more reliable population assessments for the North Pacific sperm whale.

Methods using CPUE data are only part of the population assessment of whales and there are many problems in measuring fishing effort for the North Pacific sperm whale, as Ohsumi (1980b) outlined. Each method contains defects and so we need to synthesize the results obtained by several approaches in order to obtain a reliable population assessment.

ESTIMATION OF THE AGE DISTRIBUTION OF THE CATCH

The age distribution of the whales caught is fundamental to population assessment. Age specific analyses such as cohort analysis are needed to estimate certain biological parameters such as age at recruitment and recruitment rate.

Ideally these data would be obtained by the direct age determination of each whale caught, but unfortunately such ideal data are not available. As the second best alternative, conversion of the size distribution into an age distribution using an age/length key is carried out and the body length of each individual is measured. An age/length key was provided by Ohsumi (1977) for the male sperm whale in the North Pacific. As the males grow to about 50 feet, an age/length key is useful but females stop growing at about 36 feet, and as the legal size limit was 35 feet for coastal whaling and 38 feet for pelagic whaling until 1972, it is unreasonable to use an age/length key to convert size distributions to age distributions for females.

To investigate the suitability of the age/length key, I compared the age distributions of male sperm whales which were caught in the Aleutian Islands area in 1961 and 1962; one was obtained by direct age determination and

the other was obtained using the age/length key. The sample sizes were 1,975 and 4,211, respectively. It can be seen from Fig. 1 that the age/length key is reasonable, but the problem remains as to whether the same age/length key can be used for other situations.

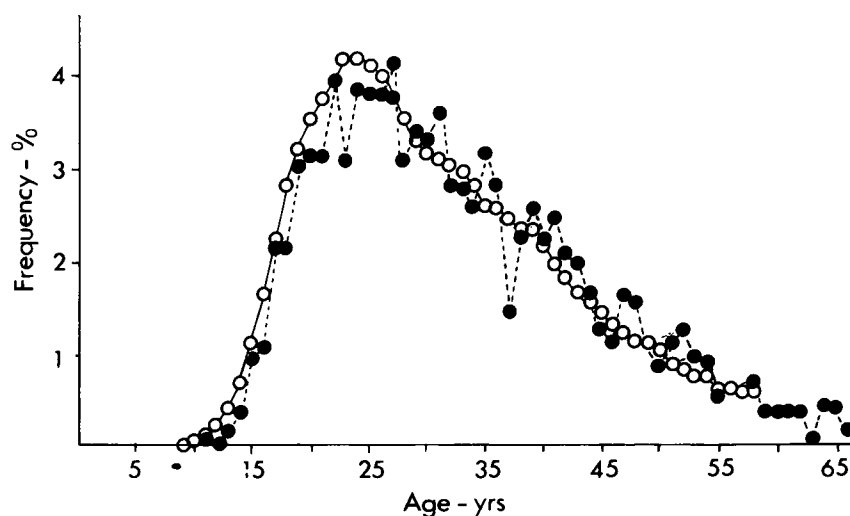


Fig. 1. Comparison of age distributions obtained (a) by direct age determination, $\bullet\cdots\bullet$; and (b) by conversion from an age/length key, $\circ\cdots\circ$; and the size distribution of males caught in the Aleutian Is. area in 1961 and 1962.

Size distributions of sperm whales caught in the North Pacific have been recorded in the International Whaling Statistics since 1946 and I have used these data for males. I also used the same kind of size distributions in 1976 from sheet NP 3 of the North Pacific data sheets. The TAGK programme of Allen (1977a) was used to convert size distributions into age distributions.

Fig. 2A and B shows the age distributions of male sperm whales from the North Pacific which were thus converted from size distributions from 1946 to 1976. The irregularities seen at 39 and 40 years of age in several years are caused by the incompleteness of the age/length key. The maximum body length in the key is 56 feet, and only 39 and 40 years of age are included in this length class, although there were some individuals of 56 feet and over in the catch records. These individuals were included into the 56 feet class for conversion and thus, the irregularity was produced when there were a relatively large number of animals of 56 feet and over. Another limitation of this key is that individuals of 59 and over (Fig. 1) are included into the lower age classes.

The pattern of age distribution changes yearly. Accompanying the development of pelagic whaling, the age distribution moved to higher ages but since the change in the legal size limit in 1973, the pattern has largely changed.

ESTIMATION OF PARAMETERS CONCERNING RECRUITMENT FROM AGE DISTRIBUTIONS

Allen (1977b) developed a computer programme CPPOP to estimate the average age at recruitment, proportion of

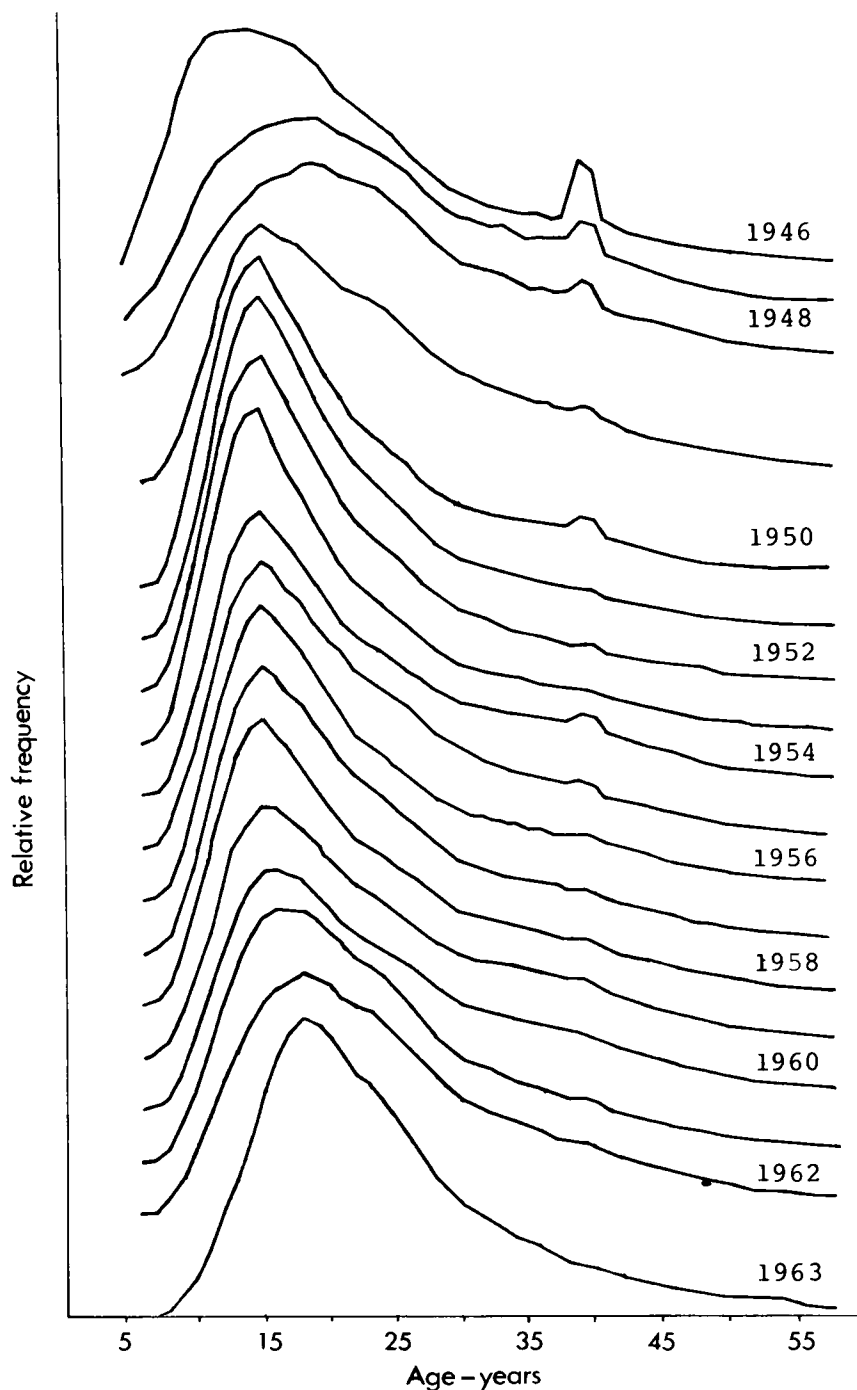


Fig. 2A. Yearly change in the age distribution of males caught in the North Pacific, 1946-63.

recruits in catch, etc., from age distributions and I have applied this programme using age distribution data obtained from the section above.

Average age at recruitment

Fig. 3 shows the yearly change in average age at recruitment thus calculated. Excluding extremely low figures obtained for some years, the ages changed within a range of 10 to 17 years, and it can be estimated that the average age at recruitment is 12 years for male sperm whales in the North Pacific as a whole.

Recruitment rate

The CPØP programme provides a value for the proportion of recruits in the catch in a year. This is regarded as recruitment rate type II. Fig. 4 shows the yearly change in the obtained values of the recruitment rate. There is a large yearly fluctuation in the values, which range from -0.067 to 0.298. However, it can be seen that the recruitment rate has not remained constant and has decreased from the late 1940s to its lowest value at the beginning of the 1960s since when it has been gradually increasing, and is highest in recent years. I smoothed the values (as shown by the broken line in Fig. 4) for convenience in a later section. The lowest value is 0.056, which is almost the same as the natural mortality, 0.05.

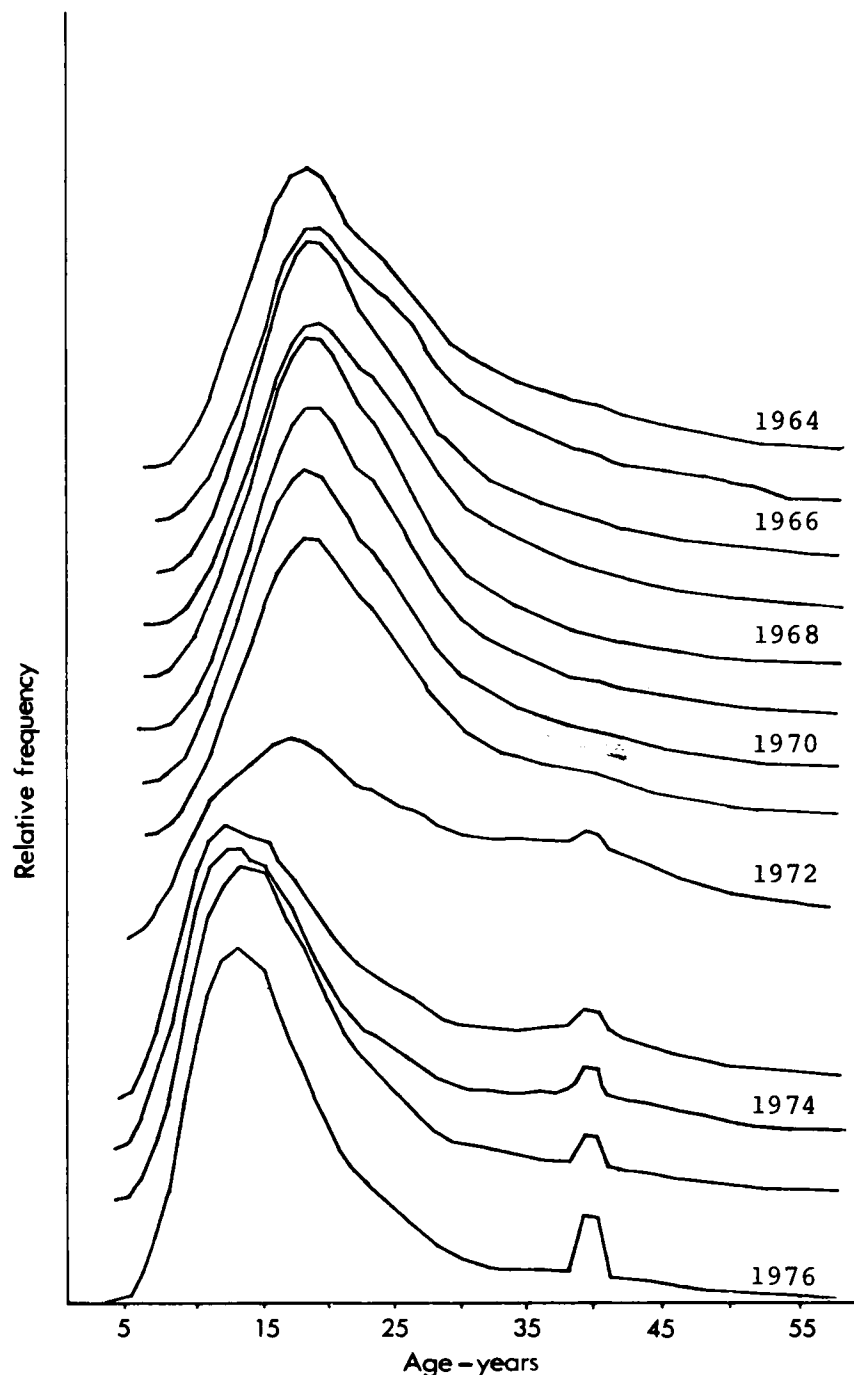


Fig. 2B. Yearly change in the age distribution of males caught in the North Pacific, 1964-76.

ESTIMATION OF POPULATION SIZE USING THE MARK/RECAPTURE METHOD

This assessment method is one of the ones which do not require CPUE data. Japan started her whale marking programme in the North Pacific in 1949, and Table 1 shows the number of effectively marked and recovered sperm whales in the North Pacific from 1949 to 1976.

Ohsumi and Masaki (1975) reported that the mistaken identification or recording of species at the time of marking

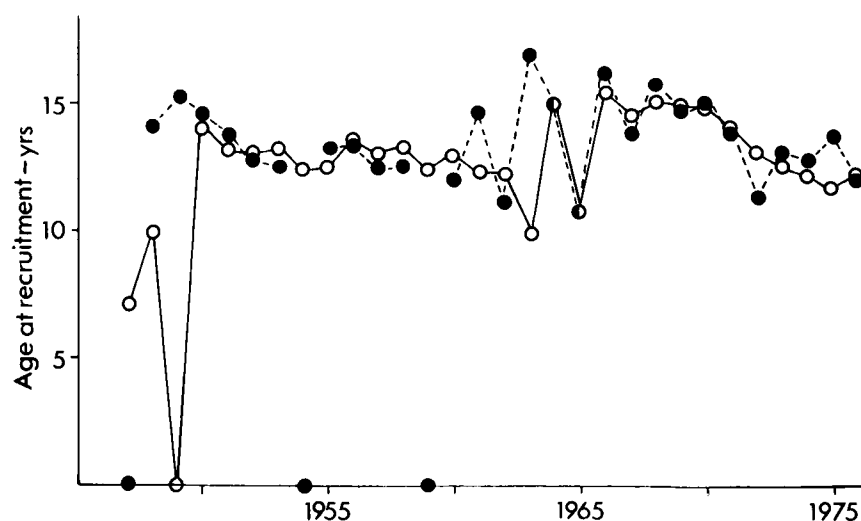


Fig. 3. Yearly change in average age at recruitment of males in the North Pacific using the CPØP programme •---• age distribution from direct determination; ○---○ age distribution from an age/length key.

will be negligible for the sperm whale and that the actual number of effective markings is about 20% more than the number recorded as 'hits', i.e. effectively marked. On the other hand, Best (1977) reported that a correction factor of 0.62 is needed to take into account incorrect reporting for marking off Durban. In this paper, I consider those whales recorded as "hits" as effectively marked.

One of the problems in applying the mark/recapture method for the sperm whale is the separation of the marked whales into each sex, because the fishing rates of sperm whales vary by sex. To solve this problem, I have only taken marked whales recorded to be 40 feet and over at the time of marking, because these whales will be almost all males. The annual numbers of marked whales of 40 feet and over are also shown in Table 1, and of these, 42 have been recovered. The records show that 29 were males, 2 were females and 11 were unknown at the time of recovery, and thus only about 6.5% of the whales of 40 feet and over were females. In this paper I use the values in column A of Table 1 as marked males.

Best (1976) assumed a tagging mortality of 5%, occurring within one month of tagging, and I have used this in calculating the number of surviving marked whales. As whale marking is internal, tag shedding does not need to be considered. The number of surviving marked whales (M) in the second year is given by the following formula:

$$M_{j,1} = (0.95A_j - R'_{j,0}) s$$

and the number surviving in the following years by:

$$M_{j,i} = (M_{j,i-1} - R'_{j,i-1}) s$$

where j is the year of marking, i is the number of years

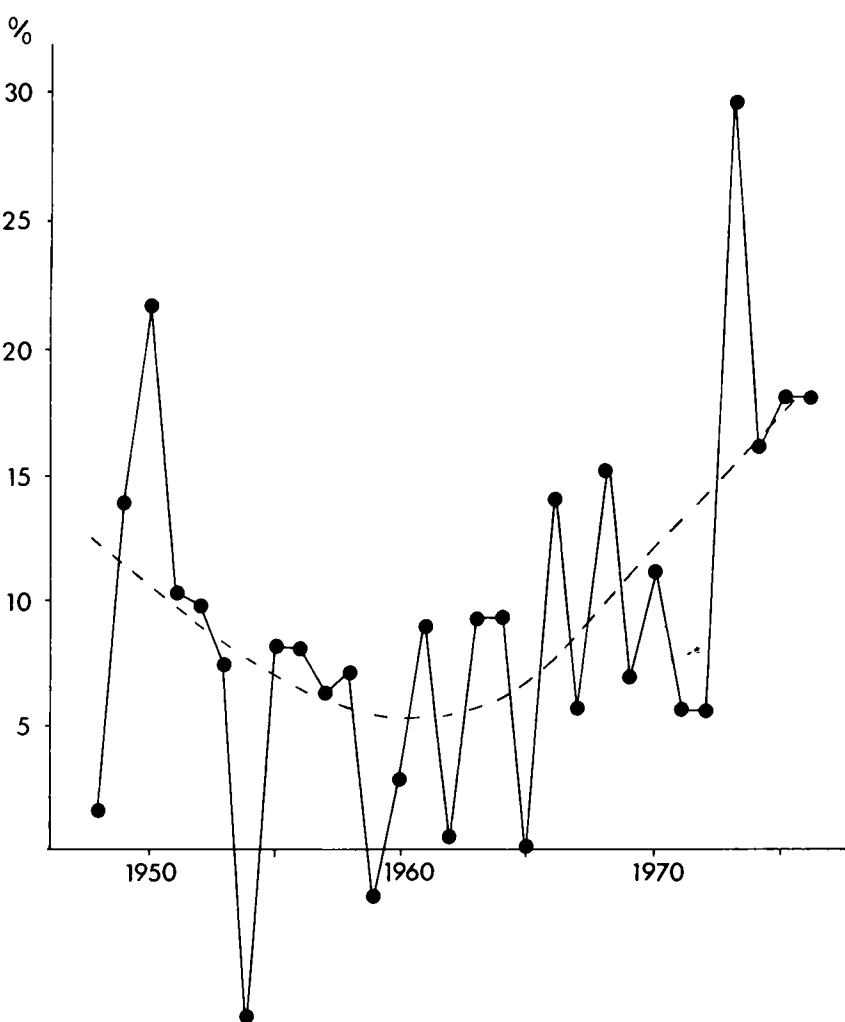


Fig. 4. Total proportion of recruits in the catch of males.

since marking, A is the number of marked whales, R' is the number of recaptures and s is the survival rate (assumed to be 0.95, i.e.1 - M). The total number surviving is the accumulation of those surviving in each year. The estimated number of surviving marked whales is shown in Table 1.

Table 1
Estimation of population sizes of male sperm whales in the North Pacific by mark/recapture

Year	Number marked		Number recovered		Number of males caught			Survived A (M) ¹	Recaptured (R) ²	Fishing rate (E) ³	Population size (000s)
	Total	≥40 ft (A)	Total	From A	Total (B)	Japan	USSR				
1949	239	5	3	—	2,203	508	1,598	5	—	—	—
1950	195	53	1	—	2,614	878	1,696	55	—	—	—
1951	223	20	4	—	2,910	982	1,766	71	—	—	—
1952	400	37	4 (2)	1 (1)	2,701	704	1,875	103	—	—	—
1953	310	26	5	—	3,077	812	1,998	121	—	—	—
1954	265	49	6	1	3,352	1,432	1,705	163	2.7	0.023	146
1955	235	44	6 (2)	2	4,172	1,947	1,921	195	5.0	0.031	135
1956	14	12	16	4	5,315	2,817	2,382	194	9.2	0.052	102
1957	29	29	16 (2)	3	5,489	2,747	2,582	211	7.3	0.039	141
1958	38	35	15 (1)	4 (1)	5,802	2,709	3,009	229	7.9	0.039	149
1959	9	8	4	—	6,056	2,724	3,101	220	—	—	—
1960	39	31	7 (2)	1 (1)	6,249	2,806	3,429	208	—	—	—
1961	16	4	10	2	5,805	2,751	3,003	193	5.2	0.027	215
1962	18	13	10	1	5,955	3,160	2,641	173	2.3	0.019	313
1963	16	15	7	—	8,760	3,453	5,136	163	—	—	—
1964	40	23	8	2	8,346	3,391	4,840	149	6.1	0.047	178
1965	31	13	9 (2)	1 (1)	11,236	3,430	7,652	132	—	—	—
1966	47	29	5	—	12,965	3,828	8,968	145	—	—	—
1967	90	22	8 (4)	1	12,960	3,863	8,929	144	4.1	0.035	370
1968	111	27	8 (3)	2 (1)	12,772	3,668	9,081	144	4.1	0.035	365
1969	120	37	4	—	11,322	3,870	7,424	167	—	—	—
1970	57	37	2	—	11,234	3,966	7,236	178	—	—	—
1971	61	33	6	5	8,250	3,170	5,052	196	16.2	0.087	95
1972	75	26	6 (3)	4 (2)	4,032	2,721	1,311	201	3.7	0.023	175
1973	114	75	5	2	4,605	2,559	2,024	251	4.5	0.022	209
1974	73	40	4	3	4,419	2,536	1,883	258	6.5	0.029	152
1975	36	5	5 (2)	3 (1)	4,261	2,493	1,768	243	4.3	0.022	194
1976	79	22	6 (1)	1	4,200	2,220	1,980	232	2.4	0.015	280

(): Recovery by USSR; ¹: Marked whales survived for 9 years from year of marking;
²: Refer to method of calculation in text; ³: R + 1/M + 1.

The figures used are for those within nine years of marking.

The most difficult problem with this technique is in determining the efficiency of finding marks in recaptured whales. Table 1 shows the annual catches of male sperm whales by Japan and the USSR in the North Pacific. The sum of the catches is 72,145 and 105,990 for Japan and the USSR respectively. If the whaling grounds for both countries are the same each year, then the accumulated recovery of marked whales should be in proportion to the accumulated catches if the recovery and reporting efficiencies are the same for both countries, i.e. the USSR should have recovered 1.47 times the number of marks recovered by Japan. However, Japan has recovered 35 and the USSR only 8 which means that the efficiency at recovering and reporting of the USSR is much lower than that of Japan. Ohsumi and Masaki (1975) estimated Soviet efficiency to be 7%. They also estimated the recovery efficiency of Japanese pelagic whaling for the sperm whale to be 78.3%. In the present examination recovery data from Japanese coastal whaling are included, and as it is thought that their efficiency will be higher than pelagic whaling, the total Japanese efficiency can be regarded to be about 80%. When this figure is used, the recovery and report efficiency for the USSR is 12.4%, therefore a better estimate of the total number of recaptured whales would be based on Japanese data only and can be calculated from the following formula:

$$R = R'_j / r_j (C_r / C_j + 1)$$

where, R is the estimated total number of recaptured whales, R' is the number of recoveries by Japan, r_j is Japanese recovery efficiency (0.8), C_j is the Japanese catch and C_r is the Soviet catch. The results are shown in Table 1.

The exploitation rate, E , was calculated from Chapman's (1951) equation:

$$E = (R + 1) / (M + 1)$$

Thus the population size can be estimated as shown in Table 1. There are large variations in the estimations from 95,000 to 370,000 with an average value of 201,200 during the years 1954 to 1976.

ESTIMATION OF POPULATION SIZE USING COHORT ANALYSIS

A population ($n_{j,i}$) of year class (j) in year (i) changes in the next year ($i + 1$) according to the following formula:

$$n_{j,i+1} = (n_{j,i} - C_{j,i}) e^{-M}$$

where, $C_{j,i}$ is the catch of year class j in year i and M is the natural mortality coefficient.

The population in the previous year ($i - 1$) is:

$$n_{j,i-1} = N_{j,i} / e^{-M} + C_{j,i-1}$$

Therefore, if the size of each year class in a year is known, the sizes of the year classes in other years can be extrapolated, when catches of the year class in each year and M are put in.

1976 was chosen as a base year. The population in each year class in 1976 can be estimated by dividing the catches in each year class by an assumed value for the exploitation rate (E_{1976}). Fig. 5 shows an example of the age distribution with population sizes in 1976, when E is assumed to be 0.04. Because of size selection of whales by the whalers, the calculated sizes of the year classes less than the age at full recruitment are too low. To correct for this, I extrapolated the population size at full recruitment by the survival rate

assuming it to be e^{-M} . Fig. 5 shows the result of the extrapolation for a survival rate of 0.951 ($M = 0.05$) for the ages below 14 years and above 2 years. Thus, the population size of each year class can be calculated by the above formula, although for the highest year class (58 years of age) in the previous year, the population size cannot be estimated from this formula. Therefore I calculated the average exploitation rate for the last ten years, 39–48 years old, and calculated the population for the year class from the catch and thus estimated the exploitation rate. The population size over a given age in a given year is the sum of the populations in each year class over the given age in that year.

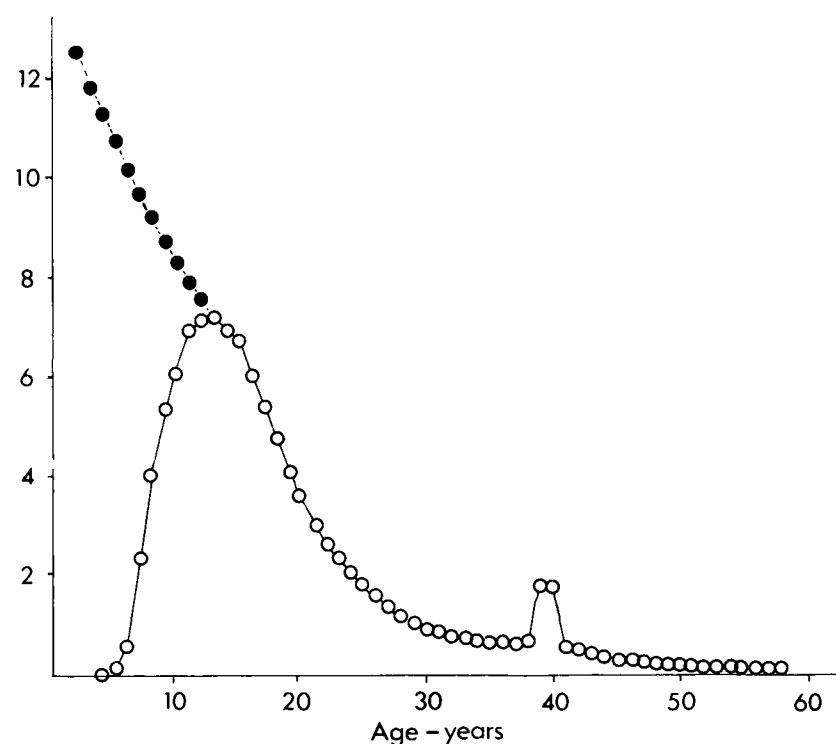


Fig. 5. Estimated age distribution of males in the North Pacific in 1976 assuming an exploitation rate of 0.04. ●---● extrapolated from 14 years to 2 years, assuming a survival rate of 0.9512.

A computer programme was formulated to calculate these population sizes using data for the age distribution of the catch in each year, the natural mortality coefficient and the exploitation rate in a standard year.

There is no new evidence to change the value of natural mortality coefficient of 0.05 which has been adopted by the Scientific Committee, and I used this value. Several values for the exploitation rate in 1976 were put into the programme. The exploitable population is the sum of the populations of each year class from the average age at recruitment (adopted as 12 years for male North Pacific sperm whales) and over.

Fig. 6 shows the yearly change in the exploitable population of males for four different exploitation rates in 1976: 0.02, 0.03, 0.04 and 0.06. According to the results, the exploitable population of males gradually increased until 1955–56, rapidly decreased from 1963 to 1971, but has remained approximately constant since 1972.

The male sperm whale population estimated by the mark/recapture method is also shown in Fig. 6, but because of the very wide range it is difficult to choose the best population estimation by cohort analysis from a comparison with these results.

As shown in Fig. 2, 5 year-old animals were not taken in the catch and so the yearly change in the population at that age (calculated by cohort analysis) will represent the undisturbed recruits. Fig. 7 shows the relative population sizes of 5 year-olds based on the population size in 1946 for each of the series of calculations noted above. (This figure also shows the estimated relative population sizes of

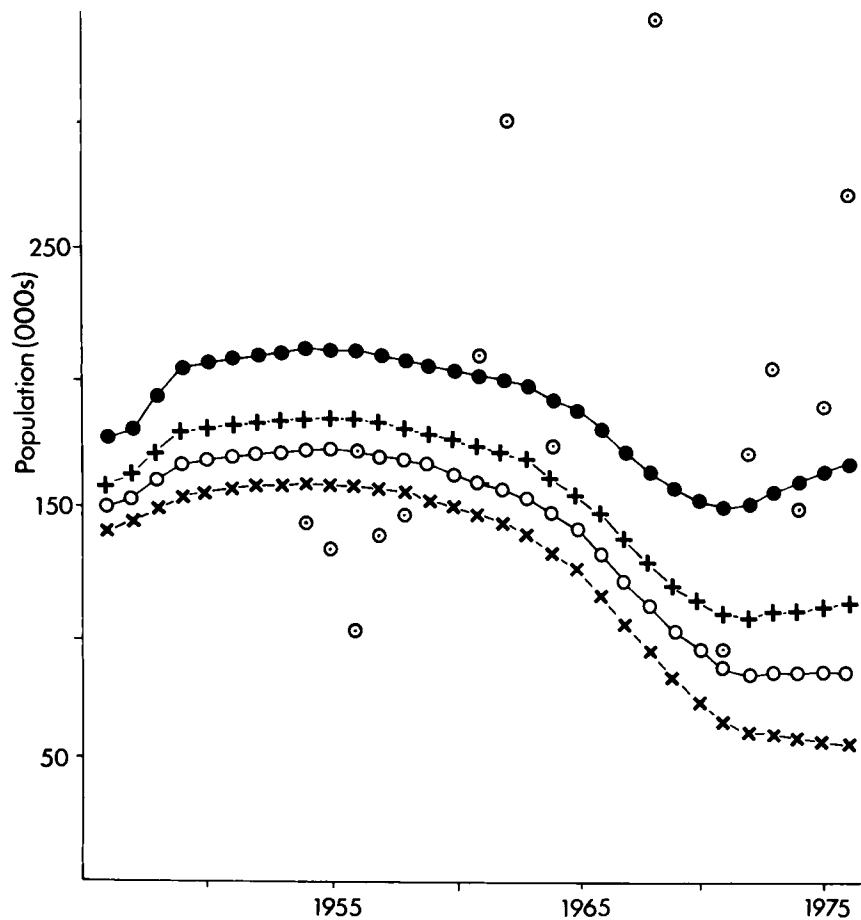


Fig. 6. Yearly change in the exploitable male population in the North Pacific estimated from mark/recapture $\circ$; and cohort analysis: $\bullet$ — $\bullet$ exploitation rate (E) = 0.02; $+$ — $+$ E = 0.03; $\circ$ — $\circ$ E = 0.04; $\times$ — $\times$ E = 0.06.

mature females calculated by the SPDYN programme and this will be examined later.) The series of population estimates based on an exploitation rate in 1976 of 0.02 is unrealistic, because there are more recruits in recent years than in earlier years. The 0.04 and 0.06 series are also unrealistic, because the number of recruits decreases too rapidly, although the mature female population size is not thought to have decreased so much over the years. From this examination, the series of $E_{1976} = 0.025$ is the most reasonable.

ESTIMATION OF THE POPULATION SIZE USING A MODIFIED DE LURY METHOD

Ohsumi (1980b) examines sperm whale fishing effort in the North Pacific, and points out several problems in its evaluation for Japanese pelagic whaling. From these I look here at the problems which apply to the modified DeLury method of Chapman (1974) to estimate the population size of male sperm whales.

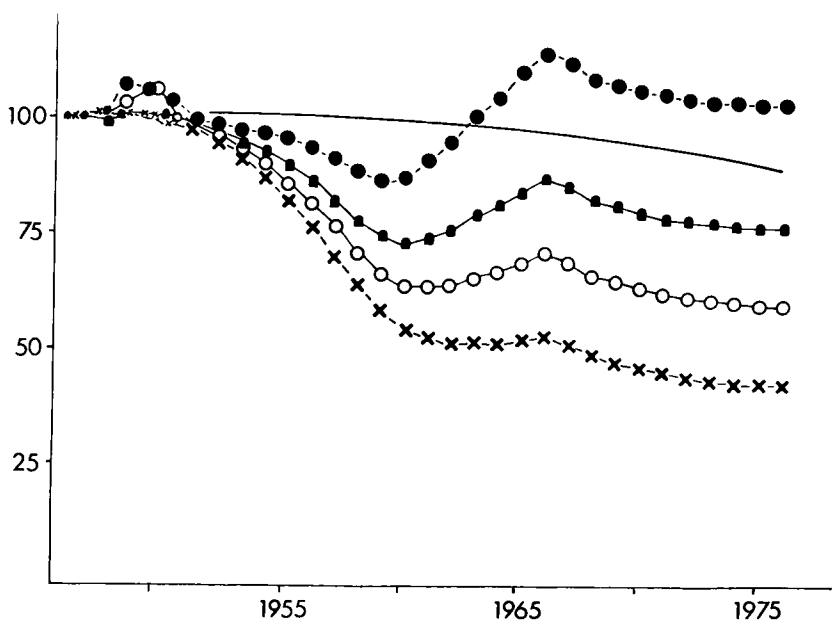


Fig. 7. Yearly change in the relative population size at age 5 years estimated from the results of cohort analysis and comparison with the relative population size of mature females (sliding 5 years later) obtained from SPDYN analysis (initial population 230,000) $\bullet$ — $\bullet$ E = 0.02; $\blacksquare$ — $\blacksquare$ E = 0.03; $\circ$ — $\circ$ E = 0.04; $\times$ — $\times$ E = 0.06.

Catch efficiency and the size of catcher boats

Ohsumi found a low correlation between the tonnage of boats and the CPUE for sperm whales in pelagic whaling and also found that efficiency is not directly proportional to tonnage if indeed there is any correlation between them. He further noted that when examining the effect of wind force, the efficiency remained almost the same for boats of over 600 tons. In this paper I use the formula

$$Y = 4.978T/1,000 + 1.344$$

as a conservative approximation to calculate the efficiency with relation to boat size, and set it constant over 610 tons.

Catch efficiency of Asdic

Ohsumi pointed out that Asdic is only used in chasing whales, and therefore its effect on the efficiency for total CDW is only small. He calculated the catch efficiency of Asdic for the total CDW of Japanese pelagic whaling taking sperm whales, to be 1.055 on average. I use this value here.

Separation of fishing effort for each sex

When both sexes are caught simultaneously, the apparent CPUE of both sexes become less than their real values, because operation time is shared between the sexes. How-

Table 2
Catch, fishing effort and CPUE of male sperm whales in the Aleutian Is. area.

Year	Catch ¹	CDW ¹	Total catch	Cumulative catch	Average tonnage	Tonnage correction	Ratio of Asdic	Asdic correction	Corrected CDW ¹	CPUE ¹
1954	363	131	1,181	—	457.4	1.000	0.000	1.000	131.0	2.771
1955	1,074	494	1,834	—	458.3	1.001	0.000	1.000	494.5	2.172
1956	1,593	471	1,924	962	557.2	1.137	0.000	1.000	535.5	2.975
1957	1,678	502	2,712	3,186	610.5	1,210	0.000	1.000	607.4	2,763
1958	1,499	423	2,901	5,772	649.9	1.210	0.313	1.017	520.7	2.879
1959	1,792	582	3,332	8,536	661.1	1.210	0.389	1.021	718.8	2.493
1960	1,798	566	3,980	11,693	676.1	1.210	0.588	1.032	706.9	2.543
1961	1,741	526	3,602	14,817	678.8	1.210	0.833	1.046	665.4	2.617
1962	2,242	861	3,578	17,596	690.2	1.210	1.000	1.055	1,099.5	2.039
1963	2,428	944	4,693	20,788	684.4	1.210	1.000	1.055	1,205.5	2.014
1964	2,094	938	4,732	24,372	692.7	1.210	1.000	1.055	1,197.8	1.748
1965	2,188	840	3,568	27,217	686.2	1.210	1.000	1.055	1,072.7	2.040

¹ In the sperm whaling season of Japanese pelagic whaling.

ever, it is difficult to separate fishing effort by sex and so I use the catch and effort data until 1965 when almost all the catch was male.

Effect of change in pelagic whaling ground

The pelagic whaling ground for North Pacific sperm whales has been moving from north to south (Ohsumi, 1980a). The density of sperm whales varies greatly by area, and as CPUE does not represent an index of abundance or population size but shows apparent density, it is dangerous to treat the series of apparent CPUEs as indices of abundance as a whole. A more prudent way to examine CPUE data is to only use data within a limited area. I have chosen an area in the Aleutian Islands waters, where large males are mostly found, as it is easier to use the catch and effort data from this area than from other areas.

Separation of fishing effort into baleen and sperm whaling seasons

Ohsumi (1980b), concludes that CPUE data from the baleen whaling season should be excluded when assessing the sperm whale population in the North Pacific and therefore I only use data from the sperm whaling season when applying the modified DeLury method here.

Table 2 shows the catch, fishing effort, catch efficiency correction factors, total catch, cumulative catch and CPUE for the male sperm whales in the Aleutian Islands area from 1954 to 1965 (10° squares P23–P26). The total catch includes the catch of male sperm whales in this area by Japanese and Soviet whaling fleets. The raw CDW is corrected as follows:

$$\text{Corrected CDW} = \times t \times a$$

where t is the tonnage correction factor, and a is the Asdic correction factor. The CPUE is calculated from the corrected CDW and catch of males in the sperm whaling season. The CPUEs in 1954 and 1955 are excluded from the following examination, as the values are smaller than those in 1956, and are not suitable for the modified DeLury method.

The modified DeLury method developed by Chapman (1974) is useful to estimate the initial population size of whales. The problem in applying it to the North Pacific sperm whale is that the available CPUE data are from 1956 when the population was not at its initial level. However, the female population is not believed to have been very depleted at that time and so the recruitment to the exploitable male population can be considered to be almost constant, at least during 1956–65. When a population is reduced from its initial level, the recruitment rate is generally greater than at the initial level ($r = M$), but it is regarded as being equal to the natural mortality coefficient (M).

The correlation coefficient of the relationship between the cumulative catch and CPUE in Table 2 is 0.919, and the male population size in the Aleutian Islands area in 1956 using the modified DeLury method is 69,470. Ohsumi (1966) estimated that the exploitable population was 86% of the actual population of males in high latitudes and thus the actual population in this area would be 80,780. Ohsumi (1966) further estimated that 41.6% of pubescent and mature males are found in high latitudinal waters from a theoretical examination of the age distributions of males in the North Pacific. If the average age at puberty of males is 10 years, then the male population over 10 years of age can be estimated at 194,180. As the average age at recruitment

in males was estimated to be 12 years in the previous section, the exploitable population of males in 1956 is therefore 175,690 using an M value of 0.05.

As shown in Fig. 6, this value corresponds to the series of the cohort analysis with an exploitation rate in 1976 of 0.04. In the discussion of the results of the cohort analysis, that rate was thought to be higher than the actual value, and so the estimated male population in 1956 of 175,690 would be lower than the actual population in that year.

ESTIMATION OF POPULATION SIZE USING THE CHPØP PROGRAMME

Ohsumi (1980b) criticised the fishing effort and CPUE of the sperm whale in the North Pacific, and concluded that it is dangerous to use the CPUE series to estimate any trend in the yearly changes in the population density of the sperm whale. Therefore any application of the CHPØP programme (Allen and Kirkwood, 1977) is impossible without modifying the apparent CPUE.

As one of the most unlikely possibilities, I used the CHPØP programme for the situation where the apparent CPUEs are calculated from the corrected CDW, assuming the catch efficiency to be proportional to the tonnage of a boat and an Asdic correction factor of 1.26. Table 3 shows the input catch and effort data for the CHPØP programme. Two recruitment rates were examined for each year: a constant recruitment of 0.05, and the smoothed figures calculated by the CPØP programme (Fig. 4).

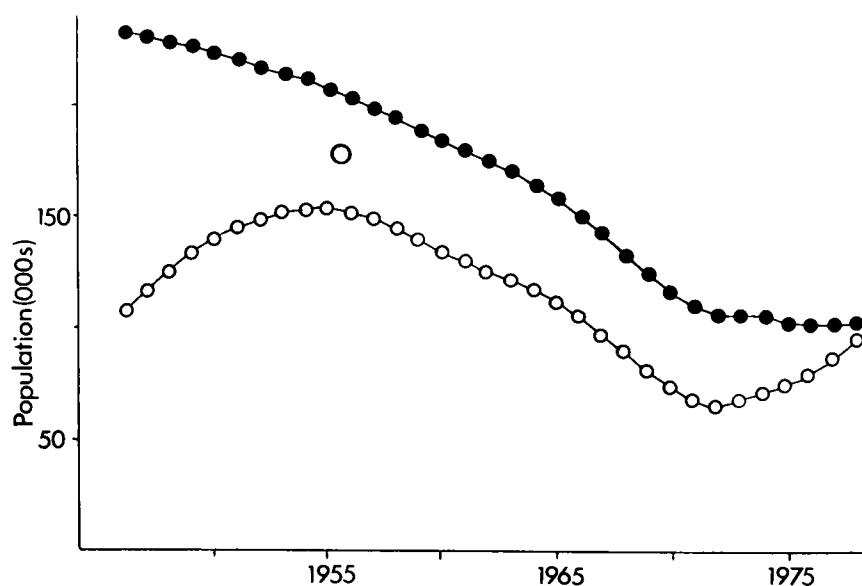


Fig. 8. Two results of the estimation of the male population in the North Pacific using the CHPØP programme and CPUE data from Table 3. ●—● constant recruitment rate 0.05; ○—○ variable recruitment rates as shown in Fig. 4; ○ estimated population size using the modified Delury method.

Fig. 8 shows the yearly change in the population of male sperm whales in the North Pacific. The absolute population values and the pattern of yearly change are different in each case. With a constant recruitment rate, the population size is 231,810 in 1946, gradually decreases until 1972, and then remains almost constant at 103,000. Using the actual recruitment rate, the population increases to 153,000 in 1955, decreases to 66,000 by 1972, after which it rapidly recovers, reaching 93,800 in 1978, assuming the catch in 1977 to equal the catch quota.

This run of the CHPØP programme was merely an academic exercise, because the CPUE data used do not represent a real index of abundance of the males for the whole North Pacific. The tonnage correction is too extreme as shown by Ohsumi (1980b) and the Asdic correction value should be lower, i.e. 1.055 not 1.26, both of which make the yearly changes in CPUE extreme. The CPUEs in

Table 3
Estimation of population size of North Pacific sperm whales, CHPØP

Area of region = 10.00
Starting year for least-square estimates = 1956, Finishing year = 1977
Starting year for backward extrapolation = 1946
Finishing year for forward extrapolation = 1978
Proportion of females protected = 0.0000

Year	Known effort		Total		Outside season		Known effort	Modifier	Catch per effort			Potential modifier effort	Known modifier effort
	Male	Female	Male	Female	Male	Female			Male	Female	Total		
1946	0	0	507	522	0	0	0.0	1.0000	0.0000	0.0000	0.0000	0.0	0.0
1947	0	0	970	666	0	0	0.0	1.0000	0.0000	0.0000	0.0000	0.0	0.0
1948	0	0	1,468	505	0	0	0.0	1.0000	0.0000	0.0000	0.0000	0.0	0.0
1949	0	0	2,203	238	0	0	0.0	1.0000	0.0000	0.0000	0.0000	0.0	0.0
1950	0	0	2,614	790	0	0	0.0	1.0000	0.0000	0.0000	0.0000	0.0	0.0
1951	0	0	2,910	838	0	0	0.0	1.0000	0.0000	0.0000	0.0000	0.0	0.0
1952	0	0	2,701	870	0	0	0.0	1.0000	0.0000	0.0000	0.0000	0.0	0.0
1953	0	0	3,077	730	0	0	0.0	1.0000	0.0000	0.0000	0.0000	0.0	0.0
1954	490	0	3,352	809	0	0	211.0	0.4570	5.0816	0.0000	5.0816	818.8	96.4
1955	1,080	0	4,172	1,171	0	0	498.0	0.4580	4,7351	0.0000	4.7351	1,128.4	228.1
1956	1,593	0	5,315	1,223	0	0	487.0	0.5570	5.8726	0.0000	5.8726	1,113.3	271.3
1957	1,699	0	5,489	1,749	0	0	509.0	0.6110	5.4630	0.0000	5.4630	1,324.9	311.0
1958	1,499	0	5,802	1,964	0	0	423.0	0.7030	5.0409	0.0000	5.0409	1,540.6	297.4
1959	1,798	2	6,056	1,558	0	0	589.0	0.7280	4.1932	0.0047	4.1978	1,813.8	428.8
1960	1,798	1	6,249	1,400	0	0	566.0	0.7800	4.0727	0.0023	4.0749	1,877.1	441.5
1961	1,765	35	5,805	1,451	0	0	556.0	0.8260	3.8432	0.0762	3.9194	1,851.3	459.3
1962	2,546	3	5,955	1,771	0	0	1,119.0	0.8700	2.6152	0.0031	2.6183	2,950.8	973.5
1963	2,692	7	8,760	1,650	0	0	1,288.0	0.8620	2.4247	0.0063	2.4310	4,282.2	1,110.3
1964	2,442	17	8,346	1,953	0	0	1,316.0	0.8730	2.1256	0.0148	2.1404	4,811.8	1,148.9
1965	2,434	26	11,236	1,442	0	0	1,078.0	0.8650	2.6103	0.0279	2.6382	4,805.6	932.5
1966	2,834	166	12,965	1,847	0	0	1,351.0	0.8590	2.4420	0.1430	2.5851	5,729.8	1,160.5
1967	2,665	335	12,960	2,411	0	0	1,217.0	0.8410	2.6038	0.3273	2.9311	5,244.1	1,023.5
1968	2,414	586	12,772	3,532	0	0	1,109.0	0.8590	2.5340	0.6151	3.1492	5,177.2	952.6
1969	2,015	985	11,322	3,611	0	0	1,507.0	0.8860	1,5091	0.7377	2.2469	6,646.2	1,335.2
1970	2,353	347	11,234	3,581	0	0	1,160.0	0.8670	2.3396	0.3450	2.6846	5,518.4	1,005.7
1971	1,517	286	8,250	2,438	0	0	1,200.0	0.8900	1.4204	0.2678	1.6882	6,331.0	1,068.0
1972	1,342	225	4,032	2,291	0	0	937.0	0.8970	1.5967	0.2677	1.8644	3,391.5	840.5
1973	1,442	360	4,605	3,962	0	0	770.0	0.9290	2.0159	0.5033	2.5191	3,400.8	715.3
1974	1,342	461	4,419	3,708	0	0	651.0	0.9340	2.2071	0.7582	2.9653	2,740.7	608.0
1975	1,222	581	4,261	3,598	0	0	577.0	0.9390	2.2554	1.0723	3.3278	2,361.6	541.8
1976	483	570	4,200	3,011	0	0	567.0	0.9710	0.8773	1.0353	1.9126	3,770.2	550.6
1977	756	305	4,300	2,800	0	0	592.0	0.9970	1.2809	0.5168	1.7976	3,949.7	590.2

the 1950s and early 1960s come from the whaling ground of the Aleutian Islands area where large males are more concentrated than in the North Pacific as a whole. Since

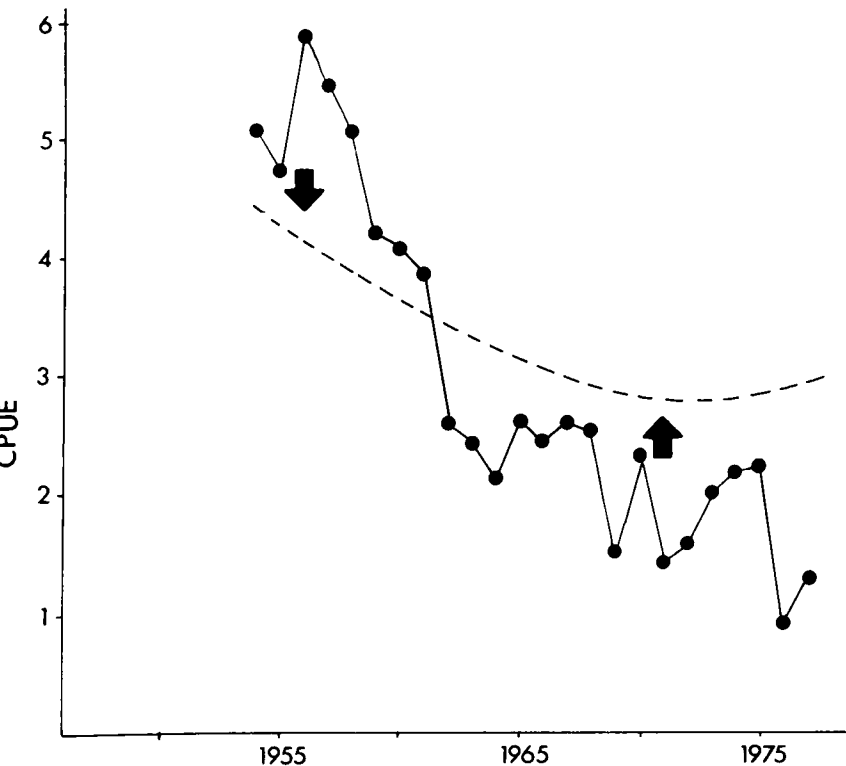


Fig. 9. Yearly change in the apparent CPUE of males caught by Japanese pelagic whaling in the North Pacific. ●—● apparent CPUE values; --- possible value of real CPUE.

1965 the catch of females has gradually increased, and the simultaneous catching of both sexes results in apparent CPUEs less than the actual values. The most serious problem is that the whaling ground does not cover the whole of the area where sperm whales are found. Fig. 9 shows the apparent CPUEs used in calculating the male population sizes using the CHPØP programme as shown in Fig. 8. As examined above, the real CPUE of males in the whole of the North Pacific will be lower than the apparent values in the earlier period of whaling and larger than those in recent years, as shown in Fig. 9. It is difficult to estimate the real CPUE values of the male sperm whale in the whole North Pacific, but they must result in greater population sizes, when used in the CHPØP programme.

It is interesting that the pattern of the yearly change in population when the calculated recruitment rates are used in the CHPØP programme resembles those in the cohort analysis shown in Fig. 6.

ESTIMATION OF POPULATION SIZES USING THE SPDYN PROGRAMME

Allen and Kirkwood (1977b) devised a computer programme, SPDYN, by which the population size in each year can be calculated by putting the initial population size and several biological parameters into the programme.

One of the problems in using this programme is in the estimation of the initial population and determining the initial year. Ohsumi (1980b) and Ohsumi and Fukuda (1972) gave the annual catches of male and female sperm whales in the North Pacific from 1910. Sperm whales were also taken by primitive whaling in the North Pacific, mainly in the 19th century, and therefore it is difficult to decide upon the initial year of exploitation. The maximum annual catch of males and females was 547 and 312 respectively up to 1929, according to Ohsumi and Fukuda (1972). They were much less than this in earlier years. Taking into account the limit of the SPDYN programme that the total period covered must not exceed 50 years, the initial year was set as 1929. The initial population size of mature females was set at 220,000 for one run and 230,000 for the other.

The next problem is to determine the values for the biological parameters to be put into the programme. I chose the following as representing a conservative approach:

Parameters	Initial level	Zero level
Ratio of juvenile mortality rates	1	1
Natural mortality rates	0.05	0.05
Pregnancy rates	0.19	0.25
Female ages at maturity	10	8
Duration of juvenile mortality rate		2
Age of social maturity for males		25
Age of recruitment for males		12
Age of recruitment for females		12
Size of harem		10
Reserve per harem male		0.3
Density dependence exponent		1.4

The annual catch data for each sex are taken from Ohsumi and Fukuda (1972) and Ohsumi (1980a), and the catch for 1977 is set as the catch quota for that year.

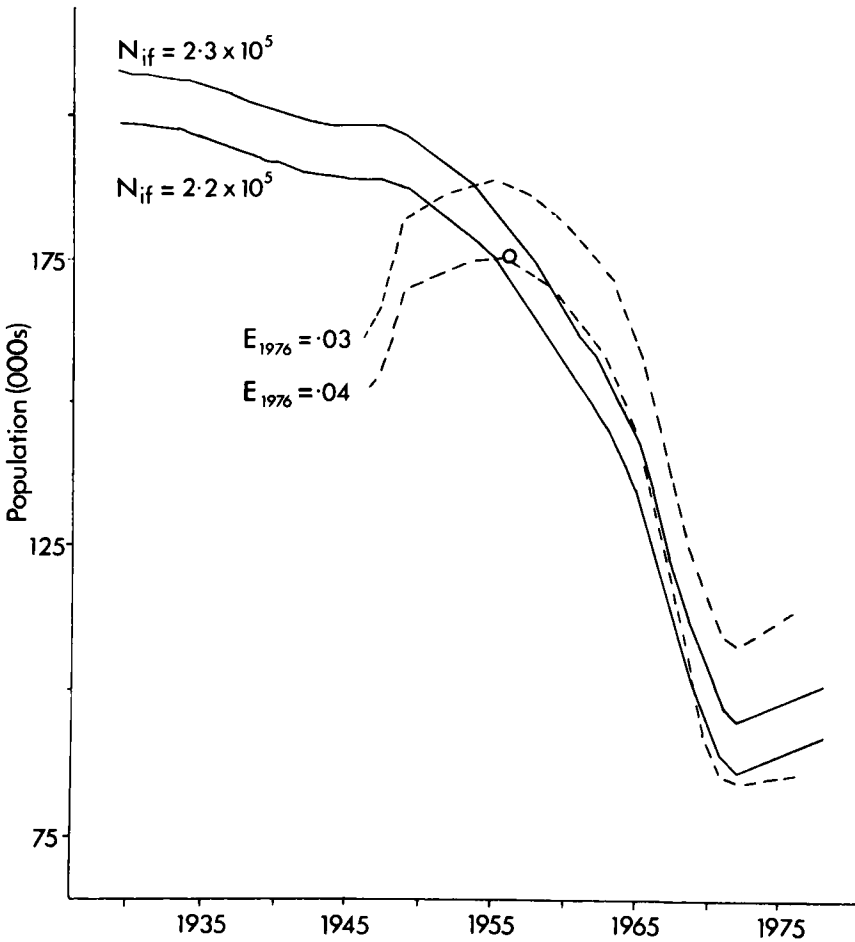


Fig. 10. Comparison of the early change in the estimated male population (a) using the SPDYN programme (—), (b) using cohort analysis (---) and (c) using the modified DeLury method (o).

Fig. 10 shows male population sizes which were calculated by the SPDYN programme. In both cases the population maintained a high level until 1947, and then decreased until 1972. Since 1972 the male population has been recovering.

The trend in the female population size can also be calculated by this programme. The female population did not decrease until the beginning of the 1950s, since when it has been decreasing, although still maintaining a high population level.

SYNTHESIS OF THE POPULATION ESTIMATES

The estimation of the male population size by the mark/recapture method does not use CPUE, but there remain many problems in applying this method for the sperm whale. Using this method the exploitable male population size ranged between 95,000 and 370,000 during the years 1954–1976, but these figures are not reliable.

Cohort analysis uses only values for M and the exploitation rate in a year, when the age distributions of the catches in each year are available, so that provided these data are reliable it is the most reliable method of population estimation. The most serious problem in applying this method is that there is no reliable figure for the exploitation rate. Looking at the recruits and their trends, 0.025 is the most reasonable value for the exploitation rate in 1976. However, if it is the true value, the male population size in 1976 would have been 168,000 which is too large when compared with the other results.

The male population would still be decreasing, if an exploitation rate of 0.05 in 1976 is applied but no other examinations show such a decline in recent years (which would suggest a value of more than 0.05). Therefore, 0.03 and 0.04 are perhaps the most reasonable values for the exploitation rate in 1976.

Reliable CPUE data are only available for the male population of the Aleutian Islands area for the years 1956–65. The exploitable population of males in 1956 was estimated by a modified DeLury method to be 176,000. Compared to the results obtained by cohort analysis, this figure may be smaller than the real figure, but it is equivalent to the situation between the two series of cohort analysis with values of 0.03 and 0.04 for the exploitation rate in 1976.

The CHPØP analysis cannot be used for population assessment unless there is a reasonable adjustment of the apparent CPUE data. However, even using extremely conservative values, the population size in 1978 is about 100,000, and when a reasonable adjustment is made to the CPUE data the result will be higher.

The SPDYN analysis is the most biologically theoretical. Comparing the results by cohort, modified DeLury and SPDYN, the series of SPDYN based on an initial mature female population of 230,000 is the most reasonable, and it includes sufficient safety allowance.

It is concluded that the initial populations of each sex were 208,100, and that the population sizes in 1978 are 100,900 males and 168,700 females.

Ohsumi, Shimadzu and Doi (1971) estimated the initial mature female population to be 239,000. At the IWC Special Meeting in Sperm Whales in Parksville (IWC, 1973) it was estimated to be 250,000, and so the present estimate of 230,000 is conservative.

Several papers have estimated the initial population of exploitable males. Ohsumi *et al.* (1971) calculated it to be

167,000 but estimated the age at recruitment to be 15 years. Using the average age at recruitment of 12 years from this analysis, the population over 12 years would be 199,900. Ohsumi and Fukuda (1972) also used 15 years. Based on the estimated initial population size of mature females, the exploitable male population (over 12 years of age) is 225,000. At the La Jolla sperm whale meeting, the initial population of exploitable males was estimated to be 230,000 from a CHPØP analysis based on Japanese pelagic catch and effort data, and 541,000 based on Soviet data. Tillman and Breiwick (1977) estimated the exploitable male population to be 183,630, for an initial year of 1948. According to the present assessment, the exploitable population size in 1948 is 197,710, from an initial population of 208,100 in 1910. Compared with these results, the estimation for the initial exploitable male population of 170,000 (IWC, 1978) is too small.

It has been impossible to directly assess the female sperm whale population because the apparent CPUE of females has been increasing. (Ohsumi and Masaki, 1977; Tillman, 1977b), and it is difficult to estimate the real population trend. Therefore, the assessment of the female population has been based on the assessment of the male population, after estimating the initial mature female population size and the age at recruitment of females. The situation is the same in the present assessment as in previous ones. Ohsumi *et al.* (1971) estimated the initial exploitable female population in the North Pacific to be 123,800 assuming an age at recruitment of 20 years. Ohsumi and Fukuda (1974) examining the growth curve of females and taking into account the legal size limit of 30 feet, estimated the age at recruitment to be 12 years, and I have adopted this value in the present assessment. Taking 12 years as the age at recruitment Ohsumi *et al.*'s value would be changed to 217,500. Ohsumi and Fukuda (1974) gave a value of 152,000 based on an age of recruitment of 20 years which would be 227,500 based on 12 years. The value in the present study is 208,100 which is the same as for males. Although there was no discussion on age at recruitment of females at the last annual meeting, the initial population size of females was given as 160,000 (IWC, 1978), which is too small, when compared with the above assessments.

Cohort analysis and the CHPØP programme suggested that the population increased up to the mid-1950s, which, if true, poses an important problem. An increase in population means that the recruitment rate exceeded the mortality rate (including natural and fishing mortality). One reason could be that the population was recovering until then. Good catch statistics are not available for primitive sperm whaling in the North Pacific. Best (1976) provided an estimation of the total sperm whale catch in the North Pacific of 60,842 from 1800 to 1909. The fishery was at its peak from 1820 to 1870, and assuming that all the whales were caught during those years, the average annual catch was 1,217. The sex ratio of the catch is not available but even if 1,000 (82%) females were caught annually during those 50 years, the female population would have recovered by the beginning of modern whaling, if the initial mature female population was 230,000 at the beginning of the primitive whaling period in 1820. Another possibility is that the increase was the result of a change in the environment of the North Pacific sperm whale. The main food of sperm whales are squids and deep sea fish. Any effect of human activity on changes in the abundance of these organisms cannot be evaluated. Large changes in the natural

environment are also difficult to investigate, at least during the earlier half of the century. Further study is needed to determine if such changes occurred or not.

Several estimates were made in the present study. According to the mark/recapture method, the average male population from 1971 to 1976 was 172,170. The population size of males in 1976 was 85,250–113,760 by cohort analysis. Even in the extreme example using CHPØP analysis the male population size in 1978 was calculated to be 93,790–103,070. I concluded that the male population in 1978 is 100,880. Ohsumi and Fukuda (1972) estimated the male population as 69,200 in 1971, but used an age at recruitment of 15 years. Tillman's (1977a) estimation was based purely on CPUE, and his value was 55,090 in 1975. As examined by Ohsumi (1980b), there are many problems in using apparent CPUE, and the real population trend would not be more severe than the apparent one. At the last annual meeting the population size of males in 1978 was estimated to be 71,000 and as it was based on the apparent CPUE, this value is also under-estimated.

Ohsumi and Fukuda (1972)'s estimation of the female population in 1971 was 101,500, based on the high estimate of the age at recruitment. The difference between their initial and 1971 population sizes is 22,500. The difference over the same period in the present assessment is 28,200, although the population size in 1971 is 179,000. At the last IWC annual meeting the female population size in 1978 was estimated to be 125,000. The difference between it and the present result (168,700) is due to the lower estimate of the initial mature female population produced by the CHPØP programme and the difference in the age at recruitment of females.

Fig. 11 shows the yearly change in the exploitable population size of both sexes resulting from the present analysis. The male population decreased rapidly after 1950, but it began to recover in 1972 as a result of the strengthening of the IWC catch limits. The population level of exploitable males is 48.5% of the initial level. The female exploit-

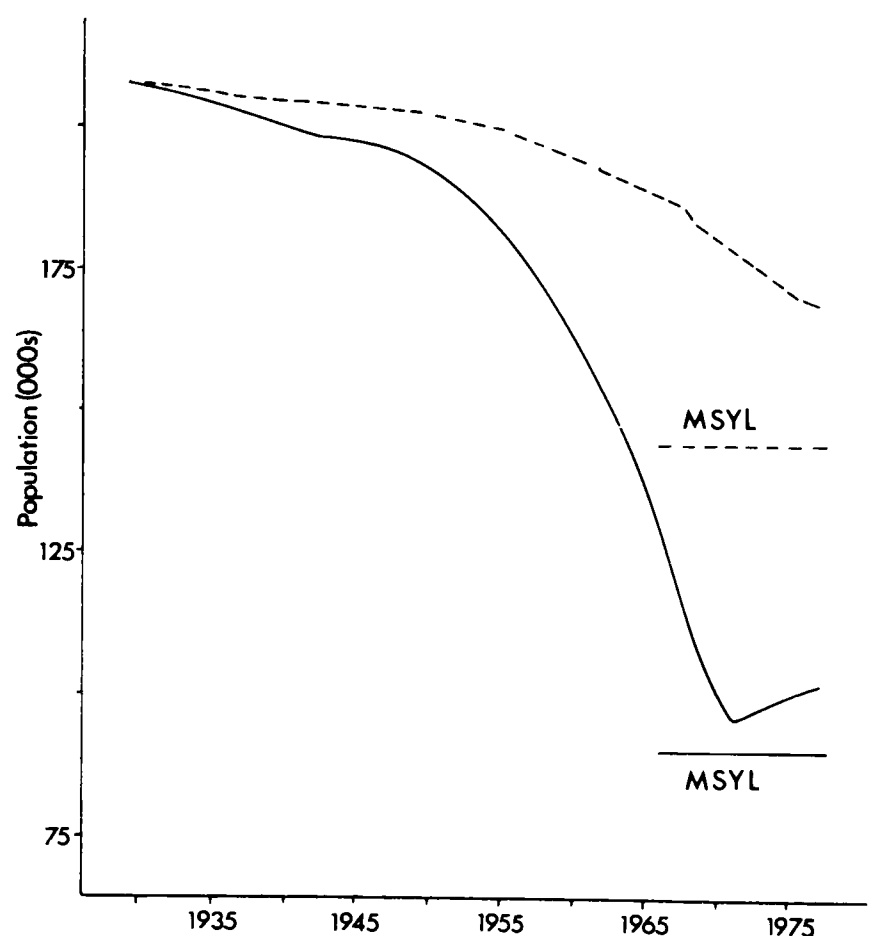


Fig. 11. Yearly change in the male (—) and female (---) exploitable populations using the SPDYN programme and the MSY population levels for each sex.

able population is still decreasing, but it remains at a high population level (81.1%) in 1978.

ESTIMATION OF CATCH LIMITS

Under the new management scheme of the IWC, catch limits are calculated automatically, when the initial, MSY and current population sizes and MSY are estimated.

Sustainable yield curves of the sperm whale in the North Pacific

Allen (1977b) developed a computer programme to calculate the sustainable yield (SY) and fishing mortality for sperm whale populations (SPVAP). Here I examine the SY curves by using several combinations of biological parameters in the SPVAP programme.

The necessary biological parameters and values are shown in Table 4. These values all need to be examined taking into account present knowledge on the biology of the sperm whale in the North Pacific. There are 192 possible combinations of these parameter values.

Table 4
Combinations of input parameters for SPVAP programme

Parameters	Input figures
Ratio of juvenile mortality	1
Natural mortality coefficient (M)	0.05 → 0.05, 0.05 → 0.04
Pregnancy rate (p)	0.19 → 0.25, 0.19 → 0.33
Female age at maturity (X _{fm})	10 → 8
Duration of juvenile mortality rate	2
Age at social maturity of males (X _{ms})	25
Age at recruitment of males (X _{mc})	12, 10
Age at recruitment of females (X _{fc})	12, 10, 14
Harem size (h)	10, 15
Reserve per harem males	0.3, 0.0
Density dependence exponent	1.4, 0.0

A sensitivity test for these parameters had been carried out at La Jolla (IWC, 1976), but I tested it again. Table 5 shows part of the test, although it is difficult to compare all the combinations. The test is based on the ratio of the MSY population level to the initial population level of mature females and MSY for the combined case of males and females.

- (a) *Age at recruitment for females*: the SY curve of females remains the same when this parameter is changed, if the other parameters are the same. Therefore the MSY population level and MSY do not change if this parameter changes.
- (b) *Age at recruitment for males*: When this parameter becomes smaller, the MSY level does not change very much, but the MSY itself becomes larger.
- (c) *Harem Size*: The MSY level becomes higher and MSY becomes larger as the harem size becomes larger.
- (d) *Reserve per harem bull*: When this parameter becomes larger, both the MSY level and MSY become smaller.
- (e) *Density dependence exponent*: An increase in this parameter results in a decrease in the MSY level and an increase in the MSY.
- (f) *Natural mortality coefficient*: Biological intuition suggests that this parameter decreases with a decrease in the population. In which case the MSY level is lower and the MSY is larger than if this parameter is constant.

Table 5
Sensitivity of various parameters in SPVAP programme¹

Input figure	MSY level ²	MSY ³
a. Age at recruitment of females		
10	73	283
12	73	282
14	73	283
b. Age at recruitment of males		
10	74	296
12	73	282
c. Harem size		
10	73	282
15	76	312
d. Reserve per harem males		
0.0	75	301
0.3	73	282
e. Density dependence exponent		
0.0	85	225
1.4	73	282
f. Natural mortality coefficient		
0.05 → 0.05	73	282
0.05 → 0.04	68	376
g. Pregnancy rate		
0.19 → 0.25	73	282
0.19 → 0.33	76	428

¹ Input figures of other parameters are the same as standard case.
² Per cent to the initial mature female population.
³ Number of whales in 10,000 initial mature females.

(g) *Pregnancy rate*: Although no evidence is available because the female population remains at a high level, it is biologically reasonable to assume that the pregnancy rate increases with a reduction in population from analogy with the baleen whales. With the increase of the difference of this parameter between different population levels, the MSY level becomes larger, as does the MSY itself.

Of the possible combinations of these parameters, two extreme cases are shown in Fig. 12. In the lowest case, the MSY level is 85% of the initial mature female population, and the MSY is 225 per 10,000 mature females in the initial populations. In the highest case, the MSY level is 65% and the MSY is 572.

Fig. 13 shows the SY curve for the case in which the combination of parameters was the same as that used in the SPDYN analysis in this paper. The MSY level is 73% of the initial mature female population, and the MSY of both sexes combined is 282 per 10,000 initial mature females, at which level the SY of males and females are 198 and 84, respectively. Fig. 13 also shows the exploitable male and female populations and the SY at each population level. The population which provides the MSY of both sexes combined is 3,800 or 42.0% of the initial size of the exploitable male population (9,048), and 6,200 or 68.5% of the initial female exploitable population size (9,048).

The above values are based on an initial mature female population of 10,000. The present assessment of the North Pacific sperm whale estimates that the initial mature female population is 230,000, and therefore the SY values must be multiplied 23 times. Table 6 shows the results of these assessments.

It can be concluded that the male population in 1978 is estimated to be 115.4% of MSY level, and should be classified as a Sustained Management Stock. The catch limit in 1978 will therefore be 4,100, because the population is

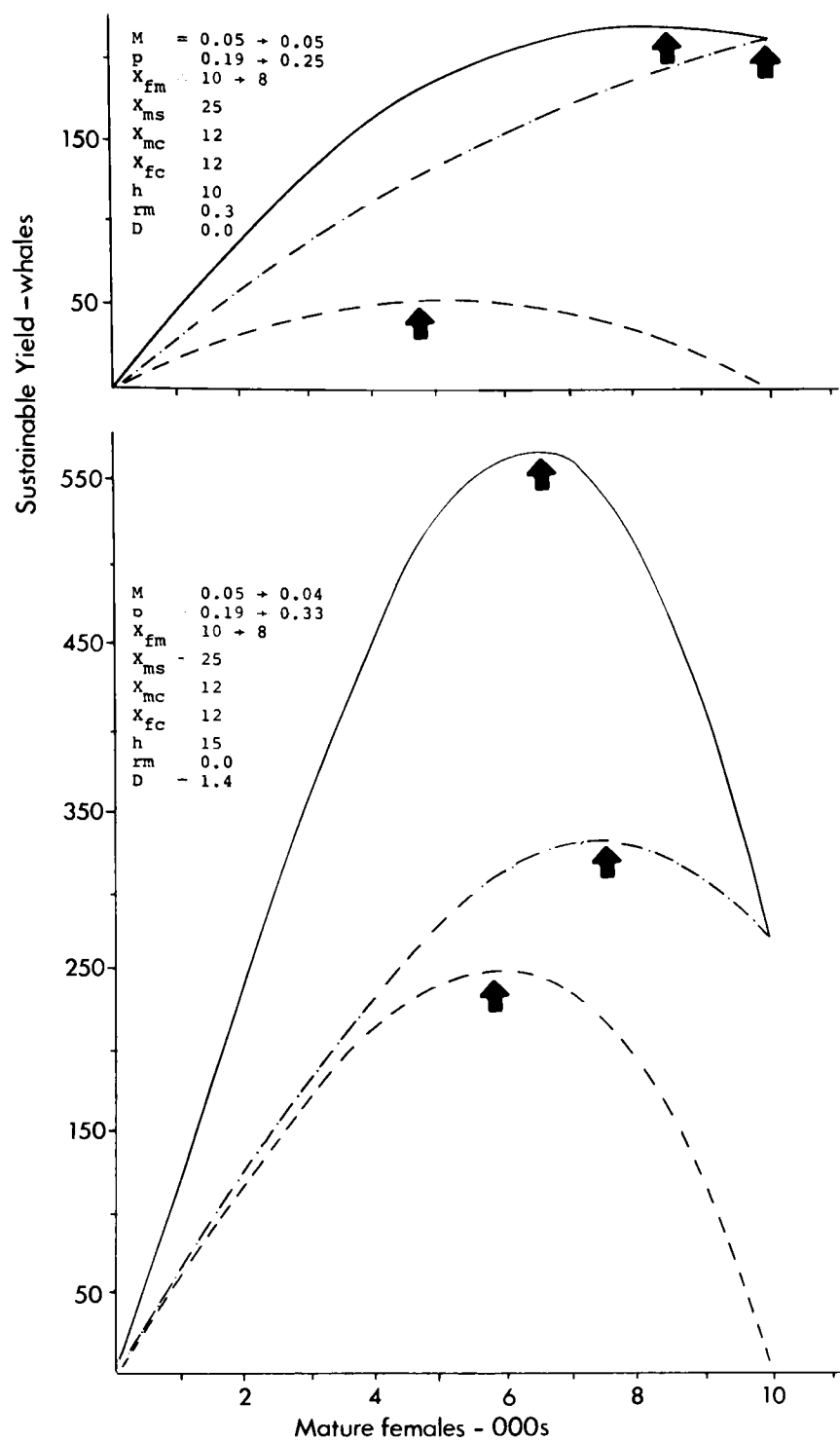


Fig. 12. Comparison of two SY curves using different combinations of biological parameters — male and female combined, ----- males, -.-.- females, ↑ MSY.

above MSY level and MSY is 4,550. The exploitable female population is calculated to be 118.3% of its MSY level in 1978, and should also be classified as a Sustained Management Stock. The catch limit of females in 1978 will therefore be 1,740, because MSY is 1,930 and the population is more than the MSY population level.

Table 6		
Results of population assessment of the North Pacific sperm whale		
	Males	Females
Initial population size	208,100	208,100
Population size in 1987	100,900	168,700
MSY population size	87,400	142,600
Current level to MSY level	115.4%	118.3%
Classification	SMS	SMS
MSY	4,550	1,930
Catch limit	4,100	1,740

The male population was classified as a Protection Stock at the last annual meeting (IWC, 1978), but this was incorrect as it should have been based on the population in 1978, because the aim was to classify the 1978 population at the 1977 annual meeting. According to the report of the Scientific Committee (IWC, 1978), the estimated male

population size in 1978 is 71,000, 42% of the initial level. An MSY level of 46% of the initial level was estimated at the meeting, and therefore the 1978 population level would be 91.3% of the MSY level, which means the male population of the North Pacific sperm whale in 1978 should be classified as a Sustained Management Stock.

Apart from this, the MSY of male sperm whales estimated at the last meeting was lower than the present result. The main reason for this was that because only apparent CPUE values were used, the estimate of the initial population size was lower.

The result of estimation of MSY for the female population at the last meeting was also lower than the present result, again because of an under-estimation of the initial population. The exploitation rate at MSY level was also lower than that of the present assessment. Input parameters for the SPVAP model must be re-examined.

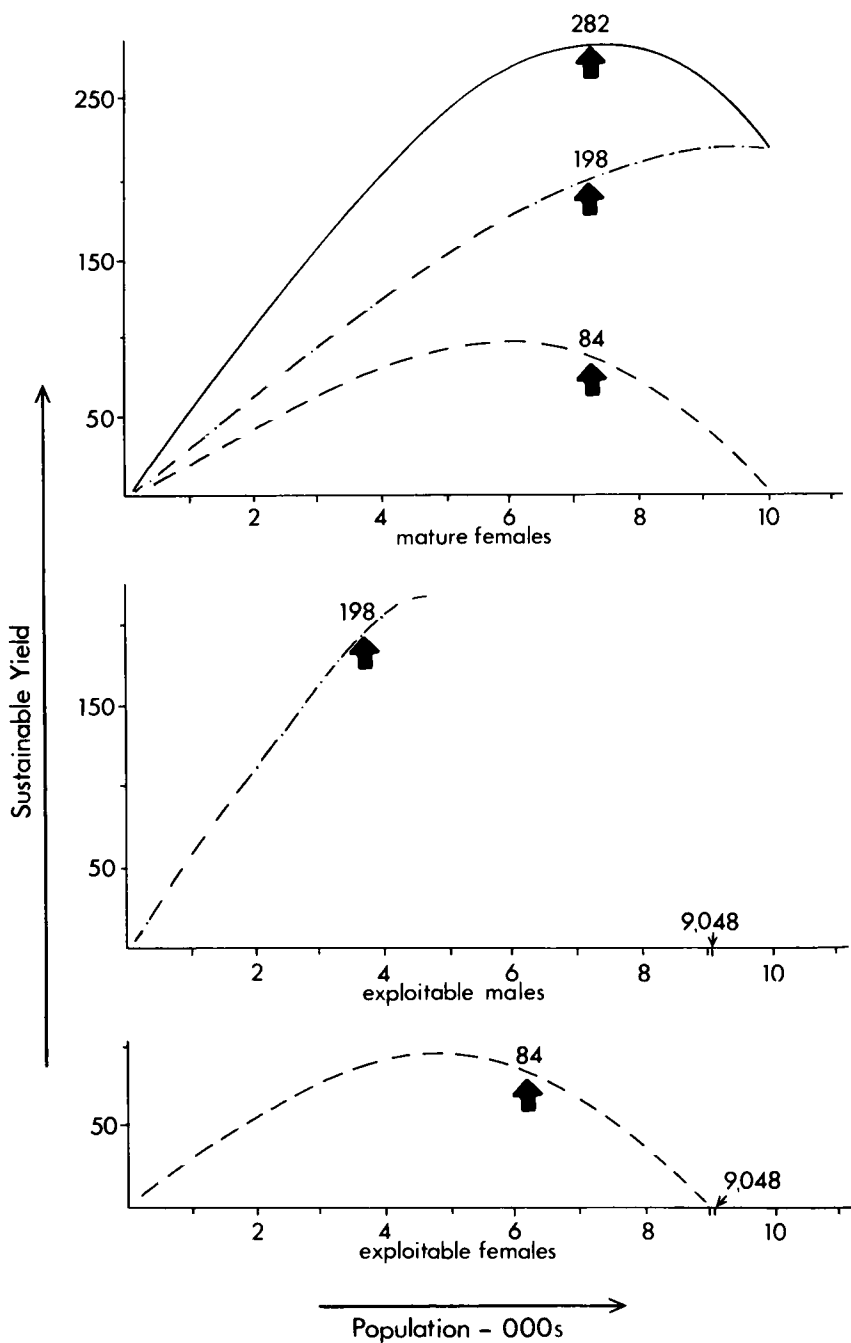


Fig. 13. SY curves of the North Pacific sperm whale. Symbols as for Fig. 12.

Replacement yields

Replacement yields were used to determine the catch limit for a population in the last annual meeting, although the replacement yield may not have been the actual replacement yield (IWC, 1978). Considering the long catch history of the sperm whale in the North Pacific, there are problems in estimating the initial population, and it is possible that the replacement yield may provide a basis for the North Pacific sperm whale catch limits.

Table 7

Replacement yields of the North Pacific sperm whales

Year	Males					Females				
	N	C	R	rII	RY	N	C	R	rII	RY
1972	94,357	4,032	9,862	0.105	5,530	178,722	2,291	9,904	0.055	1,249
1973	95,782	4,605	9,834	0.103	5,427	177,730	3,962	9,849	0.055	1,242
1974	96,564	4,419	9,819	0.102	5,372	175,142	3,708	9,836	0.056	1,361
1975	97,470	4,261	9,806	0.101	5,311	172,909	3,598	9,820	0.057	1,459
1976	98,469	4,200	9,785	0.099	5,238	170,874	3,011	9,813	0.057	1,555
1977	99,456	3,694 ¹	9,783	0.098	5,186	169,489	2,462 ¹	9,813	0.058	1,626
1978	100,875	—	9,780	0.097 ²	5,110	168,694	—	9,820 ²	0.058	1,664

N: Population size; C: Catch; R: Recruits; rII: Proportion of recruits to population; RY: Replacement yield.

¹ Catch quota.

² Extrapolated from previous figures.

Table 7 shows the yearly change in replacement yields for males and females.

The annual population figures come from the SPDYN programme. The catch in 1977 season has not yet been completed, and so the catch limit is used for that value. Recruits are calculated by the following equation:

$$N_{t+1} = (N_t - C_t) e^{-M} + R_{t+1}$$

where N is the population size, C is the catch, R is the number of recruits, M is the natural mortality coefficient and t is a year. The replacement yield is calculated as the value of C such that $N_{t+1} = N_t$, because the replacement yield is the catch which maintains the population size of one year in the next year.

The replacement yield of males has been decreasing with the increase in population, but the replacement yield of females has been increasing with the decline in population. The replacement yields in 1978 will be 5,110 and 1,660 for males and females, respectively. The replacement yield of males is larger than the MSY, and that of females is smaller than the MSY.

Recruitment rate of type II (proportional to a given population size) is also calculated in Table 7. It is found that the use of constant recruitment rate of 0.05 in the CHPØP analysis is incorrect as seen in the previous section, and the calculated recruitment rate from CPØP must also be examined further.

REFERENCES

Allen, K. R. 1977a. A computer programme to calculate age distribution for animals of known length (TAGK). *Rep. int. Whal. Commn* 27: 254-6.

Allen, K. R. 1977b. A computer programme for the estimation of new recruits in the catch (CPØP). *Rep. int. Whal. Commn* 27: 257.

Allen, K. R. 1977c. A computer programme to calculate sustainable yields and fishing mortality for sperm whale populations (SPVAP). *Rep. int. Whal. Commn* 27: 263.

Allen, K. R. and Kirkwood, G. P. 1977a. A simplified computer programme for the estimation of exploited populations (CHPØP). *Rep. int. Whal. Commn* 27: 258-9.

Allen, K. R. and Kirkwood, G. P. 1977b. Programme to calculate time series of sperm whale population components for given catches (SPDYN). *Rep. int. Whal. Commn* 27: 264-7.

Best, P. B. 1976. Status of whale stocks off South Africa, 1974. *Rep. int. Whal. Commn* 26: 264-86.

Best, P. B. 1977. Status of whale stocks off South Africa, 1975. *Rep. int. Whal. Commn* 27: 116-21.

Best, P. B. 1976. A review of world sperm whale stocks. Paper ACMRR/MM/SC/8 Rev. 1, FAO Scientific Consultation on Marine Mammals, Bergen.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample censuses. *Univ. Calif. Publ. Statistics* 1: 131-60.

Chapman, D. G. 1974. Estimation of population size and sustainable yield of sei whales in the Antarctic. *Rep. int. Whal. Commn* 24: 82-90.

International Whaling Commission. 1973. Sperm whale assessment meeting, Parksville, Vancouver Island, BC, 3-10 May, 1972. *Rep. int. Whal. Commn* 23: 55-88.

International Whaling Commission. 1977. Report of the sperm whale meeting, La Jolla, California, 16-25 March, 1976. *Rep. int. Whal. Commn* 27: 240-52.

International Whaling Commission. 1978. Report of the Scientific Committee. *Rep. int. Whal. Commn* 28: 38-89.

Ohsumi, S. 1966. Sexual segregation of the sperm whale in the North Pacific. *Sci. Rep. Whales Res. Inst., Tokyo* 20: 1-16.

Ohsumi, S. 1977. Age-length key of the male sperm whale in the North Pacific and comparison of growth curves. *Rep. int. Whal. Commn* 27: 295-300.

Ohsumi, S. 1980a. Catches of sperm whales by modern whaling in the North Pacific. Paper SC/SPC/1 (published in this volume).

Ohsumi, S. 1980b. Criticism on Japanese fishing effort for sperm whales in the North Pacific. Paper SC/SPC/2 (published in this volume).

Ohsumi, S. and Fukuda, Y. 1972. A population model and its application to the sperm whale in the North Pacific. *Rep. int. Whal. Commn* 22: 96-103.

Ohsumi, S. and Fukuda, Y. 1974. Revised sperm whale population model and its application to the North Pacific. *Rep. int. Whal. Commn* 24: 91-101.

Ohsumi, S. and Masaki, Y. 1975. Japanese whale marking in the North Pacific, 1963-1972. *Bull. Far Seas Fish. Res. Lab.* 12: 171-219.

Ohsumi, S. and Masaki, Y. 1977. Stocks and trends of abundance of the sperm whale in the North Pacific. *Rep. int. Whal. Commn* 27: 176-85.

Ohsumi, S., Shimadzu, Y. and Doi, T. 1971. The seventh memorandum on the assessment of whales in the North Pacific. *Rep. int. Whal. Commn* 21: 76-89.

Tillman, M. F. 1977a. Estimates of stock size for exploitable North Pacific male sperm whales. *Rep. int. Whal. Commn* 27: 180-5.

Tillman, M. F. 1977b. Trends in abundance of sperm whales in three areas of the North Pacific. *Rep. int. Whal. Commn* 27: 343-52.

On the Pregnancy Rate of the North Pacific Sperm Whales

Yasuaki Masaki

Far Seas Fisheries Research Laboratory, 1000 Orido Shimizu Shizuoka 424, Japan

ABSTRACT

The pregnancy rate of the North Pacific sperm whale changes by month and by latitudinal area. Assuming that mature female sperm whales are found uniformly in the waters from 20° N to 60° N, the corrected true pregnancy rate is 20.6–27.1% in the Western Division of the North Pacific.

INTRODUCTION

Studies on the pregnancy rate of the North Pacific sperm whale have been reported by Matsuura (1936), Ohsumi *et al.* (1963), Ohsumi (1965), Rice and Wolman (1970), Masaki (1970) and Ohsumi and Masaki (1976). However, the pregnancy rate, one of the biological parameters necessary for the stock assessment of the North Pacific sperm whale, has not been examined thoroughly.

It is desirable to know the yearly change in the pregnancy rate because it can be recognised as one of the reactions to changes in the population level of the sperm whale itself. However, such information is not yet known.

MATERIAL AND METHODS

The presence of corpora lutea or corpora albicantia in the ovaries, the body length of any foetuses, and the date and position of capture of 2,559 female sperm whales taken by Japanese whaling expeditions in the North Pacific during the seasons 1966 to 1976 (except 1967) have been used for this study.

Sperm whale resources should be managed rationally by each stock unit, and therefore it is desirable to analyse the value and any change in the pregnancy rate by stock unit. It was agreed by the IWC Scientific Committee in 1977 that the North Pacific sperm whale can be divided

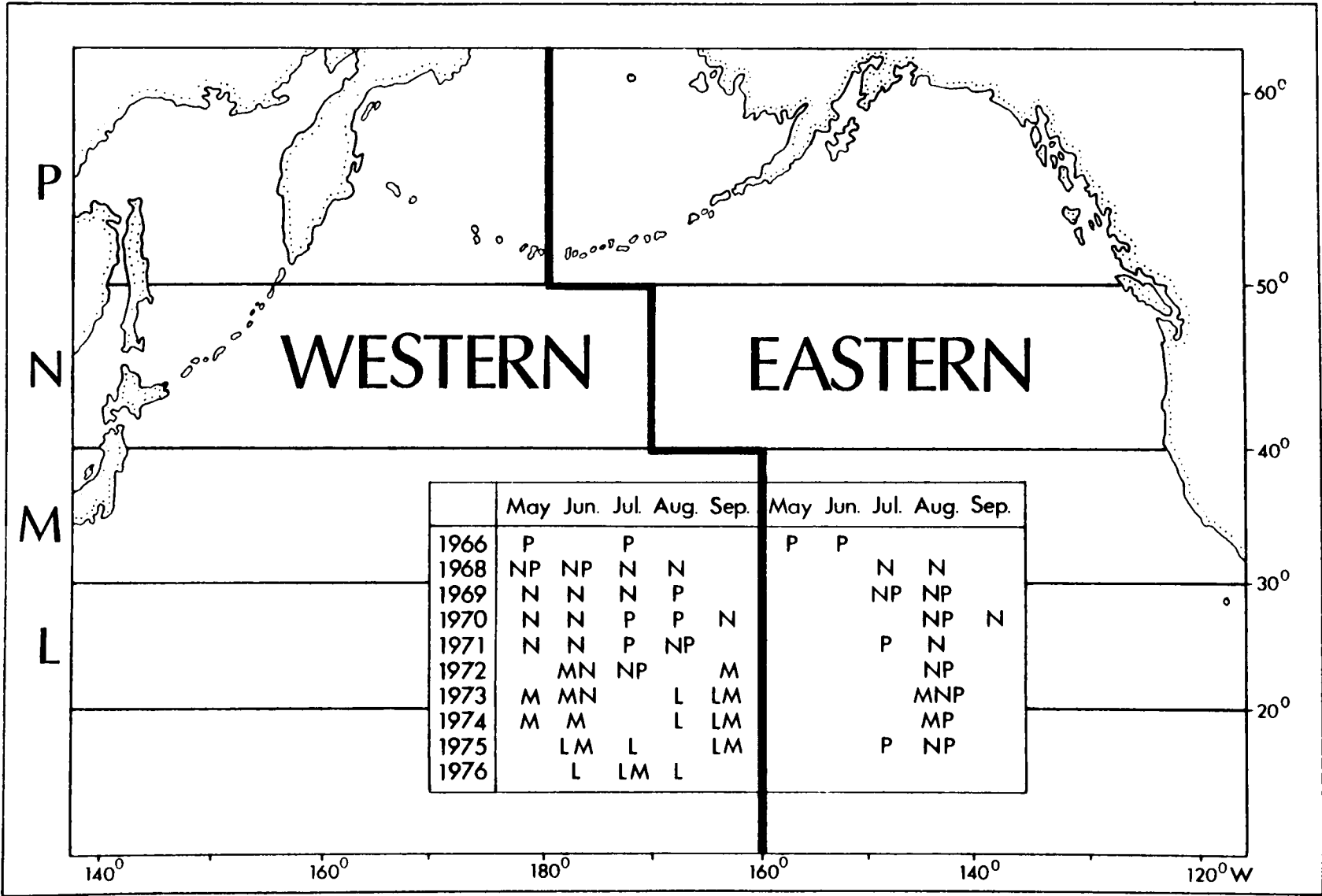


Fig. 1 Map showing the latitudinal Zones L-P, the border line between the Western and Eastern stocks of sperm whales and the changing position of capture of females by Japanese whaling expeditions from 1966–76 (except 1967).

into two stock units, the Western and Eastern Stocks (Fig. 1). The position of the female sperm whale catches by Japanese whaling expeditions for each stock unit by Zone, month and year in the North Pacific during seasons 1966 to 1976 (except 1967) is shown in Fig. 1.

In the area where the Western Stock is found, all of the females caught by Japanese whaling expeditions before the 1971 season were taken in the waters north of 40° N, whereas since the 1973 season females have been caught in the regions south of 40° N. Although the date and position of capture of females extends from May to November and from 20° N to 60° N in the western part of the North Pacific, the females of the Eastern Stock were taken mainly in July and August in the waters north of 40° N (Fig. 1). Due to the abundance of data for female sperm whales, the data used in this estimation of the pregnancy rate are limited to the Western Division of the North Pacific.

In general, the pregnancy rate is expressed as the percentage of pregnant whales in the sexually mature females. This is called “Criterion I” in this study.

The peak of the parturition and mating seasons were about August and April, respectively, and the gestation period of sperm whales in the North Pacific has been estimated to be 16.4 months (Ohsumi, 1965), so that two groups of sperm whale fetuses conceived in different years are seen in the foetal body length distribution in each month from May to September (Table 1). Therefore, as reported by Ohsumi (1965), the pregnancy rates obtained for each month from April to August are apparent ones. To calculate the true pregnancy rate, the author employed the following two methods of Ohsumi (1965): (i) to obtain the ratio of pregnant whales which conceived in that year to the total number of pregnant whales (named “true pregnancy rate I”); and (ii) by assuming that from April to August, half the pregnant whales would have conceived in the previous

year; in September, two-thirds of the pregnant whales would have conceived in the present year; and after October, all the pregnant whales would have conceived in the present year (named “true pregnancy rate II”).

Ohsumi (1965) reported that there is no objection to regarding whales with a corpus luteum in the ovaries as pregnant, i.e. “pregnant” whales include both ovulating whales and whales with fetuses. This is called “Criterion II” in this study.

Spatial segregation of sperm whales by age, sex and sexual condition has been reported by Clarke (1956), Bannister and Gambell (1965), Ohsumi (1966) and Best (1969). Therefore, when calculating the true pregnancy rate of sperm whales, the age, latitudinal position and month of capture for each whale caught must be taken into account.

MONTHLY AND LATITUDINAL CHANGES OF PREGNANCY RATE

Table 1 shows the number of sexually mature females, the total number of pregnant whales, the number of pregnant whales conceived in the year and the true pregnancy rates. Figs 2 and 3 show the monthly change in the two kinds of true pregnancy rate by month and Zone. Zones L (20° N–30° N) and M (30° N–40° N), and Zones N (40° N–50° N) and P (50° N–60° N) show similar trends (Table 2 and Figs 4 and 5).

The monthly change in true pregnancy rate II is parabolic, whereas true pregnancy rate I in both Zones LM (20° N–40° N) and NP (40° N–60° N) increases linearly by month from May to September except in Zone NP in September. Furthermore, true pregnancy rate II can be easily calculated as a ratio of the pregnant animals to the number of sexually mature females captured, without the

Table 1
Monthly change of pregnancy rate of the sperm whales caught by Japanese expeditions during seasons 1966 to 1976 (except 1967) in the North Pacific

Month	May			June				July				August			September		
Latitudinal zone	M	N	P	L	M	N	P	L	M	N	P	L	N	P	L	M	N
Western Stock																	
Number of mature female whales	101	212	12	213	293	360	46	278	27	129	138	249	25	217	175	73	11
Number of pregnant whales	27	96	2	75	79	164	20	110	10	69	70	85	14	116	42	29	3
Number of pregnant whales conceived in the year	7	15	0	36	19	81	4	64	6	42	35	65	11	66	38	23	1
True pregnancy rate (I)	6.9	7.0	0.0	16.0	6.5	22.5	8.7	23.0	22.2	32.6	25.4	26.1	44.0	30.4	21.7	31.5	9.1
True pregnancy rate (II)	13.4	22.5	8.3	17.6	13.5	22.8	21.7	19.8	18.5	26.7	25.4	17.1	28.0	26.7	16.1	26.6	18.3
Eastern Stock																	
Number of mature female whales	—	—	—	—	—	—	45	—	—	180	136	41	863	325	—	—	43
Number of pregnant whales	—	—	—	—	—	—	25	—	—	63	44	11	284	104	—	—	8
Number of pregnant whales conceived in the year	—	—	—	—	—	—	9	—	—	31	20	7	134	49	—	—	4
True pregnancy rate (I)	—	—	—	—	—	—	20.0	—	—	17.2	14.7	17.1	15.5	15.1	—	—	9.3
True pregnancy rate (II)	—	—	—	—	—	—	27.8	—	—	17.5	16.2	13.4	16.5	16.0	—	—	12.5

L: 20° N–30° N; M: 30° N–40° N; N: 40° N–50° N; P: 50° N–60° N.

Table 2

Monthly change of pregnancy rate and correction coefficient based on Criterion I for the Western Stock of sperm whales caught by Japanese whaling expeditions during seasons 1966 to 1976 (except 1967) in the North Pacific

Month	May	June	July	August	September	Average
Zone L-M (20° N-40° N)						
No. of mature female whales	101	506	305	249	248	
No. of total pregnant whales	27	154	120	85	71	
No. of pregnant whales conceived in the year	7	55	70	65	61	
True pregnancy rate (I)	6.9	10.9	23.0	26.1	24.6	17.3
True pregnancy rate (II)	13.4	15.2	19.7	17.1	19.2	16.9
Y = 1.347x + 7.473 (r = 0.802)	14.2	15.6	16.9	18.3	19.6	
Correct coefficient	1.189	1.086	1.000	0.926	0.862	
Zone N-P (40° N-60° N)						
No. of mature female whales	224	406	267	242	11	
No. of total pregnant whales	98	184	139	130	3	
No. of pregnant whales conceived in the year	15	85	77	77	1	
True pregnancy rate (I)	6.7	20.9	28.8	31.8	9.1	22.1
True pregnancy rate (II)	21.9	22.7	26.0	26.9	18.3	24.4
Y = 1.831x + 12.456 (r = 0.963)	21.6	23.4	25.3	27.1	28.9	
Correction coefficient	0.782	0.721	0.669	0.624	0.584	
Average true pregnancy rate (II) in Zone L-P (20° N-60° N)						20.6

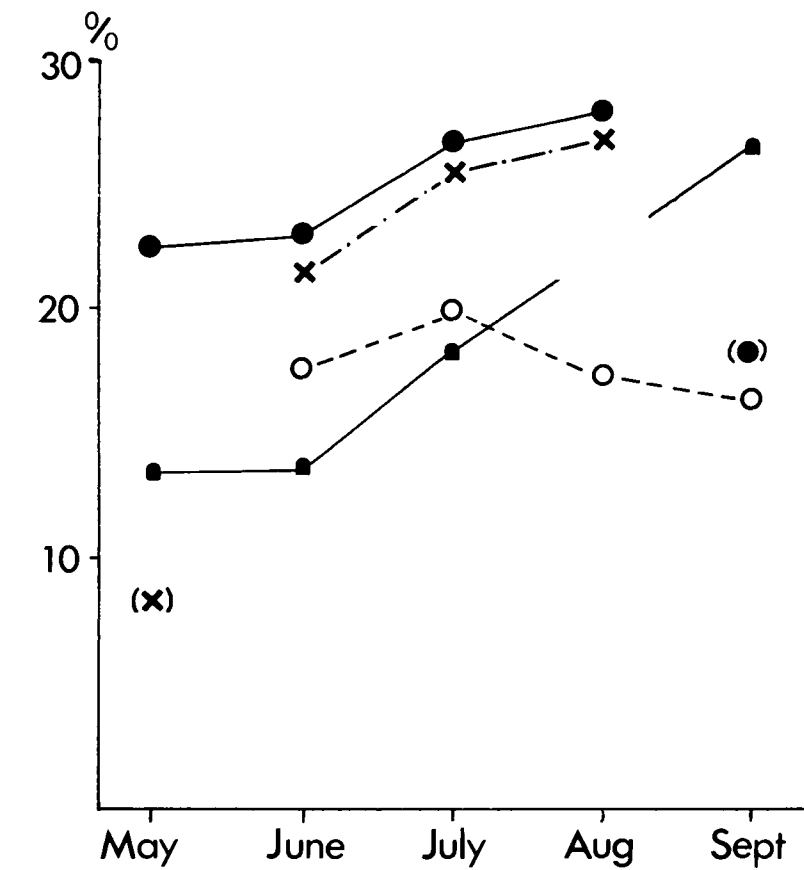


Fig. 2 Monthly change of pregnancy rate II based on Criterion I.
○ --- ○ 20 - 30°N; ■ — ■ 30 - 40°N; ● — ● 40 - 50°N; x --- x 50 - 60°N; (○) no. of mature females less than 20.

foetal body length data. For this reason, true pregnancy rate II is used in this study.

Throughout the western part of the North Pacific during May to September, the average true pregnancy rate II in Zones LM and NP was 16.9% and 24.4%, respectively, and that for the entire Western Stock was 20.6%. However, the density of mature female sperm whales may differ by month and by Zone because of the segregation mentioned above and therefore this pregnancy rate should be corrected by month, Zone and age to obtain the true pregnancy rate of the North Pacific sperm whale. Unfortunately, changes in the density of mature female sperm whales by month, Zone and age are not yet known. Therefore, an average value of 20.6% as the true pregnancy rate for the Western Stock of North Pacific sperm whales was estimated with the assumption that mature females are distributed uniformly in the waters from 20° N to 60° N. Even the true preg-

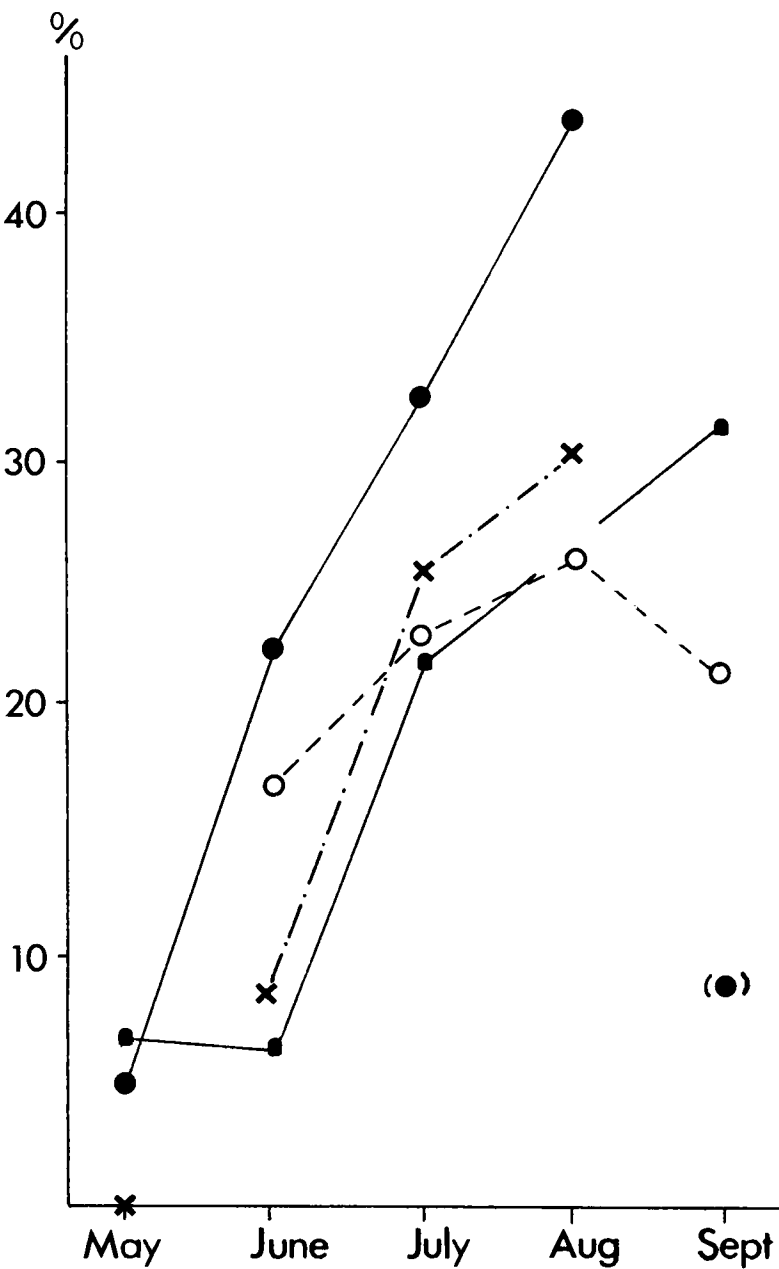


Fig.3. Monthly change of pregnancy rate I based on Criterion I. Symbols as in Fig. 2.

nancy rate based on Criterion I corrected by the distribution density of mature females may be lower than the true one because of the possibility of overlooking small embryos.

Using the Criterion II definition of “pregnant”, the average pregnancy rate I for the Western Stock of North Pacific sperm whales in Zones LM and NP during the years

Table 3

Monthly change of pregnancy rate and correction coefficient based on Criterion II for the Western Stock of sperm whales caught by Japanese whaling expeditions during seasons 1966 to 1976 (except 1967) in the North Pacific

Month	May	June	July	August	September	Average
Zone N-P (40° N-60° N)						
No. of mature female whales	101	506	305	249	248	
No. of whales with corpus luteum in ovaries	47	223	158	112	71	
True pregnancy rate (II)	23.3	22.0	25.9	22.5	19.2	22.6
Y = - 0.813x + 36.982 (r = 0.477)	24.1	23.3	22.6	21.8	21.0	
Correction coefficient	0.935	0.967	1.000	1.036	1.075	
Zone L-M (20° N-40° N)						
No. of mature female whales	224	406	267	242	11	
No. of whales with corpus luteum in ovaries	150	244	180	143	5	
True pregnancy rate (II)	33.5	30.1	33.7	29.6	(30.5)	31.7
Y = - 0.813x + 36.982 (r = 0.477)	32.9	32.1	31.3	30.5	29.7	
Correction coefficient	0.685	0.703	0.721	0.740	0.760	
Average true pregnancy rate (II) in Zone L-P (20° N-60° N)						27.1

1966 to 1976 (except 1967) was estimated to be 22.6% and 31.7% respectively, and that for the entire Western Stock in the North Pacific was estimated to be 27.1% (Table 3). These pregnancy rates might not be correct for the same reason as in the previous discussion of Criterion I. The pregnancy rate estimated by Criterion II may be larger than the true one, because some of the ova may not be fertilised.

According to Masaki (1970) and Ohsumi and Masaki (1976), the pregnancy rate of the North Pacific sperm whale is 19.8% in Areas IV (160° W-180°) and V (160° E-180°) and 18.4%-22.0% in the waters east of 170° E. These values are almost the same as those obtained from the present calculation with Criterion I. Matsuura (1936), Ohsumi *et al.* (1963) and Ohsumi (1965) reported the pregnancy rate of sperm whales in the waters adjacent to Japan as follows: 43% (28.6% as the average value from November to March) Matsuura, 1936; 25.3% (average 28.7%) Ohsumi *et al.*, 1963; 26%-29% Ohsumi, 1965. These values are almost the same as those obtained from Criterion II in the present paper.

Clarke (1957) reported that the pregnancy rate for North Atlantic sperm whales is 27.0%. Further, both Rice and Wolman (1970) for the eastern North Pacific sperm whales and Bannister (1970) for the sperm whales off western Australia reported that the pregnancy rate is 33%. These values are a little larger than those obtained from Criterion II in the present paper.

Taking into account all the results mentioned above, it is concluded that the pregnancy rate of sperm whales may be 20.6%-27.1% in the western part of the North Pacific with the assumption that mature female animals are distributed uniformly in the waters from 20° N-60° N.

YEARLY CHANGE OF PREGNANCY RATE OF THE SPERM WHALES

As already mentioned, the true pregnancy rate differs by month and by latitudinal Zone, and furthermore, the

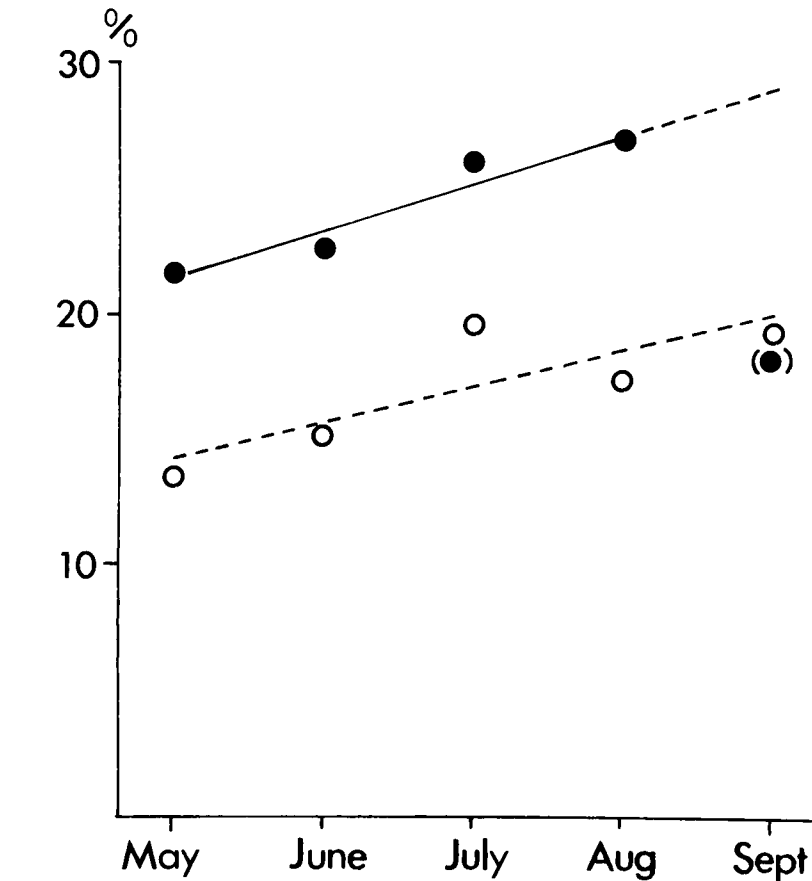


Fig. 4. Monthly change of pregnancy rate II based on Criterion I. ○---○ 20 - 40°N; ●—● 40 - 60°N; () no. of mature females less than 20.

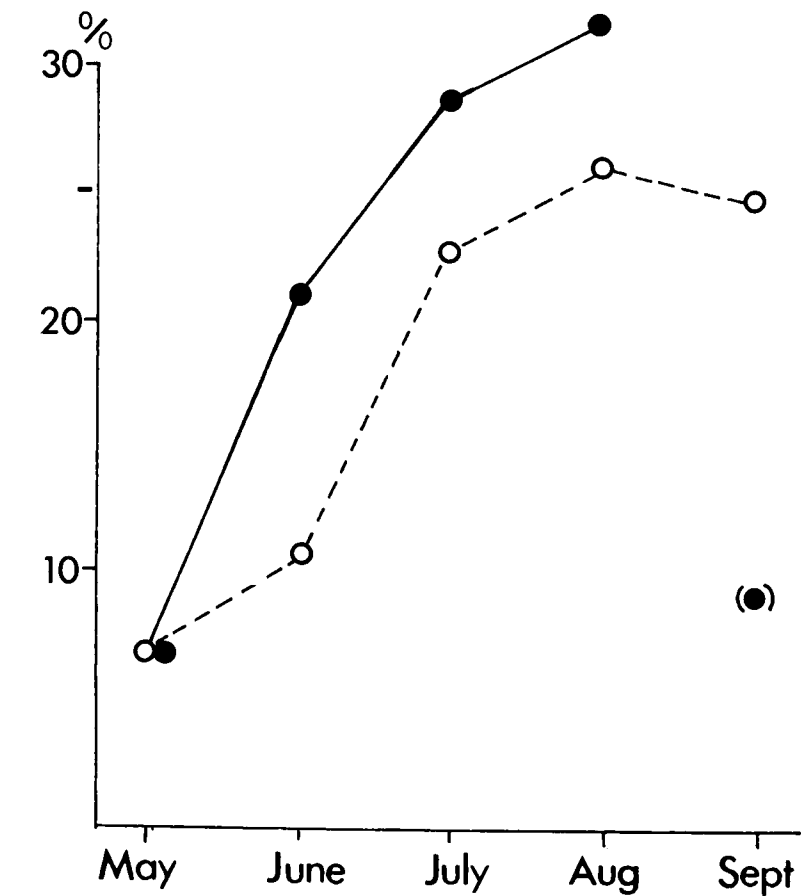


Fig. 5. Monthly change of pregnancy rate I based on Criterion I. Symbols as in Fig. 4.

Table 4
Annual pregnancy rate based on Criterion I for the Western Stock of North Pacific sperm whales

Year and Zone		May		June		July		August		September		Average pregnancy rate	
		A	B	A	B	A	B	A	B	A	B	Corrected	Uncorrected
1966	NP	(25.0)	(19.6)	—	—	24.2	16.2	23.7	14.8	—	—	15.5	23.9
1968	NP	23.2	18.2	22.4	16.2	33.3	22.3	(14.3)	(8.9)	—	—	18.9	26.3
1969	NP	25.0	19.6	30.3	21.9	21.7	14.5	26.2	16.3	—	—	18.1	25.8
1970	NP	18.5	14.5	(2.8)	(2.0)	25.0	16.7	20.0	12.5	(18.3)	(10.7)	14.6	21.2
1971	NP	19.2	15.0	17.5	12.6	27.3	18.2	31.8	19.9	—	—	16.4	23.9
1972	NP	—	—	(25.0)	(18.0)	25.8	17.3	—	—	—	—	23.0	29.6
	LM	—	—	(22.7)	(24.7)	—	—	—	—	33.3	28.9		
1973	NP	—	—	(11.1)	(8.0)	—	—	—	—	—	—	15.5	13.0
	LM	13.0	15.5	(14.3)	(15.5)	—	—	(22.2)	(20.6)	(33.6)	(28.9)		
1974	LM	13.5	16.0	13.2	14.4	—	—	15.7	14.6	13.9	12.0	14.2	14.1
1975	LM	—	—	14.2	15.4	27.5	27.5	—	—	22.3	19.3	20.7	21.4
1976	LM	—	—	17.9	19.4	17.4	17.4	16.8	15.5	—	—	17.4	17.3

Zone LM: 20° N–40° N; Zone NP: 40° N–60° N; (): based on data from less than 20 mature females.
A: Apparent pregnancy rate; B: Standardised pregnancy rate.

latitudinal area and month of capture of females have changed over the years. Therefore, to calculate the yearly average pregnancy rate, it must be at least corrected by month.

Fig. 4 presents a relationship between month of capture and the pregnancy rate based on Criterion I for Zones LM and NP. The regressions for both Zones can be expressed as follows:

Zone LM,
Zone NP,

$$Y=1.347X + 7.473$$
$$Y=1.831X + 12.456$$

$(r = 0.802)$
 $(r = 0.963)$

where, Y = Pregnancy rate (%), X = Number of month (Jan. = 1, Feb. = 2, Mar. = 3, . . .).

Using the values of the pregnancy rate calculated from these equations, the correction coefficient of the pregnancy rate is calculated by month and by Zone as shown in Table 2. Table 4 and Fig. 6 show the yearly average pregnancy rate corrected by the correction coefficient, excluding pregnancy rate values calculated from less than twenty mature females. Large yearly fluctuation in the pregnancy rate is observed and neither a definite tendency for it to increase or decrease can be observed (Fig. 6).

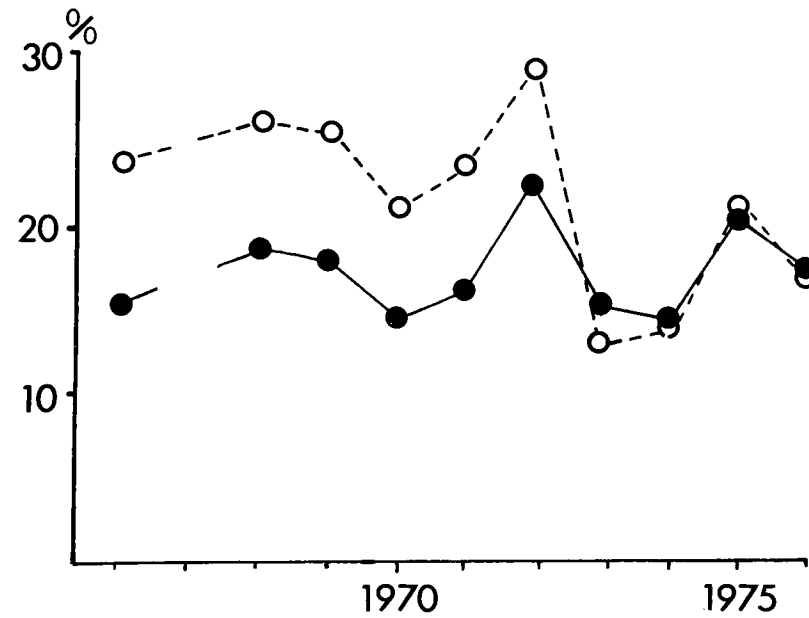


Fig. 6. Annual change of average pregnancy rate II based on Criterion I. ○---○ apparent pregnancy rate; ●—● standardised pregnancy rate.

Fig. 7 presents a relationship between the month of capture and pregnancy rate II based on Criterion II in Zones LM and NP. The regressions for both Zones can be expressed as follows:

Zone LM,
Zone NP,

$$Y=-0.782X + 28.032$$
$$Y=-0.813X + 36.982$$

$(r = 0.802)$
 $(r = 0.477)$

Yearly change in the pregnancy rate with Criterion II corrected by the same method as for Criterion I is shown in Table 5 and Fig. 8. Fig. 8 suggests a slight increasing trend, although there is large yearly fluctuation.

The trends mentioned above may not be correct, as we have discussed, because neither kind of pregnancy rate has been corrected by the distribution density for mature females. Studies on the density distribution of mature female sperm whales should be made for each stock unit by month, latitudinal Zone and age to enable the calculation of the true pregnancy rate in the future.

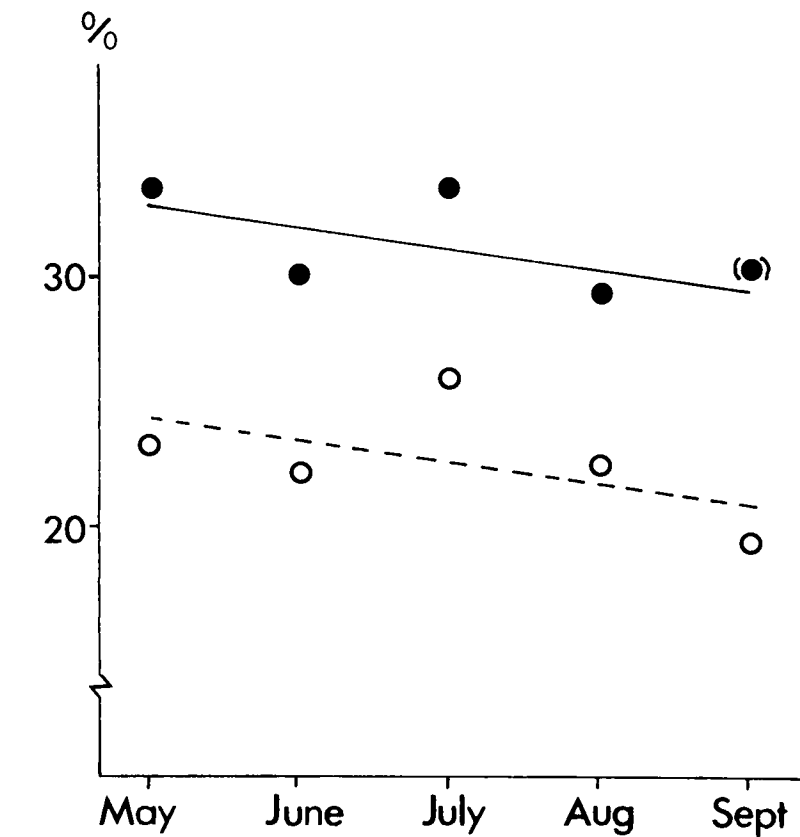


Fig. 7. Monthly change of pregnancy rate II based on Criterion II. Symbols as in Fig. 4.

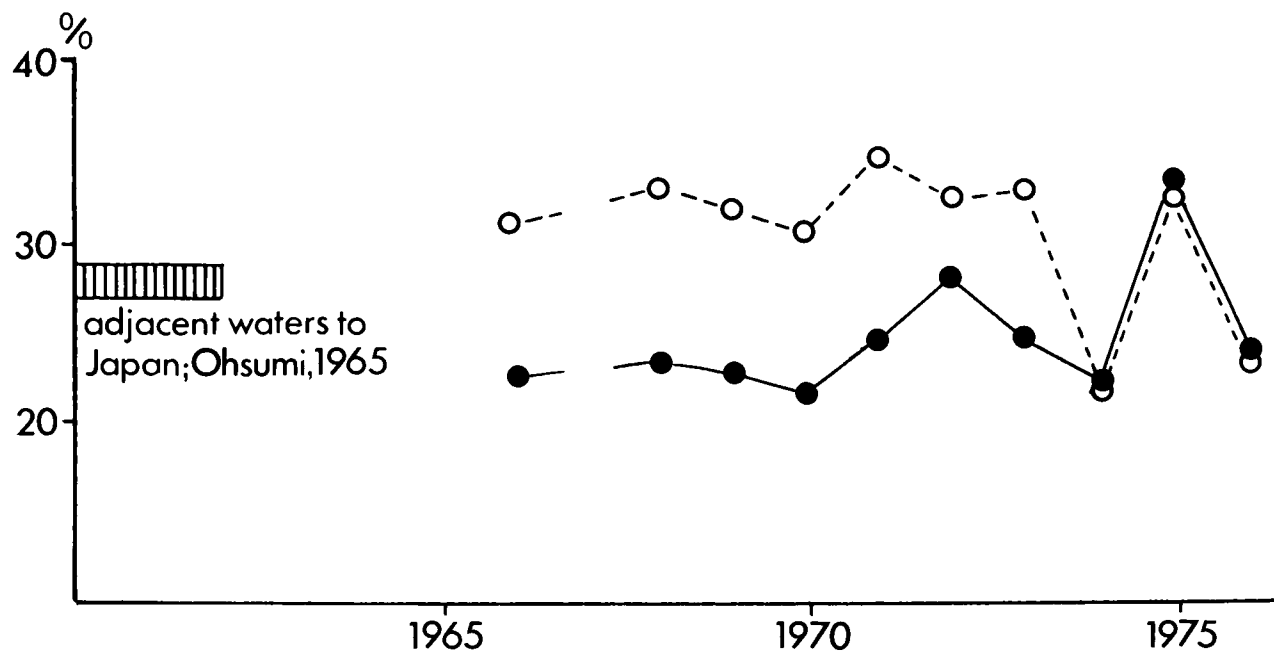


Fig. 8. Annual change of average pregnancy rate II based on Criterion II. Symbols as in Fig. 6.

Table 5
Annual pregnancy rate based on Criterion II for Western Stock of the North Pacific sperm whales

Year and Zone		May		June		July		August		September		Average pregnancy rate	
		A	B	A	B	A	B	A	B	A	B	Corrected	Uncorrected
1966	NP	(25.0)	(17.1)	—	—	32.3	23.3	29.0	21.4	—	—	22.3	30.6
1968	NP	32.1	22.0	30.7	21.6	35.3	25.5	(21.4)	(15.9)	—	—	23.0	32.7
1969	NP	31.7	21.7	34.0	23.9	30.0	21.6	30.4	22.5	—	—	22.4	31.5
1970	NP	34.8	23.8	(19.4)	(13.7)	31.7	22.8	24.4	18.1	(30.5)	(23.1)	21.6	30.3
1971	NP	35.8	24.6	25.0	17.6	37.9	27.3	38.6	28.6	—	—	24.5	34.3
1972	NP	—	—	(25.0)	(17.6)	38.7	27.9	—	—	—	—	27.7	32.1
	LM	—	—	(36.4)	(35.2)	—	—	25.5	27.4	—	—	—	—
1973	NP	—	—	(16.7)	(11.7)	—	—	—	—	—	—	24.4	32.7
	LM	26.1	24.4	(39.3)	(38.0)	—	—	(25.0)	(25.9)	(38.3)	(41.2)	—	—
1974	LM	22.4	21.0	21.6	21.1	—	—	22.9	23.7	20.5	22.1	21.9	21.9
1975	LM	—	—	20.2	19.7	35.5	35.5	—	—	40.7	43.8	33.0	32.1
1976	LM	—	—	25.0	24.4	23.1	23.1	22.1	22.9	—	—	23.5	23.4

Notes as Table 4.

REFERENCES

Bannister, J. L. and Gambell, R. 1965. The succession and abundance of fin, sei and other whales off Durban. *Norsk Hvalfangst-tid.* 54 (3): 45–60.

Best, P. B. 1969. The sperm whale (*Physeter catodon*) off the west coast of South Africa. 4. Distribution and movements. *Investl. Rep. Div. Sea Fish. S Afr.* 78: 1–12.

Clarke, R. 1956. Sperm whales of the Azores. *Discovery Rep.* 28: 237–98.

Masaki, Y. 1970. Differences between pregnancy rates of sperm whales in the North Pacific by area. Paper SP/10, presented at the Sperm Whale Biology and Stock Assessments Meeting, Honolulu, March 1970.

Matsuura, Y. 1936. Breeding habits of the sperm whale in the adjacent waters of Japan. *Zool. Mag. (Japan)* 48 (5): 260–6. (In Japanese.)

Ohsumi, S. 1965. Reproduction of the sperm whale in the North-West Pacific. *Sci. Rep. Whales Res Inst., Tokyo* 19: 1–35.

Ohsumi, S. 1966. Sexual segregation of the sperm whale in the North Pacific. *Sci. Rep. Whales Res. Inst., Tokyo* 20: 1–16.

Ohsumi, S. Kasuya, T. and Nishiwaki, M. 1963. Accumulation rate of dentinal layers in the maxillary tooth of the sperm whale. *Sci. Rep. Whales Res. Inst., Tokyo* 17: 15–35.

Ohsumi, S. and Masaki, Y. 1976. Stocks and trends of abundance of the sperm whale in the North Pacific. *Rep. int. Whal. Commn* 27: 167–75.

Rice, D. W. and Wolman, A. A. 1970. Sperm whales in the eastern North Pacific: Progress Report on Research, 1959–1969. Paper SP/3, presented at the Sperm Whale Biology and Stock Assessments Meeting, Honolulu, March 1970.

A consideration towards possible step procedures

Yoshio Fukuda

Far Seas Fisheries Research Laboratory, Shimizu 424, Japan

INTRODUCTION

The current management scheme, as specified in the Schedule, was first implemented in 1975, and has been so formulated in principle that any whale stock below the target level (MSYL) shall be allowed to recover and, as it approaches the target level, the permitted catch limit will be increased. In practice, however, the recommendations from the Scientific Committee, especially on certain stocks, have been considerably modified from year to year over the last few years, and have resulted in abrupt reductions of the catch limits and unwillingly, I believe, have driven the whaling industry into an unexpectedly difficult position. If this is left as it is I am afraid it will not only destroy any reasonably sized whaling industry, but serious doubts might be raised as to the scientific consistency of the yearly recommendations from the Scientific Committee.

IMPLICATION OF THE CURRENT MANAGEMENT SCHEME

The current scheme as written down in the Schedule, is simply a scheme to decide on the classification and catch limits for the coming season alone. It is, however, important to remember that its real significance lies in the theoretical background and the formulation of a strategy to ensure that a depleted whale stock can recover to the target level and that the whaling industries concerned can be managed successfully towards the certain recovery of the stock. Otherwise, it could not be supported by those concerned with the conservation of whales and by those seeking for more rational management of the whaling industry.

The theory of population dynamics underlying the current management scheme allows us to calculate in principle the maximum time it takes for a stock at a depleted level to recover the target level under the scheme. Suppose now that a stock under consideration will recover to the target level during the $(n + 1)$ th season starting from the next season, and of course the catch limits for these n seasons are at the same time implicitly scheduled under the current scheme, although naturally with the understanding that the catch limits in the future can probably be improved upon with additional information made available. It is understood that as an integral part of these prospective scheduled catch limits the classification and catch limits for the following season alone have been and will be adopted by the Commission. In other words, it is the exact adoption of the strategy implied by the current scheme, that the stock shall recover to the target level, at the latest during the $(n + 1)$ th season.

Now, it can be accepted without too much discussion that many alternative schedules for the catch limits over the n seasons exist, all of which are capable of bringing back the stock to the target level during the $(n + 1)$ th season. The so-called Graham scheme, provisionally adopted for

the southern sei whale stocks during the 1975/76 season, is one such alternative. More generally, any schedule is acceptable if it just protects a known number of whales required to bring the stock to the target level by the total net recruitment over the coming n seasons. This might be interpreted as a block scheme, if we regard as a block the total allowable catches over the coming n seasons as determined by the current scheme. Evidently flexibility of this kind can take into account other relevant factors for more reasonable management.

A RETROSPECTIVE VIEW

It seems sensible that the information available, inclusive of any additional information, shall be annually re-examined, that the state of a stock shall be generally re-assessed from a new viewpoint, and that, as a result, the relevant estimates might naturally be revised year after year. Reflecting upon the discussions in the last few years, however, I would like to point out a distinctive feature in them. Frankly, I feel that the discussions in the past have fallen short of a satisfactory examination and deliberate evaluation of the old and the new estimates. The use of computers has recently facilitated the introduction of a variety of sophistications of the models for estimation and in population dynamics. These in general appear to be theoretically promising, but it is another matter as to whether they are really significant or not. Nevertheless, in practice, the old estimates, I feel, are inclined to be readily rejected and replaced by the new ones because of the apparent theoretical likelihood alone. I do understand that any satisfactory deliberations on this point are difficult within the limited period of a meeting, but without such discussion the Scientific Committee can not avoid any abrupt modifications of the relevant estimates and of its recommendations to the Commission, and this could eventually lead to serious doubts on its scientific consistency.

A PRELIMINARY NOTE ON ALTERNATIVE SCHEDULING

Denoting the population level in the i -th season by P_i , the net recruitment (gross recruitment minus natural mortality) by Y_i , and the allowable catch by C_i ,

$$P_{i+1} = P_i + Y_i - C_i,$$

$$P_{i+2} = P_{i+1} + Y_{i+1} - C_{i+1}.$$

The simplest model usually defines $Y_i = Y_i(P_i)$.

Now, let us consider what happens when some amount Δ_{i+1} of the scheduled catch in the $(i + 1)$ th season be moved into the previous i -th season. It will generally reduce the population level P_{i+1} by Δ_{i+1} . However, addition of both equations indicates that this change in P_{i+1} is cancelled out. Another term that changes is $Y_{i+1}(P_{i+1})$. When P is

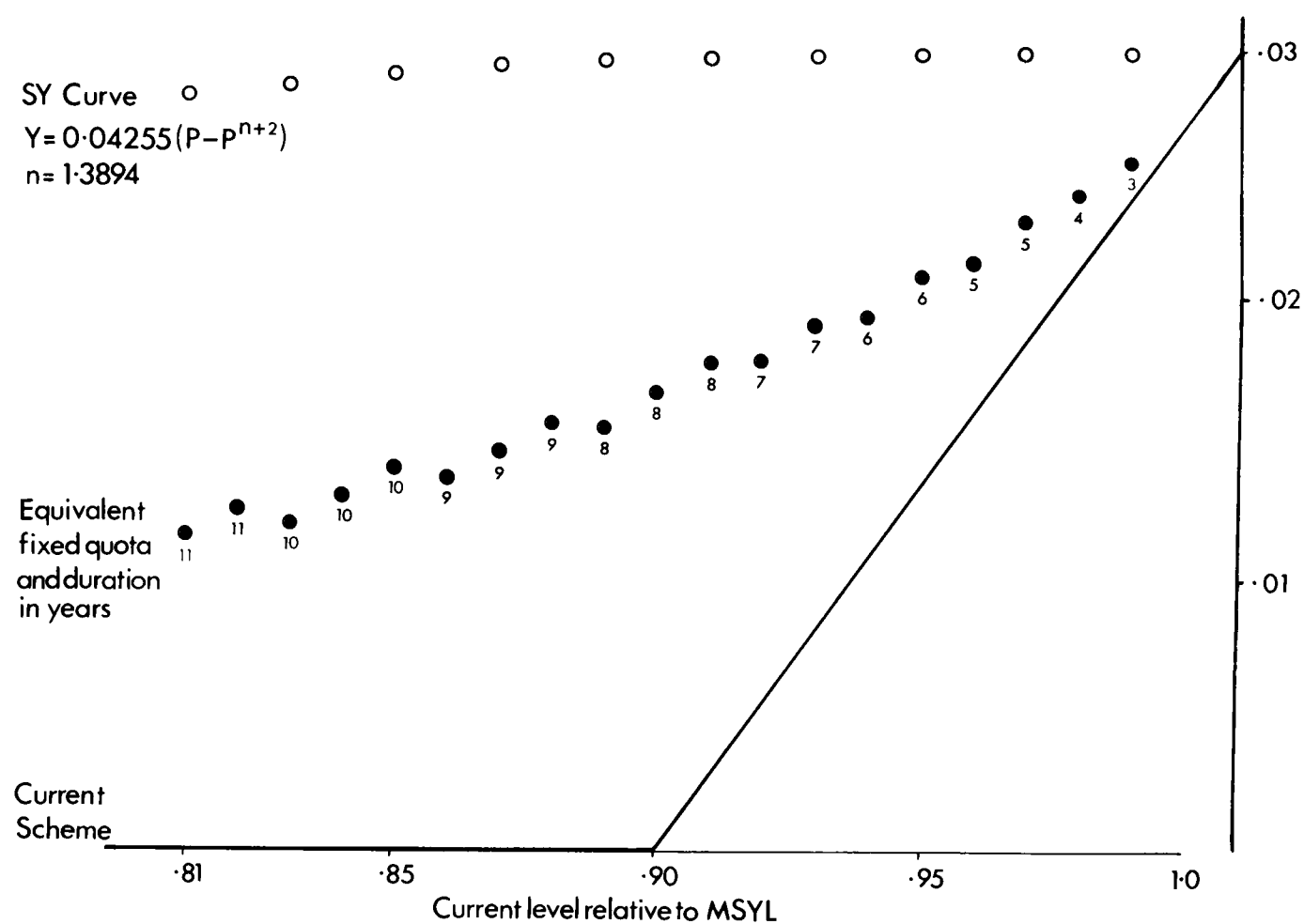


Fig. 1. Fixed catch limits (generalized Graham Scheme).

below the MSYL, then $Y_{i+1}(P_{i+1} - \Delta_{i+1})$ is less than $Y_{i+1}(P_{i+1})$. And P_{i+1} will also be reduced from the original one.

In order to cancel out this resultant effect on P_{i+2} within these two seasons, i.e. to keep P_{i+2} at the same level as the original one, a somewhat reduced amount Δ_i needs to be added to the scheduled catch C_i in the previous season. Then approximately

$$\Delta_i = \Delta_{i+1} / (1 + Y'_{i+1}),$$

where Y'_{i+1} is the first derivative of $Y(P)$ at P_{i+1} .

Suppose that a stock will recover to the target level at the latest during the $(n + 1)$ th season from this season and the series of catch limits over the n seasons are so scheduled under the current scheme, then successive application of the above rule will provide a variety of alternative schedules, either of which will meet the requirements implied under the current scheme that the stock will recover to the target level at the latest during the $(n + 1)$ th season starting from the next.

Speaking a bit more realistically, recruitment to the exploitable stock occurs at a certain age. If estimated from the parent stock, recruitment over the coming n seasons is pre-determined independently of the possible P_i in those seasons. If the net recruitment in the i -th season is independent of P_i , then the scheduling of the catch limits will be entirely arithmetic. In the case of male sperm whales the recruitment is determined by the female level at some time before, that is, independently of the male population level itself.

EXAMPLE: GENERALISED GRAHAM SCHEME

I would like to stress here that there exist a variety of alternative schedules which would meet the strategy implied by the current management scheme and that a satisfactory schedule can be fixed as soon as other relevant factors are specified for more reasonable management.

Just for illustration, however, let us consider a generalised Graham scheme, which appears to be one of the simplest and to have some advantages over the direct application of the current scheme.

- (1) Firstly, determine the latest time the stock under consideration would recover to the target level under the current scheme. Suppose that the stock will recover during the $(n + 1)$ th season starting from the next.
- (2) Then determine a fixed catch limit over those n seasons to meet the strategy as follows:

$$\text{Fixed catch limit} = C/N,$$

where

$$C = \sum_{i=1}^n C_i \frac{i}{\pi} f_j + C_i$$

$$N = \sum_{i=1}^n \frac{i}{\pi} f_j + 1$$

$$f_j = 1 / \{1 + Y'(P_j)\}$$

Fig. 1 indicates fixed catch limits over the n seasons (shown in brackets) when the stock follows a power model (MSYL at 0.6 of the initial) and its MSY is equal to 0.03 times MSYL.

Naturally, as it is, the figure shows that the fixed catch limit changes much more gradually against any fluctuation in either direction of the estimated current level than in the case where the current scheme is directly applied. Actually several interesting factors are involved in the abrupt modifications experienced in the past years. It seems difficult to sort these out immediately, but to spread them over several seasons would appear to absorb a good deal of unwillingly large effects brought about by direct application of the current scheme, without contradicting the current management policy of the Commission.

Size Distribution of Male Sperm Whales in the Pelagic Catches

K. Radway Allen

Division of Fisheries and Oceanography, CSIRO, Cronulla, Australia

This paper presents data on the size distributions of male sperm whales in the North Pacific in a graphical form which facilitates the identification, by inspection, of trends and differences between countries, between years, and between statistical areas. The data have been derived from the NP3 forms.

Fig. 1 shows the percentage size distributions by areas for Japanese pelagic catches over 1955–76 (solid lines),

and Soviet pelagic catches over 1965–76 (broken lines). The total numbers measured of each sex by nation, year and area are given in Table 1.

Fig. 2 shows the percentage size distributions in each latitudinal 10° Zone for each nation separately for 1972–76 combined.

Table 1

Numbers of males and females measured in catches by Japanese and USSR pelagic fleets in North Pacific Areas II–VI in certain years

Areas		II		III		IV		V		VI	
		Japan	USSR	Japan	USSR	Japan	USSR	Japan	USSR	Japan	USSR
Males	1954	—	—	—	—	486	—	—	—	—	—
	1955	—	—	—	—	848	—	232	—	—	—
	1956	—	—	—	—	784	—	809	—	—	—
	1957	—	—	—	—	1,031	—	668	—	—	—
	1958	—	—	—	—	424	—	1,075	—	—	—
	1959	—	—	—	—	1,109	—	689	—	—	—
	1960	—	—	—	—	1,295	—	503	—	—	—
	1961	—	—	24	—	1,212	—	529	—	—	—
	1962	—	—	134	—	1,794	—	612	—	—	—
	1963	116	—	137	—	1,289	—	1,143	—	—	—
	1964	12	—	95	—	1,641	—	693	—	—	—
	1965	27	1,856	117	1,482	1,568	2,423	722	1,352	—	565
	1966	7	1,213	82	1,780	1,555	2,435	1,197	2,213	—	1,326
	1967	0	1,614	561	1,707	1,455	2,261	640	1,006	—	2,349
	1968	65	2,767	727	1,518	826	1,192	797	1,665	—	1,889
	1969	411	2,151	476	864	483	2,303	645	1,011	—	1,096
	1970	216	1,330	494	672	984	3,042	659	490	—	704
	1971	224	0	342	0	470	2,387	481	1,714	—	951
	1972	307	167	434	313	247	366	337	131	—	334
Females	1973	416	713	579	33	154	306	283	362	—	629
	1974	117	594	553	98	404	317	268	317	—	697
	1975	70	394	311	32	644	121	197	352	—	869
	1976	0	36	43	221	127	476	313	273	—	815
	1954	—	—	—	—	0	—	—	—	—	—
	1955	—	—	—	—	0	—	0	—	—	—
	1956	—	—	—	—	0	—	0	—	—	—
	1957	—	—	—	—	0	—	0	—	—	—
	1958	—	—	—	—	0	—	0	—	—	—
	1959	—	—	—	—	1	—	0	—	—	—
	1960	—	—	—	—	1	—	0	—	—	—
	1961	—	—	0	—	1	—	0	—	—	—
	1962	—	—	6	—	3	—	0	—	—	—
	1963	0	—	0	—	0	—	7	—	—	—
	1964	2	—	4	—	11	—	0	—	—	—
	1965	13	197	8	128	5	61	0	112	—	25
	1966	5	99	40	68	24	127	102	133	—	42
	1967	0	84	161	77	33	81	141	38	—	167
	1968	58	126	144	65	8	36	375	103	—	165
	1969	460	309	124	69	25	203	375	60	—	132
	1970	54	421	83	125	62	285	148	202	—	296
	1971	117	0	29	0	0	209	140	179	—	72
	1972	71	2	89	0	21	2	31	100	—	321
	1973	184	440	86	66	14	364	76	366	—	1,048
	1974	61	484	30	13	213	359	157	359	—	1,110
	1975	25	286	34	104	365	149	157	425	—	1,008
	1976	0	70	0	69	466	99	104	214	—	972

Some of the points emerging from Fig. 1 are —

- (a) There is a general tendency for bi-modal distributions to occur with one peak at about 50–52 ft, and another which was at about 40–42 ft when the 38 ft size-limit was in force, and lower when the limit was reduced to 30 ft. This effect may be partly a direct reflection of the population length composition and thus be a consequence of an asymptotic growth curve. It may also be partly a result of the location of the whaling operations in relation to the differential distribution of whales of different sizes.
- (b) The size distribution in a nation's catch is often consistent for a considerable period, which is then followed by an abrupt change to a new pattern. Japanese catches for Area V of 1955–65, 1966–69, and 1970–72 provide a good example of this.
- (c) In most years and Areas Japanese and USSR catches are generally similar. In some years and Areas, however, they show marked differences. In particular, the USSR catches in Area III in 1969–70, Area IV in 1966–71, and Area V in 1971 consisted predominantly of relatively small animals in the 38–45 ft size range, while the Japanese catches were dominated by large animals, principally 47–52 ft.
- (d) These changes in the size distribution from year to year reflect differences in the population components which are being exploited. Changes in CPUE from year to year are therefore not directly comparable as a means of assessing changes in population size if they are associated with changes in size distribution.

- (e) Changes in size distribution also imply changes in age at recruitment.

The Zonal distributions shown in Fig. 2 are complicated by changes in Zones in which the fleets operated before and after the change in size limit at the beginning of 1973. However they suggest the existence of three main Zonal bands:

- (1) *Series L, 20°–29° N*: there are comparatively few large animals over 45 ft but these include relatively more very large bulls, over about 54 ft.
- (2) *Series M and N, 30°–49° N*: both the small animals (under 45 ft) and the large ones (over 50 ft) are well represented.
- (3) *Series P, 50° N and above*: there are few small animals under 40 ft, but the medium and large groups, between about 45 ft and 53 ft predominate. The very large animals, over 53 ft, are not however as numerous as in Series L.

These results suggest that in the most southerly series, mainly in the tropics, the population consists principally of breeding herds characterised by many juvenile and some very large harem bulls. In the intermediate latitudes, 30–49° N, there are still some juveniles, but the animals are mainly medium to large bachelor bulls, approaching harem master size. In the far North, above 50° N, there are few juveniles and medium to large bulls predominate, although the very largest may have tended to leave for the breeding areas.

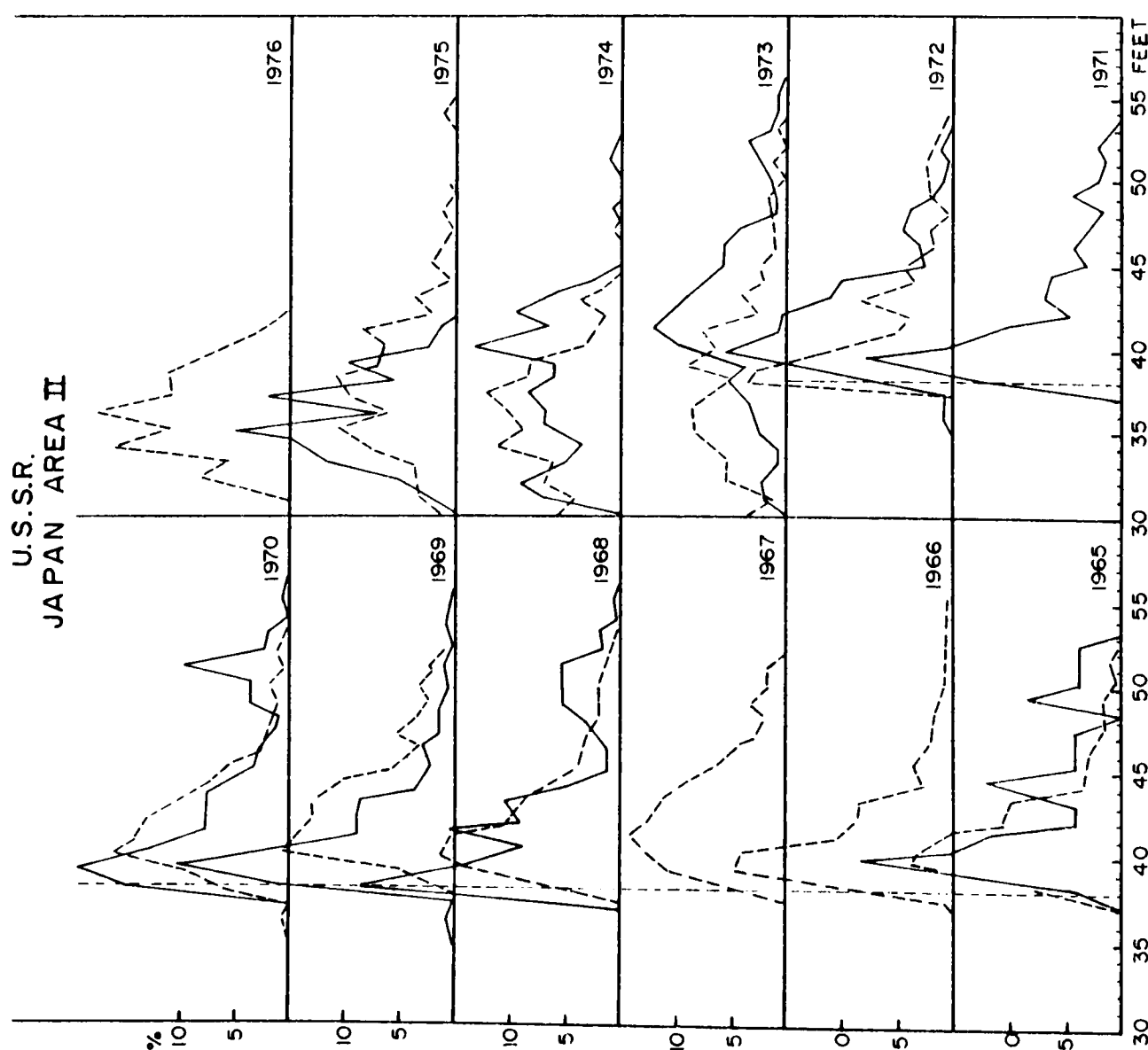


Fig. 1. Percentage size distributions of male sperm whales taken by Japanese and USSR pelagic fleets in Areas II–VI in certain years for all latitudes combined.

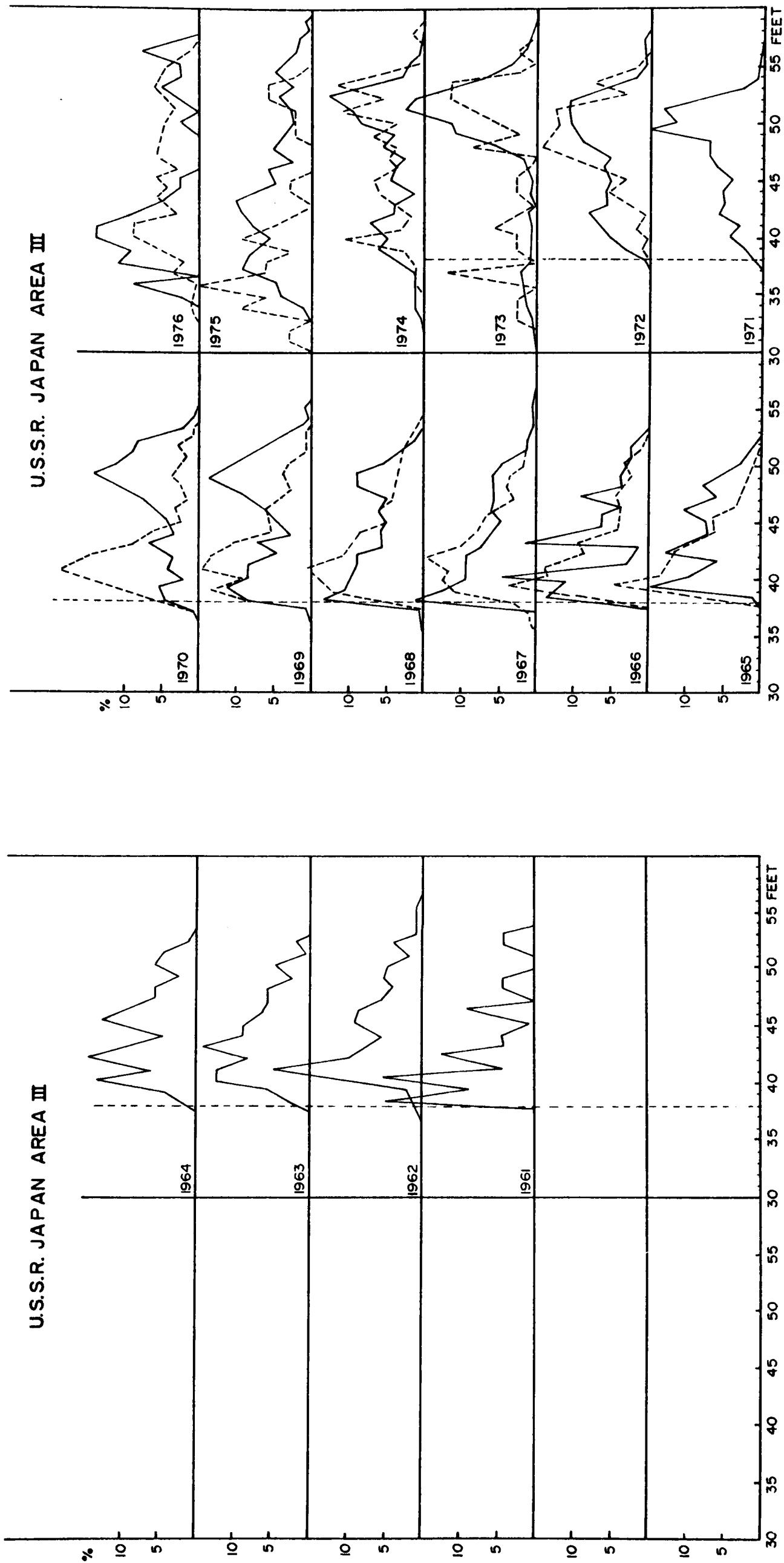


Fig. 1. (continued).

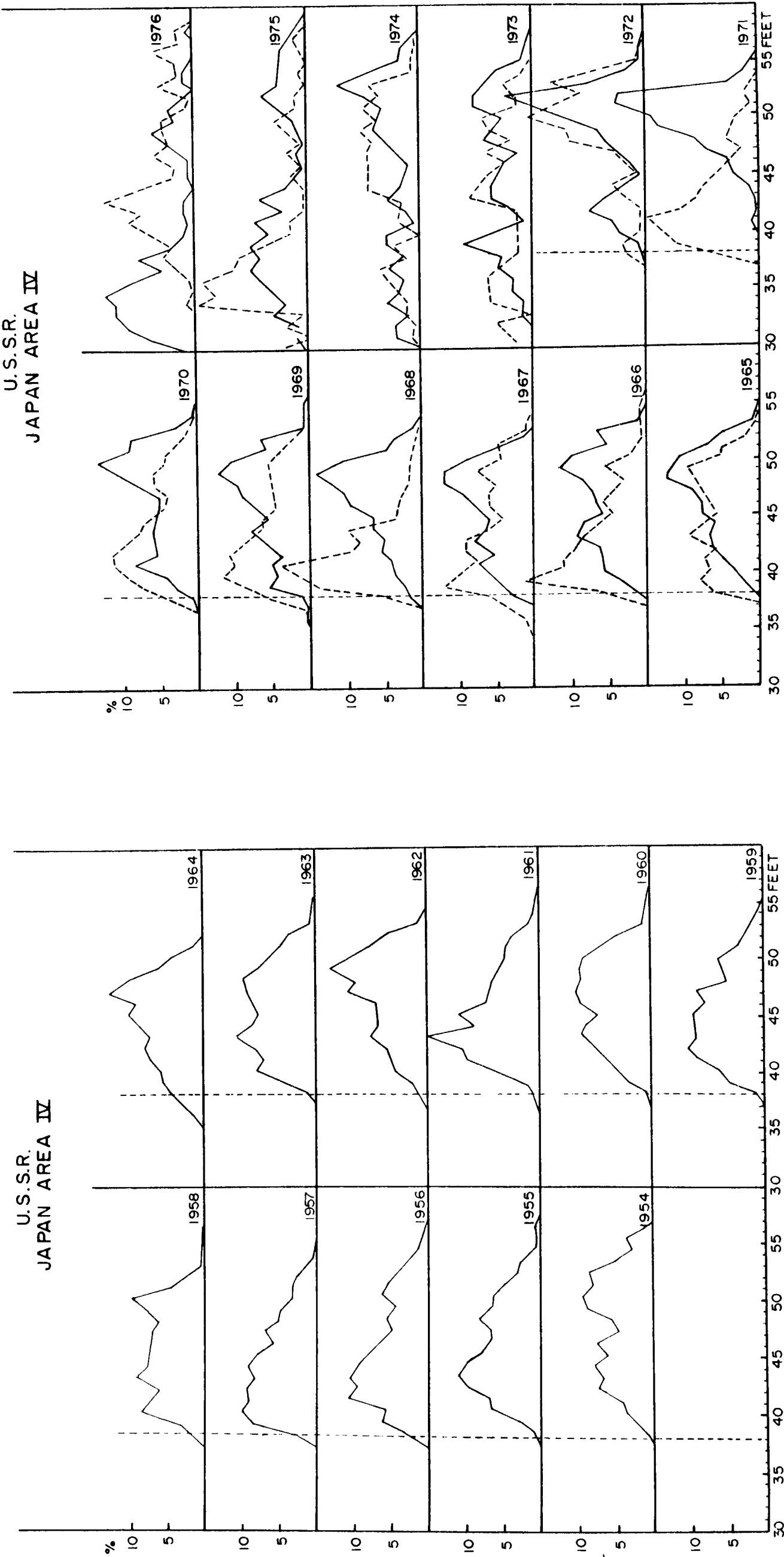


Fig. 1. (continued).

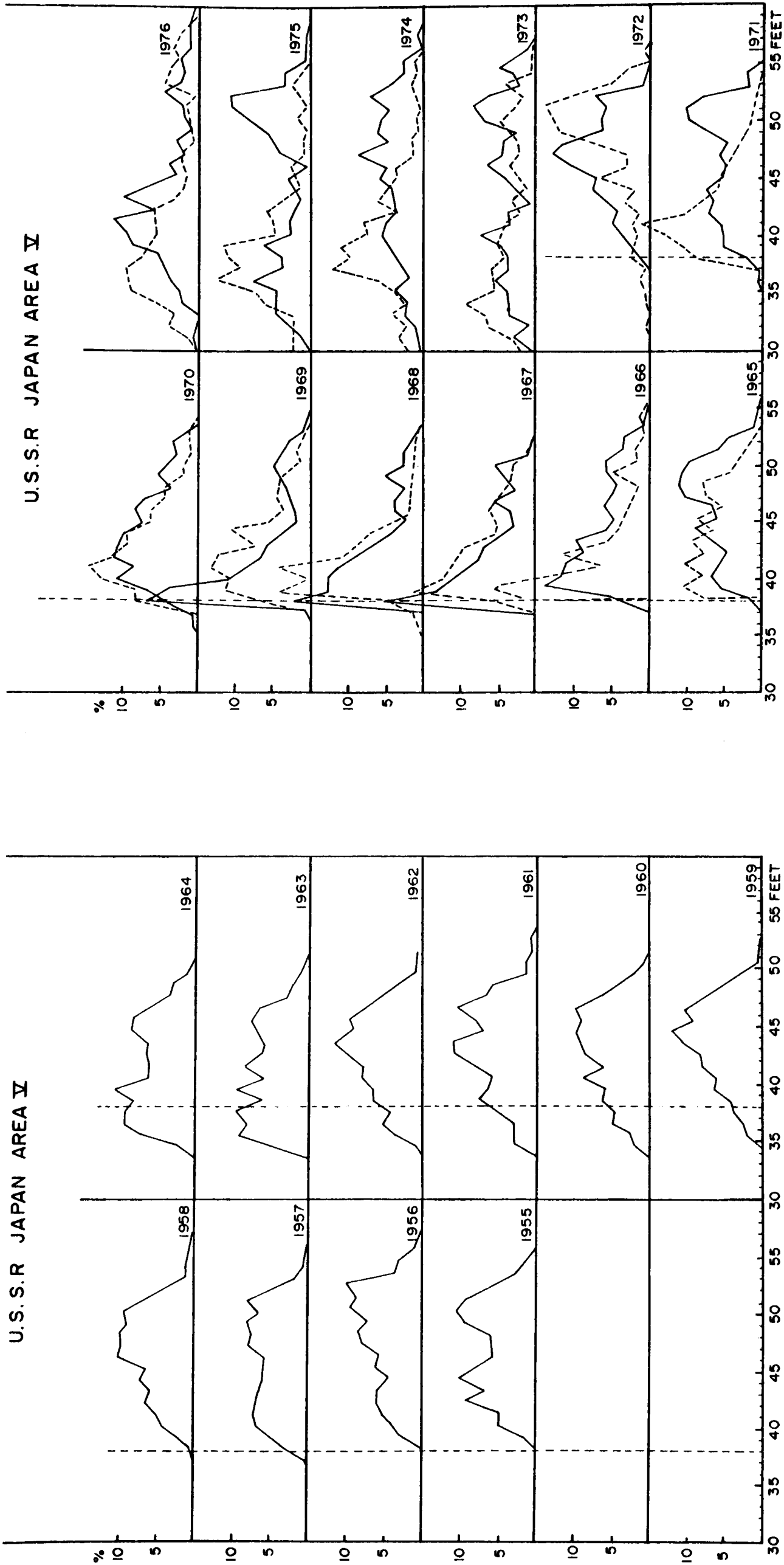


Fig. 1. (continued).

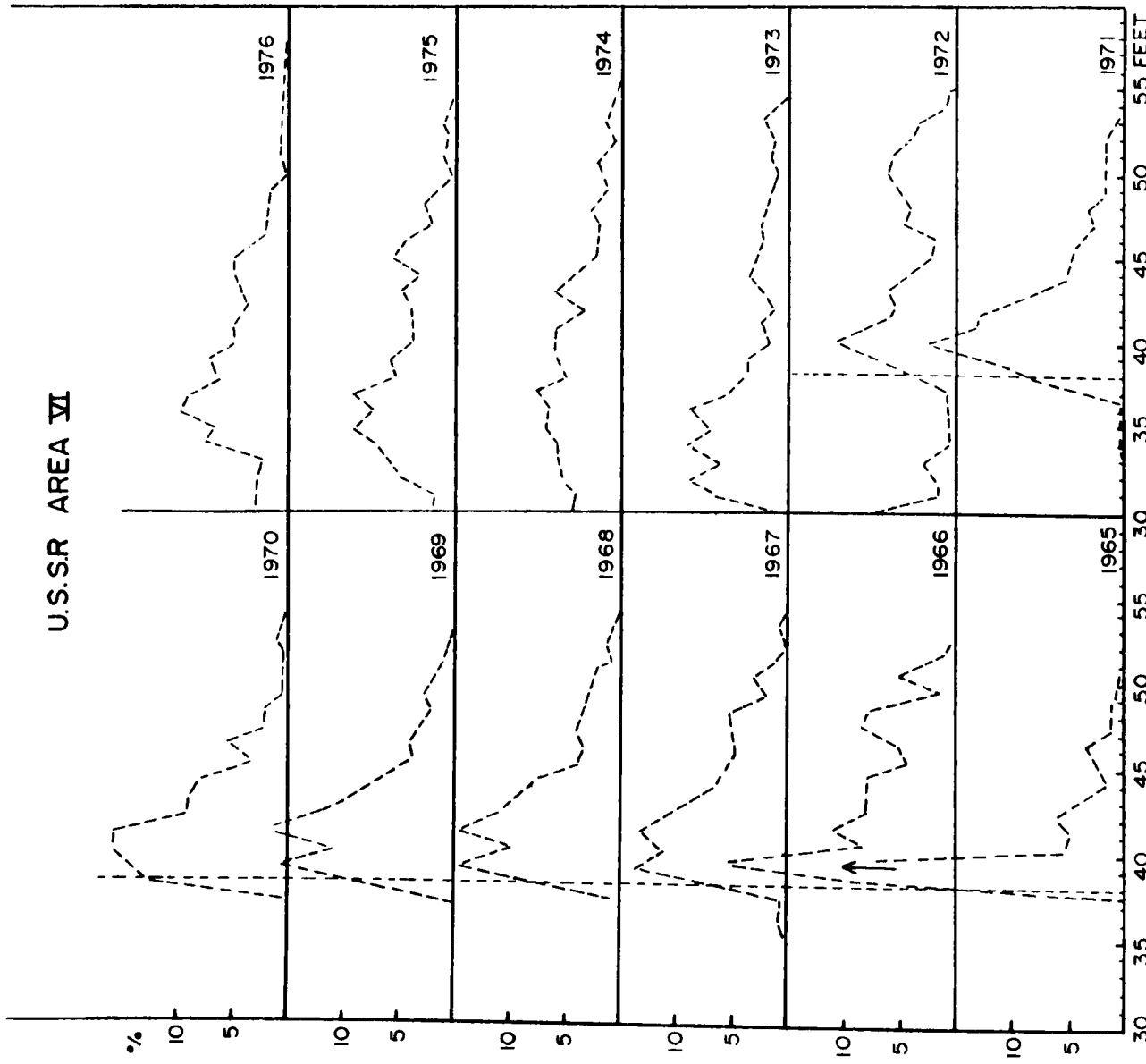


Fig. 1. (continued).

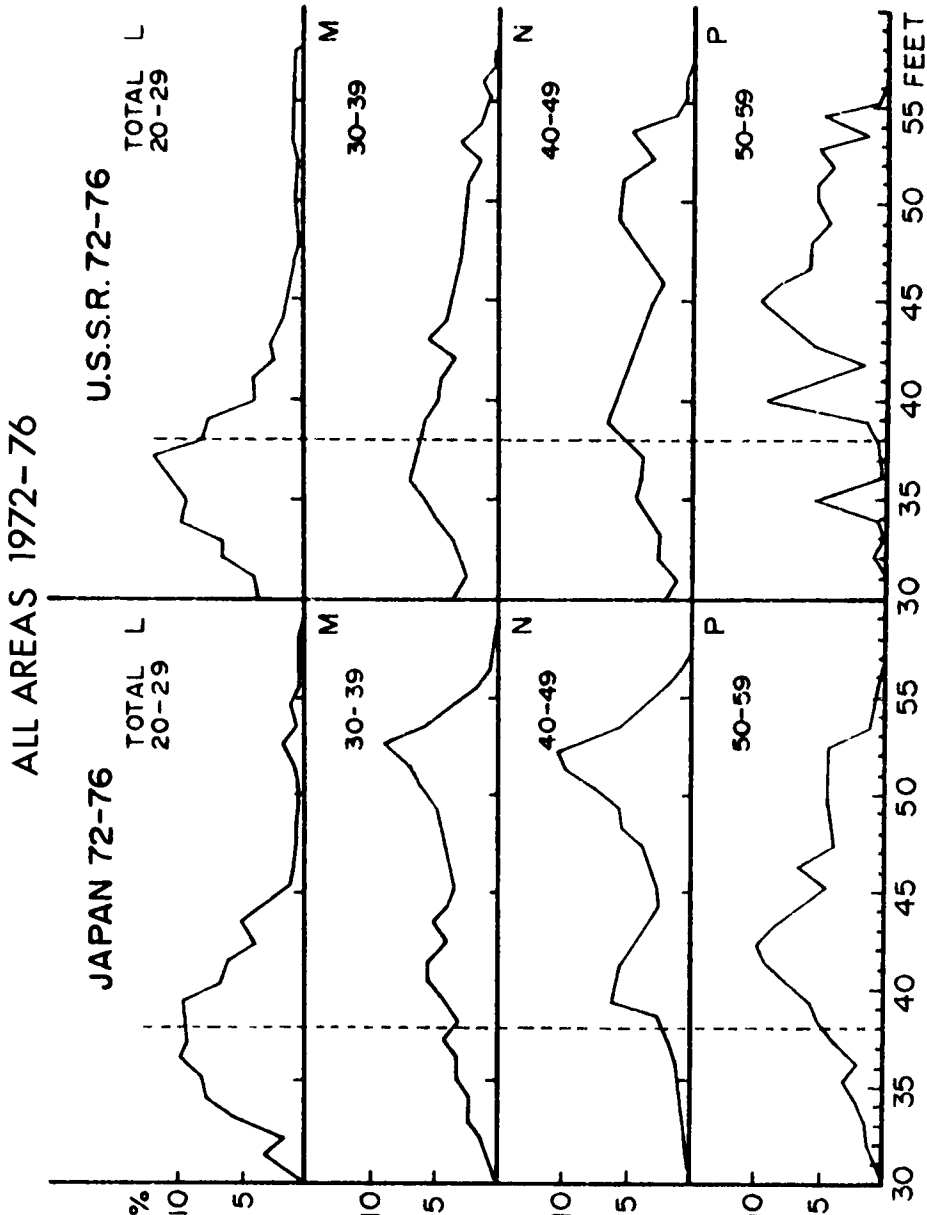


Fig. 2. Percentage size distributions of male sperm whales taken by Japanese and USSR pelagic fleets in Series L, M, N, and P in the years 1972-76 combined; all longitudinal areas combined.

On the Mathematical Structure of Possible Sperm Whale Models

J. R. Beddington and G. P. Kirkwood

ABSTRACT

This paper formulates as non linear difference equations the structure of possible sperm whale models. The particular influences on fecundity of population density and sex ratio are discussed and methods for formulating alternative sub models within the overall framework of the population model are discussed.

INTRODUCTION

Both the underlying biology and the manner of harvesting demand that any management model for sperm whales should distinguish between the sexes. In this paper, we consider a general mathematical model which reflects the essential dynamics of sperm whales, and show how the model may be manipulated to obtain estimates of the unexploited population levels, and the MSY levels and catches. In common with the assumption of the current sperm whale model, we assume that density dependence if any, occurs solely in fecundity. We describe several alternatives to the functional form of fecundity contained in the current sperm whale model and examine the properties of the alternative models. Finally, noting that at present no direct data exist allowing discrimination between the various functional forms, we examine the data needs for selection and validation of the appropriate model.

Our analysis here is complementary to that of the computer simulation models, which take more account of the biological complexities of sperm whales. Our aim is to highlight the essential principles involved which are followed in detail by the simulation models.

THE BASIC MATHEMATICAL MODEL

For a population in which it is assumed that there are always sufficient males to ensure maximal fecundity, it is possible to derive from a fully age structured model an equation giving the dynamics of the mature female population of the form

$$X_{t+1} = \lambda X_t + \lambda^k X_{t-k} F(X_{t-k}) \quad (1)$$

This derivation assumes that the annual survival rates are constant and equal for all ages (λ), that only mature female density affects their fecundity, and that the age at female sexual maturity is constant (k). A fuller description of the assumptions may be found in Beddington (1977). A similar model was studied by Clark (1976).

In the sperm whale, for important behavioural reasons, the sex ratio of mature animals is likely to affect the female fecundity, and the model form may be extended to two sexes as

$$X_{t+1} = \lambda_F X_t + \frac{1}{2} \lambda_F^k X_{t-k} F(X_{t-k}, Y_{t-k}) \quad (2)$$

$$Y_{t+1} = \lambda_M Y_t + \frac{1}{2} \lambda_M^j X_{t-j} F(X_{t-j}, Y_{t-j}) \quad (3)$$

Here X_t and Y_t denote the numbers of mature females and males, λ_F and λ_M their annual survival rates and k and j their ages at sexual maturity. $F(X_t, Y_t)$ is a function specifying the birth rate and the sex ratio at birth is assumed to be 50:50.

In the absence of exploitation, the possible equilibria for this model may be identified by writing $X_{t+1} = X_t = X_{t-k} = X^*$ and $Y_{t+1} = Y_t = Y_{t-j} = Y^*$. Substituting in equation (2) and (3),

$$X^* = \lambda_F X^* + \frac{1}{2} \lambda_F^k X^* F(X^*, Y^*) \quad (4)$$

$$Y^* = \lambda_M Y^* + \frac{1}{2} \lambda_M^j X^* F(X^*, Y^*) \quad (5)$$

From this, we may derive an expression relating the fecundity at equilibrium and the female survival rate

$$F(X^*, Y^*) = 2(1 - \lambda_F)/\lambda_F^k \quad (6)$$

and the sex ratio at equilibrium is given by

$$\frac{Y^*}{X^*} = \frac{\lambda_M^j (1 - \lambda_F)}{\lambda_F^k (1 - \lambda_M)} \quad (7)$$

The sex ratio in the unexploited stock will thus only be one if $j = k$ and $\lambda_M = \lambda_F$

Exploitation may be simply incorporated into equations (2) and (3) by writing

$$X_{t+1} = (X_t - C_F) \lambda_F + \frac{1}{2} \lambda_F^k X_{t-k} F(X_{t-k}, Y_{t-k}) \quad (8)$$

$$Y_{t+1} = (Y_t - C_M) \lambda_M + \frac{1}{2} \lambda_M^j X_{t-j} F(X_{t-j}, Y_{t-j}) \quad (9)$$

Where C_F and C_M are the catches of mature females and males. In practice the ages at recruitment are not equal to the ages at maturity. However incorporation of differing ages at recruitment and maturity merely adds some algebraic complexity and does not affect the essential features of this analysis, and thus this factor is ignored.

CALCULATION OF MSY

At equilibrium under exploitation

$$\lambda_F C_F = X^* (\lambda_F - 1) + \frac{1}{2} \lambda_F^k X^* F(X^*, Y^*) \quad (10)$$

$$\lambda_M C_M = Y^* (\lambda_M - 1) + \frac{1}{2} \lambda_M^j X^* F(X^*, Y^*) \quad (11)$$

and the total yield C is given by

$$C = C_F + C_M$$

The maximum sustainable yield, C_{MAX} , may be obtained by finding where the partial derivatives $\frac{\partial C}{\partial X^*}$ and $\frac{\partial C}{\partial Y^*}$ vanish at non zero values for X^* and Y^* .

Functional forms of the fecundity function

In the current sperm whale model, for constant X_t , $F(X_t, Y_t)$ is assumed to remain constant as Y_t diminishes until a critical value of Y_t is reached, below which the fecundity reduces linearly to zero with Y_t . For a constant sex ratio, the fecundity is assumed to increase with decreasing X_t according to a modified logistic form. For the purposes of calculating MSY, a modified form of $F(X_t, Y_t)$ is assumed in which fecundity drops to zero for levels of Y_t below the critical level.

A more plausible model for the effect of sex ratio would be a smooth relationship between fecundity and sex ratio, with a steady increase in fecundity, becoming maximal at a sex ratio where sufficient mature males are available. Provided this functional form also allowed an increase in fecundity with reducing female density, the MSY would be obtained in the way already described, and the model would behave similarly to the current model, although the actual level of MSY would be different.

There are two alternative forms for such a model (i) fecundity remains constant for all female densities, and (ii) fecundity decreases with decreasing female density. In the absence of any other density dependent factors, these forms are unsatisfactory in that they imply that the equilibrium population level in the unexploited state is unstable. A final model type that has not been previously considered is one in which fecundity is affected by the actual process of exploitation, in addition to the presence or absence of indirect density effects. Such a model would involve a functional form for the fecundity $F(X_t, Y_t, C_F,$

$C_M)$. There are no insurmountable difficulties in handling these models and an MSY would be defined in the usual way; however in the case of (i) and (ii) no female crop could be taken.

Data needs

At present there are no direct data available to allow the validation of any of the above functional forms. In order to do so a series of data specifying pregnancy rates for different levels of male and female population levels is required. Given such a series, it should be possible to select the most appropriate functional form and to obtain estimates of its parameters. We note however that the data requirements for distinguishing between the alternative models are stringent. A data set on pregnancy rates comparable to that for some of the southern ocean baleen whales seems a minimum requirement for model validation, and in particular, pregnancy data are needed for a wide range of male and female population levels.

In concluding we remark that similar analyses to those in this paper can elucidate the structure and properties of other possible models that incorporate varying mortality rates or ages at maturity.

REFERENCES

- Beddington, J. R. 1978. On the dynamics of sei whales under exploitation. *Rep. int. Whal. Commn* 28: 169–72.
 Clark, C. W. 1976. A delayed-recruitment model of population dynamics with an application to baleen whale populations. *J. Math. Biol.* 3: 381–91.

Estimates of Pregnancy Rates – North Pacific

D. G. Chapman
College of Fisheries, University of Washington

INTRODUCTION

In SC/SP/Doc 4 Masaki (1980, Table 1) gives observed pregnancy rates by Zone and month for 1966 to 1976 (except 1967). However, during the months May to September whales may give birth so that the proportion carrying near term (large) fetuses will decrease. On the other hand, this is the period of conception so that whales carrying early (small) fetuses will increase. Hence in any month the proportion of each of the two groups will be less than the true pregnancy rate. In addition the rates will be biased because lactating whales are protected. We consider these two problems separately.

1. ESTIMATION OF PREGNANCY RATE – WESTERN AREA

The proportion of mature females with large fetuses will form a decreasing sigmoid curve from May to September while the proportion with small fetuses will be graduated by an increasing sigmoid. The asymptotic levels of these two sigmoid curves will yield two estimates of the apparent pregnancy rate. They are of course estimates of pregnancy rates in different years but since the data available are a 10 year average, this aspect is not considered.

The basic data from Masaki (1979) for the Western area are shown in Table 1.

Table 1.

Proportion of early and late term pregnant females by month and Zone.

Zone	Month				
	May	June	July	August	September
L	—	.17	.20	.26	.22
	—	.18	.13	.08	.02
M	.07	.07	.19	—	.32
	.20	.20	.15	—	.08
N	.07	.23	.33	.44	—
	.38	.23	.21	.12	—
P	0	.09	.25	.30	—
	.17	.37	.25	.23	—

(Proportions in P are based on small samples).

The simplest estimate of the apparent pregnancy rate is to use the largest value in each series. This yields

Pregnancy Estimates by Method and Zone

Estimate	Zone			
	L	M	N	P
Early Term	0.26	0.32	0.44	0.30
Late Term	0.18	0.20	0.38	0.37
Average	0.24	0.26	0.41	0.33

The early term estimates are based generally on August or September observations when a relatively large fraction of the females have very young calves and will be protected.

The late term estimates are based on May (or June) observation when most of the calves accompanying females are much older. From observations elsewhere it is much more difficult to identify the correct cow-calf pair and hence the degree of protection of lactating females is less. Hence the late term estimate is closest to the true pregnancy rate.

This procedure needs to be improved in several ways –

- (1) A model should be fitted to the apparent pregnancy rates over the summer months and the asymptote estimated by a statistical procedure.
- (2) Better information is needed on the proportion of mature females excluded from the kill (and hence the sample) by the ban on taking lactating females. Using the largest observed apparent pregnancy rate rather than obtaining an estimate of the asymptote from the model underestimates the apparent pregnancy rate. But the protection of lactating females causes the apparent rate to be higher than the true rate. Thus these biases act in opposite directions and from preliminary exploration seem to be of about the same general size. It is reasonable to take late term estimates as the best available estimate of the pregnancy rate by Zone over 1966/76.

Since the rates differ substantially between Zones, it is important to find the correct weighting to determine an average value for the population. One approach is to use CPUE as a measure of comparative population sizes (this assumes Zone area differences are negligible). The comparison that is most likely to be free of biases is within seasons and within countries. Comparisons are available between Zones L and M for 1973/76 and between Zones M and N for 1966/75. The relative proportions determined are shown in Table 2.

Table 2.

Relative proportions of female sperm whales by Zone and method of comparison.

	Japanese CPUE	USSR CPUE	Average
L	.52	.71	.61
M	.31	.19	.25
N	.18	.10	.14

The weighted average of the late term estimates using these weights is 0.21 (the weighted average with weights from the Soviet CPUE comparison is 0.22, from the Japanese CPUE comparison is 0.20).

The improvements suggested above as well as a reconsideration of the weighting need to be considered prior to the next regular meeting of the Committee.

2. ESTIMATION OF PREGNANCY RATE –
EASTERN AREA

Data are also given, Masaki (1980) from which pregnancy rates for the Eastern area can be calculated though the available information is much less than in the Western area, both by Zones and months. The estimates are shown in Table 3.

The maximum rates are Zone N, 0.18, and Zone P, 0.36. In both cases these are probably underestimates since they are determined from late term pregnancy females in months after some births have occurred. Also there seems to be inadequate data on Zone P catches so that it is difficult to determine a weighted average. At this time it may be most appropriate to use the Western value (0.21) for the whole North Pacific.

Table 3.
Proportion of early and late term pregnant females by month and Zone.

Zone	Month			
	June	July	August	September
N	—	0.17	0.16	0.09
	—	0.18	0.17	0.09
P	0.20	0.15	0.15	—
	0.36	0.18	0.17	—

Several of these are based on small samples.

REFERENCE

Masaki, Y. 1980. On the pregnancy rate of the North Pacific sperm whales. Paper SC/SPC/4 (published in this volume).

Natural Mortality Rate – Males

D. G. Chapman

College of Fisheries, University of Washington

Heincke – estimates of total mortality rate (Z) for early and late years are as follows:

Heincke – Estimates of Z 1946–50, 1972–76.

Year	Estimate	Age span	Year	Estimate	Age span
1946	0.073	(20–34)	1972	0.054	(20–34)
1947	0.064	(20–34)	1973	0.056	(20–34)
1948	0.068	(20–34)	1974	0.056	(25–34)
1949	0.073	(20–34)	1975	0.065	(28–37)
1950	0.070	(25–34)	1976	0.064	(28–37)
Average	0.0696			0.0596	

By age span is meant the range of initial ages of the Heincke estimate which were averaged to give the tabulated values.

For each age there is an estimate of Z. For the lowest ages these estimates are too low because of incomplete recruitment. Around 20 years the series of estimates level off at presumably the true total mortality. Above age 35 (approximately) the estimated total mortality rates increase, either because of the age length key used or because mortality increases with age. If the latter explanation is correct the estimates derived from the ages 20+, 21+ . . . 34+ are an average over all ages. In considering the time series of Heincke total mortality estimates, these increase after 1950, are rather lower in the early 1960s, increase again in the late 1960s but they fall off once more in the 1970s. The estimates for the last 5 years are given in the Table.

Analysis of the Pregnancy Rates of Sperm Whales in the North Pacific

J. R. Beddington

Department of Biology, University of York, Heslington, York YO1 5DD, U.K.

Masaki (1980) presented data on the pregnancy rates of North Pacific sperm whales which involve a pooling of the information for the years 1966/76. Such data do not permit analysis of any yearly trends of pregnancy rates with changes in various stock characteristics such as the sex ratio of mature animals and the female density.

In this document data kindly supplied by Masaki are presented for where they exist for each of the years 1966/76, for each of the months May-September and for each of the Zones P, N, M, L. The data presented in Table 1

consist of the number of sexually mature animals in the sample (a), the total number pregnant (b) divided into the number who have conceived that year (c) and the number who have conceived the previous year (d). Chapman (1980) indicates that the best estimate for the pregnancy rate in a year may be obtained by using the highest value for the series (c) presumed to be increasing each month from a low value in May to a high value in September or by using the highest value for (d) in the succeeding year presuming a decay from the highest value in May to the lowest value in

Table 1.
Figures in brackets give the appropriate proportion pregnant.

	May	June	July	August	September
Area L					
1966-1972	—	—	No Data	—	—
1973 (a)				18	7
(b)				8	3
(c)				6 (.33)	3 (.43)
(d)				2 (.11)	0 (0)
1974 (a)				35	92
(b)				11	17
(c)				11 (.31)	17 (.18)
(d)				0 (0)	0 (0)
1975 (a)		143	69		76
(b)		50	38		22
(c)		25 (.17)	17 (.25)		18 (.24)
(d)		25 (.17)	21 (.30)		4 (.05)
1976 (a)		70	209	196	
(b)		25	72	66	
(c)		11 (.16)	47 (.22)	48 (.24)	
(d)		14 (.20)	25 (.12)	18 (.09)	
Area M					
1966-1971	—	—	No Data	—	—
1972 (a)		11			21
(b)		5			7
(c)		2 (.18)			3 (.14)
(d)		3 (.27)			4 (.19)
1973 (a)	23	14			7
(b)	6	4			4
(c)	3 (.13)	1 (.07)			3 (.43)
(d)	3 (.13)	3 (.21)			1 (.14)
1974 (a)	78	102			19
(b)	21	27			6
(c)	4 (.05)	8 (.08)			6 (.32)
(d)	17 (.22)	19 (.19)			0 (0)
1975 (a)		167			26
(b)		38			12
(c)		8 (.05)			11 (.42)
(d)		30 (.18)			1 (.04)
1976 (a)			27	1	
(b)			10	0	
(c)			6	0 (0)	
(d)			4 (.15)	0 (0)	

Table 1 (continued).

		May	June	July	August	September
Area N						
1966-1967		-	-	No Data	-	-
1968	(a)	45	208	51	7	
	(b)	25	94	34	2	
	(c)	9 (.2)	47 (.23)	20 (.39)	2 (.29)	
	(d)	16 (.36)	47 (.23)	14 (.27)	0 (0)	
1969	(a)	60	94	60		
	(b)	30	57	26		
	(c)	6 (.1)	29 (.31)	18 (.3)		
	(d)	24 (.4)	28 (.30)	8 (.13)		
1970	(a)	46	18			11
	(b)	17	1			3
	(c)	0 (0)	0 (0)			1 (.09)
	(d)	17 (.37)	1 (.06)			2 (.18)
1971	(a)	60	20		18	
	(b)	23	7		12	
	(c)	0 (0)	3 (.15)		9 (.5)	
	(d)	23 (.38)	4 (.20)		3 (.17)	
1972	(a)		2	18		
	(b)		1	9		
	(c)		1 (.5)	4 (.22)		
	(d)		0 (0)	5 (.28)		
1973	(a)		18			
	(b)		4			
	(c)		0 (0)			
	(d)		4 (.22)			
Area P						
1966	(a)	2		62	38	
	(b)	1		30	18	
	(c)	0 (0)		16 (.26)	9 (.24)	
	(d)	1 (.5)		14 (.23)	9 (.24)	
1967		-	-	No Data	-	-
1968	(a)	11	46			
	(b)	1	20			
	(c)	0 (0)	4 (.09)			
	(d)	1 (.09)	16 (.35)			
1969	(a)				130	
	(b)				68	
	(c)				46 (.35)	
	(d)				22 (.17)	
1970	(a)			30	45	
	(b)			15	18	
	(c)			8 (.27)	10 (.22)	
	(d)			7 (.23)	8 (.18)	
1971	(a)			33	4	
	(b)			18	2	
	(c)			6 (.18)	1 (.25)	
	(d)			12 (.26)	1 (.25)	
1972	(a)			13		
	(b)			7		
	(c)			5 (.38)		
	(d)			2 (.15)		

Table 2*

Zones					
	P	N	M	L	Average
1965	.24				.24
1966	.26				.26
1967	.35	.36			.355
1968	.17	.40			.285
1969	.35	.37			.36
1970	.36	.38			.37
1971	.25	.28	.27		.27
1972	.15	.22	.21	.11	.19
1973			.43	.43	.43
1974			.32	.31	.31
1975			.42	.25	.335
1976			.22	.24	.23

* See Text for explanation.

September. Table 2 summarises these maximal values for each area for the period 1966/67. These summarised data were tested for a linear trend with time within areas but no statistically significant trend was observed.

A similar analysis was performed on the data averaged over areas for each year with the same result. However, it was noted that for area L, for which large sample sizes were available, there was an apparent decrease in pregnancy rates over time. Clearly data for 1977 are required for this area to see if this is a real phenomena.

REFERENCES

Chapman, D. G. 1980. Estimates of pregnancy rate – North Pacific. Paper SC/SPC/17 Rev. 1 (published in this volume).
Masaki, Y. 1980. On the pregnancy rates of the North Pacific sperm whale. Paper SC/SPC/4 (published in this volume).

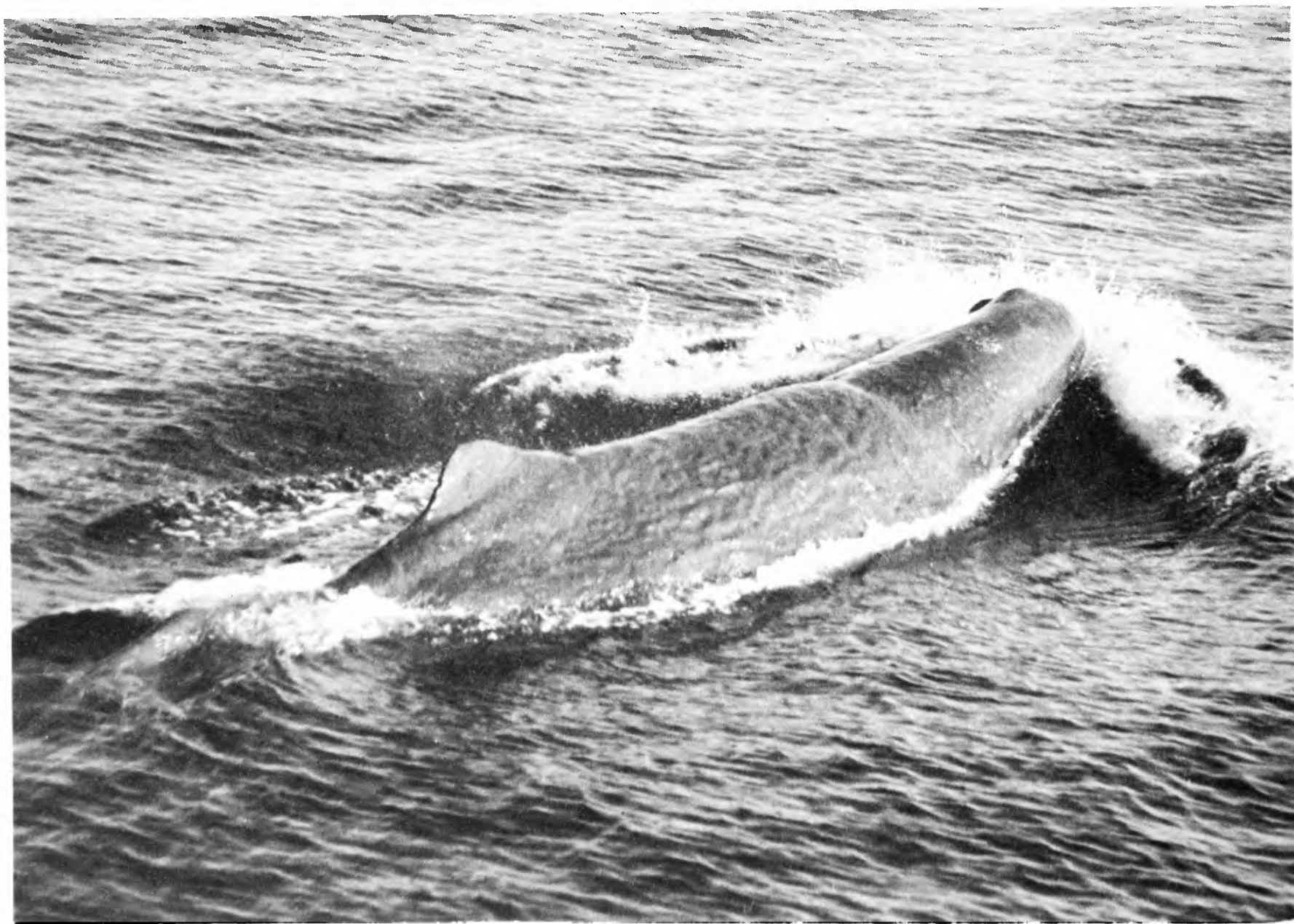


Bull sperm whale photographed from a helicopter south of Terceira, Azores Islands on 23rd July, 1955.

Photograph by courtesy of Robert Clarke.



Harem school of sperm whales on 29 November 1964, 29°03'S, 71°48'W.



Solitary male sperm whale on 28th November 1964, 29°16'S, 70°47'W.

Photographs by courtesy of Robert Clarke.

Report of the Sub-Committee on Sperm Whales

Cambridge, June 1978¹

1. APPOINTMENT OF RAPORTEURS

Duties were shared by Best, Cawthorn and Anderson.

2. ADOPTION OF AGENDA

The sub-committee adopted the agenda used at the special meeting in Cronulla, 1977 (p.9).

3. REVIEW OF DOCUMENTS AND STATISTICAL MATERIAL

SC/30/Docs 4, 10, 11, 14, 15, 17, 22, 33, 52, 58, 63, 64, 65, 66 on sperm whales were available to the sub-committee. Catch data for 1977/78 seasons were available from BIWS, provided by Vangstein. Peruvian data for catches by sex and length were provided in SC/30/Doc 68. Kirkwood had ensured that available catch data from 1946/47 to the present were accessible on the Cambridge University Computing Laboratory facilities.

4. EFFORT MODIFIERS

4.1 It was pointed out that at the Cronulla meeting the effort modifiers developed had been applied to catcher days rather than searching hours. Beddington (SC/30/Doc 3)² proposed a new model for sperm whale fishing effort based on a breakdown of a Catcher Day's Work into time wasted, time handling and time searching. It was agreed that these factors would vary over time, i.e.

1. In the early years of the North Pacific pelagic fishery in the 1950's, operations were carried out in high latitudes but in later years they had shifted to lower latitudes, so that the effective day-length had changed over time.
2. Industrial conditions had changed with more resting time allowed for catcher crews now than in the past.
3. With the shift in the latitude of operations, the object of the chase had changed from large males to herds of females and small males; chasing and handling times for these smaller animals would differ.
4. This change in the object of the chase would also have produced changes in the searching time, because the chasing time expended per whale would not be the same both for groups of animals and large solitary bulls. These changes would all affect the length of components of the working day and hence available searching time per day.

It was agreed that a small sub-committee would draw up a time budget for a Catcher Day's Work for the North Pacific sperm whale fishery with estimates of likely change over time.

The initial group reached broad agreement on the qualitative nature of changes in the Catcher Day's Work time budget and after further discussion in the sub-committee an expanded group (consisting of Beddington, Allen, Kirkwood, Ohsumi, Bannister, Doubleday and Best) were asked to quantify the components where possible

with the following results, where $CDW = T_r + T_s + T_c + T_h + T_t + T_w$

4.2 Time resting (T_r) = 24 hour day length correction

In the North Pacific areas of operation have changed with current areas further south than previously. There is thus a correction to be applied for changes in day length. In addition there have been changes in working conditions, with crews requiring increased resting times. However, these two changes are correlated and as a single correction factor, an integer value for the mean of three mid-season months was used, with mid-season taken as 5 July. Day lengths used are the period between civil sunrise and civil sunset for the various latitudes (Table 1).

Table 1
Day length, civil sunrise to civil sunset, Northern Hemisphere
(6° below horizon)

Series	Mean latitude	Day length at 5 July (hrs)	Mean day length at 5 June, 5 July, 5 August	Integer value used (hrs)
Q	62°N	24.0	24.0	24
P	55°N	18.0	17.3	18
N	45°N	16.1	15.8	16
M	35°N	14.9	14.5	15
L	25°N	14.1	13.9	14

4.3 Time handling (T_h) = handling time per whale

Time handling is defined as the period between a whale being struck and the catcher resuming a search. The major effect with changing operations in recent years is probably tonnage-dependent, with an effect only evident when vessels over 600 t entered the fishery. There is little information on handling times for smaller vessels. After 1957, however, most vessels catching sperm whales were over 600 t and despite the advantages of such larger vessels in their increased seaworthiness in bad weather, that effect may have been offset by increased handling times resulting in part from the increased height of the deck above sea level.

Handling time for the smaller males and females in current catches may be less than in the catches of earlier operations. However, the effects are likely to counteract each other with any net change small and difficult to quantify. The sub-committee agreed to accept the values for handling time given by Ohsumi in SC/SPC/Doc 2: pelagic 20 minutes; coastal 32 minutes.

4.4 Time wasted (T_w)

CPUE estimations have tended to deal with male catches only. Where female sperm whales are taken as part of a catch, the T_w component will have to be modified to compensate for time spent in catching and handling females. At the Cronulla meeting, a correction factor was applied to CDW for the proportion of female sperm whales in the catch, where:

$$CDW \text{ (adjusted)} = \text{Total CDW} - (\text{female catch} \times 1.20)/11.83$$

¹ also published in *Rep. int. Whal. Commn* 29:65-74.

² *Rep. int. Whal. Commn* 29:149-54.

With the change to the current procedure for CPUE estimation based on the catch/unit searching time, a modified form of the correction factor was applied (see Appendix C).

4.5 Time towing (T_t)

Towing time, which includes picking up time, can be expected to increase with decreasing stock numbers, an increase which may be balanced by changes in efficiency in more recent operations. In earlier operations a specific catcher was designated as tow boat within a pelagic fleet. As soon as sufficient whales had been taken, the designated tow boat would return to the factory ship with the whales taken. In current operations, no particular catcher is designated as a tow boat when sufficient whales are taken. However, there are documented values for T_t only for recent operations and the sub-committee agreed to adopt those given by Ohsumi in SC/SPC/Doc 2: pelagic 0.2217 hours per catcher per whale; coastal 2.13 hours per catcher per whale.

It was recognised that with a probable increase in the distance offshore of the whaling grounds in the coastal operations, towing time would also have increased; however, much of the increase would have taken place after dark and the figure given by Ohsumi was adopted for the whole period.

4.6 Chasing time (T_c)

The sub-committee agreed that it was necessary to obtain measures of chasing time for as many operations as possible. Ohsumi (SC/SPC/Doc 2) gave data on time budgets for pelagic and coastal whaling operations in the North Pacific during the 1977 and 1976/77 seasons respectively. The sub-committee adopted values of 0.5682 hours for current pelagic operations and 0.22 hours for current coastal operations.

It was noted that some of the technological changes that have occurred in the Japanese fleets have not been adopted by other fleets. The Soviet scientists reported that they had requested that information on chasing times in Soviet operations be collected and that the data would be made available as soon as it was obtained.

The sub-committee agreed that the effect of Asdic was on chasing time, which includes time spent on unsuccessful chases.

The effectiveness of Asdic is dependent to a very great extent on the skill of the operator, the type of Asdic in use, local ocean conditions and the species being hunted. Two main types of Asdic equipment are available — a fixed beam, shallow deflection type best suited to baleen whaling, and a variable or deeper-deflection type more suited to sperm whaling operations. Consequently Asdic factors should be calculated for individual operations.

Best stated that operations off Durban had used Asdic sets which were more effective in sperm whaling than the sets used by Japanese operations in the North Pacific and Antarctic. It also appeared likely that the effectiveness of Asdic at Durban was enhanced by co-operation between catches during the chase, particularly of female schools. After some discussion it was considered that such co-operation did not occur in higher latitudes, where schools of bulls were the object of the chase or when large solitary bulls were being chased.

The Soviet scientists stated that the North Pacific Soviet fleet only had 3–5 vessels with Asdic, that it had been

introduced only for 3–4 seasons for experimental use in both the North Pacific and the Antarctic and was of the sort most useful for baleen whales.

The Peruvian fleet of three catchers has been fitted with Asdic since 1968 and has used the equipment consistently since then.

The Western Australian fleet has been fitted with Asdic since 1971, one set being of the Durban “sperm whale” type.

Data presented by Mitchell (SC/30/Doc 39) on chasing times for a Nova Scotia operation in 1970–72 gave a mean time to capture for successful chases of 1.86 hours $\pm$ 19 hours 00 minutes. Ohsumi (SC/SPC/Doc 2) gave values for average chasing time for pelagic operations of 0.59 hr (35 minutes), including unsuccessful chases. He estimated that chasing times varied from about 22 minutes for 30–35 ft whales to 35 minutes for 50–55 ft whales. In coastal operations, again including unsuccessful chases, an average time of 13 minutes per whale is given by Ohsumi. The sub-committee agreed that more detailed information on time budgets for all operations was essential and recognised that the values given by Mitchell are indicative of the long chasing times likely in areas where large solitary males are taken. (Asdic was sometimes used in the Canadian operation.)

The only available detailed CDW time budgets were those prepared by Ohsumi *loc. cit.* and the sub-committee asked Beddington, Kirkwood and Doubleday to investigate methods of assessment of the effects of Asdic on catch per searching hour, in particular to provide a modifying factor for pre-Asdic operations. Values for the Asdic correction factor of 0.26 hours per whale caught and 1.57 hours per whale caught for North Pacific pelagic and coastal operations respectively and 4.54 hours per whale caught for Southern Hemisphere pelagic operations were adopted (Appendices I and II).

The sub-committee noted the considerable difference between the correction factors (4.54 hours per whale caught in the Southern Hemisphere and 0.26 in the North Pacific pelagic operations). It was agreed that the high value for the Southern Ocean accords with an operation dealing with a high proportion of single adult males, widely dispersed. It was suggested that the much lower correction factor for North Pacific pelagic operations may result from differences in water depth and different distributions and densities of stocks.

The sub-committee agreed that it was not reasonable to pool the obtained values, and after considerable discussion agreed to adopt the values calculated for each operation.

4.7 Time searching (T_s)

Time available for searching is derived by difference once the other components of CDW are estimated. It was noted that with the increase in fuel oil prices after the oil crisis in 1973, catcher boat speeds have been reduced from 14.5 knots to 12 knots, a change of 17%. This should be taken into account in the calculation of post-1973 effort for both the North Pacific and the Southern Ocean.

5. STOCK IDENTITY

5.1 Northern Hemisphere

North Pacific

The proposal in SC/30/Doc 58 for three stock divisions, based on distributions of different fluke notch shapes, was

examined by the sub-committee. It was recognised that the report was preliminary and required additional data.

The sub-committee again discussed briefly the paper submitted by Mitchell to the Cronulla meeting (SC/SPC/Doc 20). While noting Mitchell's view that biological evidence for three separate stocks was growing, the sub-committee agreed to the boundary as shown in Fig. 1. The boundary agreed to at the Cronulla meeting was retained north of 50°N.

The change was considered by the Scientific Committee to be a conservative one in that the zone of mixing recognised by Ohsumi and Masaki (1977, *Rep. int. Whal. Commn* 27: 173) was excluded from the Eastern Division stock, the earlier boundary having run through the Hawaiian group.

The sub-committee recognised that in recommending yields for the Western Division, it might be necessary to further divide the Western Division into two statistical areas to ensure that catch effort was more evenly distributed.

Mitchell believed that a more conservative approach is to include the 10° square P26 in an eastern stock on the basis of distribution of catches and general trends in the migration of sperm whales and anecdotal information on their movement through the eastern Aleutians (cf. Cronulla document SC/SPC/20).

Ohsumi believed that marking results showed that a significant amount of mixing of stocks of large males occurred between 160°E and 160°W, north of 50°N and that consideration should be given to delineation of a discrete mixing zone in that region which should also be treated as a separate statistical area.

5.2 Southern Hemisphere

In the absence of any additional information, the nine current Southern Hemisphere sperm whale management Divisions were accepted by the sub-committee.

6. BIOLOGICAL PARAMETERS

6.1 Pregnancy rate

The sub-committee agreed that a likely range of pregnancy rates in a stock which contained an adequate number of

mature males was from 20% when the females were essentially unexploited, to 25% when the female stock was close to zero. Some evidence of an increase in pregnancy rate with increased exploitation of females was given in SC/30/Doc 33 for the Durban stock – this response appeared to occur mainly in older females.

A model of pregnancy rate change based on the assumption that there was essentially a random search of males for females (SC/30/Doc 17) was considered by the Committee to produce biologically unrealistic results, in that there was essentially no response in pregnancy rate to a reduction in population until stocks of females had been reduced to nearly 50% of their initial size.

The sub-committee agreed that for the present, a density dependent exponent of 1.4 should continue to be used for changes in this parameter: the degree of change shown by the Durban stock to a relatively small degree of reduction tended to support this assumption rather than that of a linear response.

Allen noted that, under the modified logistic model, the MSY for a given value of ($r_0 - m$) increases as the density dependent exponent, and therefore the MSYL, is increased. Thus if the value of ($r_0 - m$) used in any model has been estimated directly, as from the considered maximum reproductive potential of the species, there is a risk that use of an over-estimate of the MSYL will lead to an over-estimate of MSY, and under the New Management Procedure, a reduction of the population. The cut-off applied in the New Management Procedure to the quota for populations estimated to be below MSYL would, however, operate from the estimated and not the true MSYL, thereby preventing further population reduction, provided the true population level relative to unexploited is known. The potential risk associated in this way with an over-estimate of MSYL will also not apply where the value of ($r_0 - m$) is deduced from an estimate of current recruitment rate, and not estimated directly.

6.2 Reserve male ratio

The Committee had before it two alternative models of the effect of a reduction in the ratio of males to females. The first of these was the assumption in the existing model that

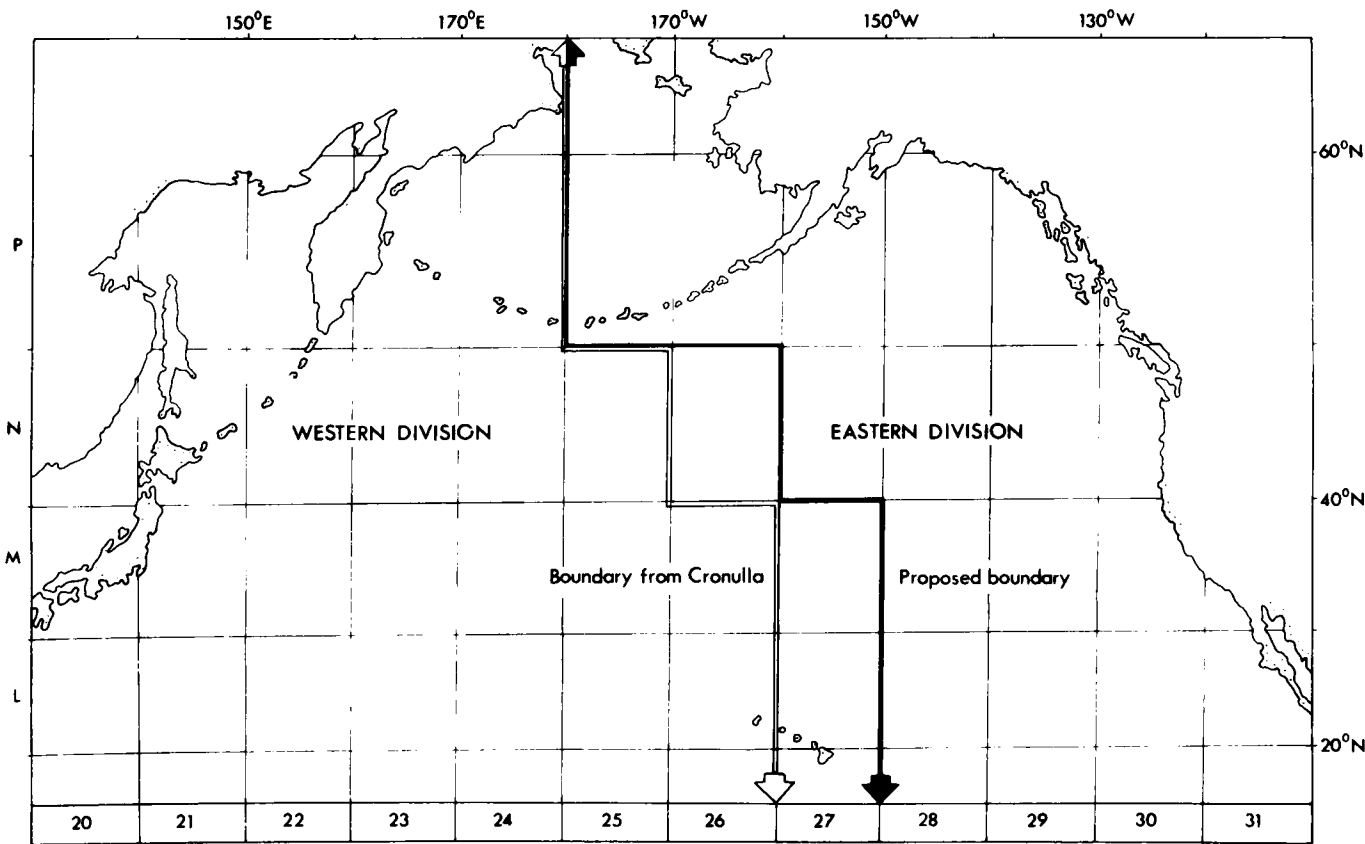


Fig. 1. North Pacific sperm whale stock Divisions.

Table 2a

Sperm whale population parameters – North Pacific

		1976 (a)	1977 (b)			1978 (c)		Notes
			pre-1960	61-72	73-77	60-72	72-78	
Average age at recruitment	♂	15	13	15	13	16	13	By inspection of length frequency data pre-1972 stock figures corrected for 13-16 year classes.
	♀	15	10	15	13	10	10	
Average age at maturity (*Social maturity.)	♂*	25	25			25		Both values are for both exploited and unexploited stocks. <i>Rep. int. Whal. Commn</i> 27: 241.
	♀	10	10			10		
Natural mortality rate	Juvenile	0.05	0.0589			0.055		More conservative figure agreed to by sub-committee.
	Mature	0.33-0.05	0.0589			0.0926		From balance equation.
Mean number of mature females available to a school master		10	10			10		Mean school size 15 with 1.5 mature males. <i>Rep. int. Whal. Comm</i> 27: 241.
Reserve male ratio		0.3	0.3			0.3		To give 2 males per school of 15 females. <i>Rep. int. Whal. Commn</i> 27: 42.
Pregnancy rate (theoretical values)	Unexploited	19	20			20		Theoretical minimum 4-year calving interval. <i>Rep. int. Whal. Commn</i> 27: 42.
	Exploited	25	25			25		
Density-dependent exponent		1.4	1.4			1.4		Representing an MSY level of 60%. <i>Rep. int. Whal. Commn</i> 28: 61.

(a) Canberra 1977 (values except for mean age at recruitment as at La Jolla, *Rep. int. Whal. Commn* 27: 42).
(b) Cronulla 1977 (see *Rep. int. Whal. Commn* 28: 60–62 and SC/30/Rep 2).
(c) Cambridge, 1978.

42.)

there was no change in the pregnancy rate until the mature male stock had fallen to a critically low level (taken to be a ratio of two mature males to each school of mature females). The pregnancy rate would then fall in a linear fashion to zero as the male:female ratio declined to zero.

The alternative model made no assumptions about the reserve male ratio, but assumed that the limiting factor to fertilisation was the probability of adequate mixing of males and females (SC/30/Doc 4). Assuming the probability of 100% mixing at the initial ratio of males to females in the unexploited stocks, the model indicated that if the females remained unexploited the slow initial decline in

pregnancy rate would accelerate as male stocks were progressively depleted.

The Committee had much discussion about the validity of these two models. Some members considered that the second model was a more reasonable representation of the likely response given the dispersed nature of female schools on the breeding grounds, and they considered that an assumption of perfect mixing between the sexes at all levels down to a highly disturbed sex-ratio and reduced density was unrealistic. They also considered that it is more conservative to adopt this model.

Other members felt that because of the nature of the

Table 2b

Sperm whale population parameters – Southern Hemisphere

		1976 (a)	1977 (b)	1978 (c)	Notes
		(Div. 9)			
Average age at recruitment	♂	20 (15)		20	To be refined by reference to length frequency analysis of Divisional catches.
	♀	13 (13)		13	
Average age at maturity (*Social maturity.)	♂*	25	25	25	As for Northern Hemisphere.
	♀	8.5–10	10	10	
Natural mortality rate	Juvenile – 1	0.133	0.133	0.055	Juvenile mortality derived from balance equation in analysis.
	Mature – 1 (2 yrs +)	0.05	0.05		
Mean number of mature females available to a school master		10	10	10	As for Northern Hemisphere.
Reserve male ratio		0.3	0.3	0.3	As for Northern Hemisphere.
Pregnancy rate	Unexploited	0.19	0.19	20	Theoretical values, as for Northern Hemisphere.
	Exploited	0.25	25	25	
Density-dependent exponent		–	1.4	1.4	As for Northern Hemisphere.

(a) *Rep. int. Whal. Commn* 27 (1977): 42.
(b) *Rep. int. Whal. Commn* 28 (1978): 57.
(c) Cambridge, 1978.

sperm whale's social organisation it was reasonable to assume that effective pregnancy rates would be maintained until the ratio of mature males to females dropped very considerably. They pointed out that the critical reserve ratio used inferred that at this level mature males fertilised only three females annually, i.e. 1.5 per mature male per year. They also indicated that the model was conservative in that it assumed that all males below 25 years of age played no part in breeding (despite the fact that males 10 years and older are capable of producing spermatozoa), and that it assumed that school masters remained with the school for the duration of the breeding season and did not move between schools after fertilising the females present. These members of the sub-committee also felt that it was unrealistic to assume that there would be a problem of adequate mixing of sexes in such a mobile and apparently highly evolved mammal.

It was felt that the suitability of either model might be judged from the correlation between trends in apparent pregnancy rates and the relative degree of reduction of male and female stocks.

Chapman, Best, Breiwick and Bannister undertook analysis of apparent pregnancy rates for Albany (Western Australia), Peru, Southern Hemisphere Divisions 4 and 5 and the Western stock of the North Pacific (Appendix IV). Significant trends with time could only be detected for the Australian data (adjusted to account for missed fetuses) and the Western stock of the North Pacific (by comparing the summed 1966–69 data with those summed for 1974–76). In both regions a statistically significant decline was observed.

The sub-committee agreed that a reserve male value of 0.3 males per 10 mature females would be adopted prior to the assessments being available. While many members of the sub-committee considered that a value of 0.3 was sufficiently conservative, others did not and would have preferred a higher value.

Mitchell and Fortom-Gouin believed that either the reserve breeding male ratio be increased or that protection of both breeding bulls and cows should be extended to cover more of the breeding season (see Table 1 and recommendation 2, Mitchell and Kozicki, 1978, *Rep. int. Whal. Commn* 28: 195–8).

6.3 Age at recruitment

North Pacific

A sub-group (Allen, Beddington and Kirkwood) examined length distributions for Areas III + IV and V (representative of catches in current Eastern and Western Divisions) and age distributions of the total North Pacific as provided at the Cronulla meeting (SC/SPC/9 and 3). By inspection of those data and Ohsumi's raw age-length key (1977, *Rep. int. Whal. Commn* 27: 298) they agreed that the average age of recruitment in both Divisions should be taken as 16 years, corresponding to an average length of 39 feet. However, they recognised that in the years 1966–69 inclusive, in the Western Division, there was a much higher proportion of small animals in catches and those years were omitted from CPUE estimations for the Western Division.

The sub-committee agreed to adopt the value of 16 years as the average age at recruitment for males in both Divisions, and that a value of 10 years would be used for the average age of recruitment for females in both areas.

7. STOCK ESTIMATION

7.1 Stock estimation programs

The sub-committee had available programs used at the Cronulla meeting for stock estimations, with the new alternative outlined in SC/30/Doc 12 in which a maximum likelihood estimation technique is used rather than the least squares fitting approach previously employed.

In addition, the sub-committee discussed at length the applicability of the approach in SC/30/Doc 4 (see Sections 7.1, 7.2) and agreed that it could be incorporated into both the stock estimation procedure POPDYN and SPVAP, the MSYL and yield estimating procedure. During the course of the meeting, however, it became apparent that there would be insufficient time to incorporate the necessary changes in POPDYN and SPVAP and the sub-committee agreed to use the procedures adopted at Cronulla with subsequent modifications for maximum likelihood estimation.

7.2 Stock estimates

The Committee agreed that stock estimates should be obtained from Japanese pelagic data for both Western and Eastern Divisions. The Soviet data did not give adequate time series showing a decline in CPUE which could be used in the estimations. The time series used for Japanese and Soviet data are given in Appendix V.

The years 1966–69 were omitted from the Japanese Western Division estimation following inspection of length frequencies in the catches, where the sub-committee noted that a different component of the stock was being exploited over that period.

The sub-committee noted that in estimating the 1979 catches, it had been assumed that catch limits set by the Special Meeting of the Commission in Tokyo represented the actual catch in 1978.

The sub-committee agreed that although information on catches in the early years of the North Pacific fishery were not complete, those available should be included and therefore estimates of initial population size are for the year 1910. The data available are given in SC/30/Doc 11.

The results of the assessments are shown in Table 3.

The POPDYN model predicted that pregnancy rates in the Western stock would remain fairly constant (at around 21.5%) prior to 1970, but would decline thereafter as a result of the reserve male ratio falling below 0.3 from 1970 onwards.

The pregnancy rate predicted in 1975 was 11.5%, representing a decrease of 46.5% from 1968. The decline in

Table 3
North Pacific stock sizes ($\times 10^3$)
(Average age at recruitment shown in parentheses)

	Western Division	Eastern Division
	Males	
1910	104.7 (16)	121.0 (16)
1979	35.1 (16)	89.8 (16)
	Females	
1910	145.6 (10)	168.3 (10)
1979	110.2 (10)	162.6 (10)

observed pregnancy rates between 1966–69 and 1974–76 (and which apparently referred to the Western stock – see Appendix IV) was 38%. The sub-committee noted that this agreed with predictions from the current model and that proposed in SC/30/Doc 4, but did not provide an adequate basis for determining which pregnancy rate model was the more appropriate. The matching of the observed decline with that predicted by the POPDYN model, however, did provide some confirmation of the population trends produced by this method.

Classifications and catch limits – North Pacific
Using the population estimates obtained above the SPVAP programme was employed, with population parameters as already defined to give MSY levels and yield. The results are shown in Table 4.

Table 4				
Estimated stock sizes and MSY and recommended catch limits				
North Pacific				
(Average age at recruitment shown in parentheses)				
	Western Division		Eastern Division	
	Males	Females	Males	Females
1910 stock (× 10 ³)	123.4 (13)	145.6 (mature)	142.7 (13)	168.3 (mature)
1979 stock (× 10 ³)	52.7 (13)	110.2 (mature)	111.4 (13)	162.6 (mature)
1979/1910	42.7%	75.7%	78.1%	96.6%
MSY level/ 1910 stock	45.9%	80.4%	45.9%	80.4%
MSY	2897	641	3349	741
1979 MSY level	93%	94%	170%	120%
Classification	SMS	SMS	IMS	IMS
Catch limits	782	231	3014	667
Total catch males	3796			
females	898			

The sub-committee noted that the decline in observed pregnancy rates since 1966–69 was in the same order as the changes in pregnancy rate predicted for a drop in reserve male ratio and noted with some concern that current yields were based on a declining stock. Extrapolations from the 1979 stock level, made with an assumption of zero catches in the period 1979–89, are given in Table 5.

8. NEED FOR CLOSED SEASON FOR MALES

The sub-committee referred to the decision at Cronulla (IWC/SPEC 77/02) and Canberra (*Rep. int. Whal. Commn*

28: 70) and confirmed its view that the present closed seasons for socially mature males in both the North Pacific and Southern Hemisphere should be retained.

The sub-committee also considered the effects of taking females from breeding schools. It was noted that information available indicated more cohesion in female schools than in all male or mixed schools, and that school masters appeared to spend only a short period with the breeding schools (see 6.2). While some members recognised that protection of females during the breeding season would be a more conservative measure, others considered current management procedures allow a sufficient margin of safety.

Table 5
North Pacific sperm whales – Western Division stock
Extrapolation from 1979 to 1989 based on zero catches from 1979 onwards

Year	Exploitable females	Exploitable males 16–24	Exploitable males over 25	Total exploitable males	Ratio females: males
1979	110,200	28,500	6,600	35,100	16.7:1
1980	110,700	31,200	7,200	38,400	15.4:1
1981	109,900	33,500	8,100	41,600	13.6:1
1982	108,100	35,300	9,300	44,600	11.6:1
1983	106,100	36,800	10,700	47,500	9.8:1
1984	104,100	37,900	12,100	50,000	8.6:1
1985	102,000	38,800	13,600	52,400	7.5:1
1986	99,700	38,800	15,300	54,100	6.5:1
1987	97,500	37,800	17,200	55,000	5.7:1
1988	95,400	35,800	19,200	55,000	5.0:1
1989	93,400	33,400	21,300	54,700	4.4:1

Ages at recruitment to exploitable stocks are 10 years for mature females, 16 years for immature males and 25 years for socially mature males. The decline in pregnancy rates which is estimated to have begun in 1970 will thus not be reflected in a decline in exploitable female stocks until 1980, in exploitable immature male stocks until 1986 and socially mature male stock until 1995.

The sub-committee recognised that the peak conception period off western South America, particularly off Peru, may well occur earlier in the year than in other parts of the southern ocean. It urges analyses of available data for previous Division 9 catches so that an appropriate regulation can be framed for that area.

While the sub-committee therefore recognises a possible latitudinal shift in the timing of the peak of conception in the Southern Hemisphere the information available for the North Pacific indicate no such changes over the latitudinal zones covered by the present fishery.

Appendix I

ESTIMATION OF CHASING TIME PRIOR TO THE INTRODUCTION OF ASDIC IN SPERM WHALING

J. R. Beddington, G. P. Kirkwood and W. G. Doubleday

Introduction

At the Cronulla meeting of the Scientific Committee, data were presented on the effect of Asdic on the catch per catcher day of both the pelagic and coastal whaling of the Japanese whaling operations (Ohsumi SPC/SC/Doc 3).

In the same document the present state of the components of the time budget of both operations were presented. In discussion it was claimed that the main effect of Asdic was to alter the chasing time of the catcher boat. This paper presents a method of calculating the necessary

change in chasing time that would be produced by the observed changes in catch per catcher day, on the assumption that this is truly the main effect.

Model structure

Assume each catcher day worked (CDW) has the following components:

CDW = 24 hours

where T₀ is the total number of daylight hours, and T_r the resting time.

Then

T₀ = T_s + hW + T_cW = T₀ + T_r

where: T_s = No. searching hours/day; h = No. handling hours/whale; T_c = No. chasing hours/whale/day; and W = total catch of whales per day.

If C is the catch of males per CDW, the previously used catch per unit effort, then the corresponding catch per searching hour is

C / (T₀ - hW - T_cW)

Assuming vessels with and without Asdic were fishing the same whale stocks, and were identical in all respects except for Asdic, the catches per searching hour of the different vessels in the same year should be equal.

Then for a male only catch:

C / (T₀ - hC - T_cC) = C' / (T₀ - hC' - xC')

where the dashes denote vessels without Asdic, and x is the unknown chasing time per whale caught without Asdic. Then:

x = T_c + T₀ (1/C' - 1/C) hours/whales caught/day.

If C = (1 + α)C', so that α is the previous "Asdic factor",

x = T_c + T₀ (α / (C'(1 + α))) hours/whale caught/day

and the change in chasing time per whale caught per day is thus:

(T₀ α) / (C'(1 + α))

Results

Table 1 presents the decrease in catching time per whale in hours that would be necessary for some specified

improvement in the catch per catcher day. Two other factors influence this decrease: the duration of the working day T₀ and the pre-Asdic level of catch per catcher day. Data are tabulated for three levels of the working day, five levels of pre-Asdic catch per catcher day and six levels of percentage of increase in the catch per catcher day.

Table 1
Decreases in chasing time in hours following the introduction of Asdic

	Alpha	Pre-Asdic CPUE				
		0.5	1	2	3	4
T ₀ = 16 hours	0.05	1.5	0.7	0.3	0.2	0.1
	0.1	2.9	1.4	0.7	0.4	0.3
	0.2	5.3	2.6	1.3	0.8	0.6
	0.3	7.3	3.6	1.8	1.2	0.9
	0.4	9.1	4.5	2.2	1.5	1.1
T ₀ = 18 hours	0.5	10.6	5.3	2.6	1.7	1.3
	0.05	1.7	0.8	0.4	0.2	0.2
	0.1	3.2	1.6	0.8	0.5	0.4
	0.2	6.0	3.0	1.5	1.0	0.7
	0.3	8.3	4.1	2.0	1.3	1.0
T ₀ = 20 hours	0.4	10.2	5.1	2.5	1.7	1.2
	0.5	12.0	6.0	3.0	2.0	1.5
	0.05	1.9	0.9	0.4	0.3	0.2
	0.1	3.6	1.8	0.9	0.6	0.4
	0.2	6.6	3.3	1.6	1.1	0.8
	0.3	9.2	4.6	2.3	1.5	1.1
	0.4	11.4	5.7	2.8	1.9	1.4
	0.5	13.3	6.6	3.3	2.2	1.6

We comment only that the values of the chasing time change include time spent unsuccessfully chasing whales.

For catching operations using Asdic, we have available estimates of T₀, h and T_c. We may now obtain an estimate of the chasing time before the introduction of Asdic.

Catches of males per CDW are available for Japanese pelagic whaling operations in the North Pacific for vessels with and without Asdic between 1958 and 1961. During that period the catch of females was extremely small, so that we may assume that in the above notation W = C.

In both the Southern Ocean and Japanese coastal fisheries a substantial female catch occurred during the period for which comparative information is available. It is a straightforward process to adjust this estimation procedure to allow for this catch.

In concluding we note that such estimates of the change in chasing time would be made for within season comparisons of catch per catcher day. They are thus likely to be underestimates of the true change.

Appendix II

ESTIMATES OF THE EFFECT OF ASDIC ON CHASING TIME FOR JAPANESE WHALING OPERATIONS

J. R. Beddington and G. P. Kirkwood

Using the procedure outlined in Appendix I, the following results were obtained for the effect of Asdic on the chasing times of catcher boats.

Pelagic North Pacific (data source Ohsumi SC/SPC/Doc 2)
Mean value of chasing time change for various expeditions = 0.26 hours/whale caught.

Standard error = 0.116.
d.f. = 6.

Individual estimates of change in chasing time were obtained and averaged to produce mean.

Mean daylength: Pelagic (P zone) 18 hr; Coastal 11.6–15.5 hr.

Coastal North Pacific
Mean values of male CPUE for males = 0.805.
Mean value for Asdic factor = 0.254.
(Data source Ohsumi SC/SPC/Doc 2)
Mean value of female CPUE obtained from Tillman, 1977
(*Rep. int. Whal. Commn* 27: 343–50) = 1.188.
Estimate of chasing time change = 1.57 hours/whale caught.

Southern Ocean – Mean daylength 19 hr.
Value of CPUE per year obtained from Gambell (*Rep. int. Whal. Commn* 27: 280–6).
Values of Asdic factor obtained from Ohsumi (SC/SPC/Doc 2).
Mean value of CPUE = 0.863.
Mean value of Asdic factor = 0.26.
Estimate of change in chasing time = 4.54 hours/whale caught.

Appendix III

CALCULATION OF EFFORT AND CPUE

G. P. Kirkwood and J. R. Beddington

If T_s = searching time in hours, T_h = handling time in hours, T_c = chasing time in hours then:
 T_s = Catcher days x Day length correction – Male catch ($T_h + T_t + T_c$) – Female catch x Total female time
 T_c = (1 – Proportion of fleet with Asdic) x Asdic correction + Basic chasing time + r (mean length – mean length₁₉₇₇)
where r is derived from length : chasing time regression line.

Effort =
$$\frac{\text{No. hours searched} \times \text{proportion of fleet less than 600 t} \times \text{Speed in knots}}{\text{Pre-1973 speed (= 14.5 knots)}}$$

CPUE =
$$\frac{\text{Male catch}}{\text{Effort}}$$

The following values were used:

	North Pacific		Southern Hemisphere
	Coastal	Pelagic	
Handling time (hr): T_h	0.53	0.33	0.33
Towing time (hr): T_t	2.13	0.2213	0.2213
Chasing time (hr): T_c	0.22	0.5682	0.5682
Chasing time correction (hr/whale)	+1.57	+0.26	+4.54
Total time/female (hr)	1.2	1.137	1.13
Mean length (1977) (ft)	41.9	41.9	–
Length/ T_c (min/ft)	–	0.4656	–

The proportion of the Japanese fleets equipped with Asdic was as follows:

North Pacific ¹			Antarctic Expeditions ²		North Pacific ¹			Antarctic Expeditions ²	
Pelagic	Coastal				Pelagic	Coastal			
1954	0	–	1955/56	0.0	1966	1.00	0.40	1966/67	0.800
1955	0	–	1956/57	0.038	1967	1.00	0.50	1967/68	0.857
1956	0	–	1957/58	0.091	1968	1.00	0.90	1968/69	0.974
1957	0	0	1958/59	0.176	1969	1.00	0.90	1969/70	0.971
1958	0.30	0	1959/60	0.256	1970	1.00	1.00	1970/71	0.971
1959	0.40	0	1960/61	0.357	1971	1.00	1.00	1971/72	0.973
1960	0.60	0.15	1961/62	0.547	1972	1.00	0.95	1972/73	0.971
1961	0.85	0.18	1962/63	0.633	1973	1.00	0.95	1973/74	0.967
1962	1.00	0.25	1963/64	0.628	1974	1.00	0.94	1974/75	0.964
1963	1.00	0.33	1964/65	0.653	1975	1.00	0.94	1975/76	–
1964	1.00	0.30	1965/66	0.750	1976	1.00	0.93		
1965	1.00	0.32							

¹ Ohsumi, S. (SC/SPC/Doc 2, approximate values from Fig. 5).

² Ohsumi, S. Sperm whale catch efficiency by Japanese whaling catcher boats in the Antarctic. (*Rep. int. Whal. Commn* 27: 305–7.)

Appendix IV
D. G. Chapman, P. B. Best and J. M. Breiwick

Table 1

Grouped pregnancy rate data for North Pacific sperm whales
(presumed Western Pacific stock) – biological records SC/SPC/19

Month	1966–69	1974–76	Diff. (% of 1966–69 value)
	No. of mature females (% current preg.) (% previous preg.)	No. of mature females (% current preg.) (% previous preg.)	
May	118 (12.7) (35.6)	78 (5.1) (21.8)	–60 –39
June	348 (23.0) (26.1)	482 (10.8) (18.3)	–53 –30
July	173 (31.2) (20.8)	305 (23.0) (16.4)	–26 –21
August	175 (32.6) (17.7)	232 (25.4) (7.8)	–22 –56
September	–	213 (24.4) (2.3)	
Mean			–38

Chi-square value (current preg.) = 13.32, p < 0.05.
(previous preg.) = 14.49, p < 0.05.
There is thus a significant decline in the 1974–76 rate of about 38%
of the 1966–69 pregnancy rate.

Table 2

Australia (from SC/30/Prog Rep 1)

Year	No. exam.	% Preg. ¹	% Doubtful	Adjusted preg. ² 37%	% Preg. (adjusted)
1964	65	30.8 ³	18.5	6.8	37.6
1965	46	26.1 ³	8.7	3.2	29.3
1973	101	23.8 ⁴	11.9	4.4	28.2
1974	156	12.2 ⁵	26.9	10.0	22.2
1976	153	9.8 ⁵	7.2	2.7	12.5
1977	43	14.0 ⁵	23.3	8.6	22.6

- ¹ All current pairing season.
- ² Based on sizes of corpora lutea.
- ³ Biologists.
- ⁴ Technician.
- ⁵ Inspectors.

Table 3

USSR data¹ (Southern Hemisphere) from SC/30/Doc 65

Div. 4	1964/65–1971/72			1972/73–1967/77		
	n	% early	% late	n	% early	% late
Nov.	117	11.1	30.8	341	7.6	15.5
Dec.	54	3.7	31.5	0	–	–
Jan.	10	20.0	10.0	28	10.7	14.3
Feb.	2	0	0	0	–	–
March	9	44.4	0	0	–	–
April	4	25.0	0	0	–	–
	196			369		
Div. 5						
Oct.	54	0	33.3	0	–	–
Nov.	11	9.1	27.3	9	0	22.2
Dec.	35	14.3	45.7	0	–	–
Jan.	4	0	50.0	20	10.0	40.0
Feb.	0	–	–	0	–	–
March	1	0	100.0	0	–	–
April	12	16.7	8.3	0	–	–
	117			29		

¹ Partly biologists' records.

Table 4

Apparent pregnancy rates: Peru (Division 9) from Valdivia (pers. comm.)

	1975				1976				1977				Total			
	N	% Preg.	% R.O. ¹	Total	N	% Preg.	% R.O. ¹	Total	N	% Preg.	% R.O. ¹	Total	N	% Preg.	% R.O. ¹	Total
January	–	–	–	–	–	–	–	–	5	0	40.0	40.0	5	0	40.0	40.0
February	–	–	–	–	–	–	–	–	5	0	20.0	20.0	5	0	20.0	20.0
March	–	–	–	–	–	–	–	–	2	0	0	0	2	0	0	0
April	–	–	–	–	5	0	0	0	22	9.1	22.7	31.8	27	7.4	18.5	25.9
May	–	–	–	–	14	0	42.9	42.9	23	0	8.7	8.7	37	0	21.6	21.6
June	–	–	–	–	25	4.0	32.0	36.0	–	–	–	–	25	4.0	32.0	36.0
July	–	–	–	–	–	–	–	–	–	–	–	–	0	–	–	–
August	–	–	–	–	4	25.0	0	25.0	–	–	–	–	4	25.0	0	25.0
September	–	–	–	–	12	8.3	50.0	58.3	–	–	–	–	12	8.3	50.0	58.3
October	12	8.3	33.3	41.6	18	5.6	27.8	33.3	–	–	–	–	30	6.7	30.0	36.7
November	5	20.0	80.0	100	–	–	–	–	23	4.3	17.4	21.7	28	7.1	28.6	35.7
December	–	–	–	–	–	–	–	–	27	14.8	18.5	33.3	27	14.8	18.5	33.3

¹ All carcasses opened at sea and foetuses frequently lost. Hence all animals with corpora lutea but no foetus have been classed as “recently ovulated” (R.O.), but many of these may have been pregnant.

Appendix V
NORTH PACIFIC CPUE DATA

Year	Western Division				Eastern Division			
	♂	♂ CPUE	♀	♀ CPUE	♂	♂ CPUE	♀	♀ CPUE
(a) Japanese pelagic								
1954	0	0.0	0	0.0	479	0.1584	0	0.0
1955	229	0.1456	0	0.0	847	0.1448	0	0.0
1956	808	0.3135	0	0.0	781	0.2008	0	0.0
1957	604	0.1799	0	0.0	1007	0.2876	0	0.0
1958	960	0.2605	0	0.0	397	0.1997	0	0.0
1959	687	0.2250	1	0.0003	1080	0.2156	1	0.0002
1960	439	0.2486	0	0.0	1258	0.2099	1	0.0002
1961	497	0.2876	10	0.0058	1206	0.2065	1	0.0002
1962	600	0.1638	0	0.0	1893	0.1469	9	0.0007
1963	1094	0.1796	1	0.0002	1510	0.1100	0	0.0
1964	698	0.1732	0	0.0	1710	0.1217	17	0.0012
1965	667	0.1940	3	0.0009	1670	0.1328	23	0.0018
1966	1449	0.1816	71	0.0089	1307	0.1080	64	0.0053
1967	1716	0.1672	173	0.0169	940	0.1459	162	0.0252
1968	1398	0.1393	376	0.0375	916	0.2011	202	0.0444
1969	763	0.0650	378	0.0322	1251	0.1330	607	0.0645
1970	1558	0.1602	197	0.0203	719	0.1247	137	0.0238
1971	869	0.0748	140	0.0120	640	0.1159	146	0.0264
1972	610	0.0750	65	0.0080	732	0.1529	160	0.0334
1973	464	0.0944	90	0.0183	965	0.2041	270	0.0571
1974	711	0.1413	370	0.0735	609	0.2222	80	0.0292
1975	695	0.1323	467	0.0889	295	0.1954	49	0.0325
1976	466	0.0743	570	0.0909	17	0.0251	0	0.0
1977	0	0.07	0	0.0	0	0.0251	0	0.0
(b) Soviet								
1961	0	0.0	0	0.0	0	0.0	0	0.0
1962	534	0.1191	32	0.0071	1080	0.0726	305	0.0205
1963	972	0.1030	212	0.0225	3321	0.0368	334	0.0037
1964	1953	0.0765	403	0.0158	2446	0.0399	445	0.0073
1965	3400	0.0689	180	0.0036	4252	0.0782	339	0.0062
1966	5821	0.0838	314	0.0045	3146	0.1000	155	0.0049
1967	5273	0.1079	273	0.0056	3663	0.1150	175	0.0055
1968	4572	0.1016	303	0.0067	4459	0.1440	192	0.0062
1969	4233	0.1001	399	0.0094	3192	0.0861	374	0.0101
1970	5369	0.1081	831	0.0167	1869	0.0851	498	0.0227
1971	5052	0.1138	460	0.0104	0	—	0	—
1972	830	0.0361	423	0.0184	481	0.0306	2	0.0001
1973	1241	0.0316	1809	0.0461	734	0.0482	474	0.0311
1974	1195	0.0301	1585	0.0399	688	0.0401	495	0.0288
1975	1355	0.0382	1639	0.0463	413	0.0444	343	0.0369
1976	1727	0.0400	1567	0.0363	253	0.0426	124	0.0209
1977	0	0.0400	0	0.0363	0	0.0	0	0.0

A Possible Model for the effect of Adult Sex Ratio and Density Fecundity of Sperm Whales¹

J. R. Beddington² and R. M. May³

INTRODUCTION

This paper concentrates upon an alternative mathematical form to the current one now used for expressing the effect of sex ratio on the fecundity of sperm whale populations. The current model assumes that only when the ratio of socially mature males to females falls below a critical threshold will fecundity decrease. Beddington and Kirkwood (1980) discussed the unlikely nature of this assumption and suggested that a more realistic form would be one which allowed both the absolute density of the population and the sex ratio to affect fecundity in a continuous way. Obtaining an empirical idea of this relationship is likely to be difficult as two trends will be likely to be occurring during exploitation, as the population decreases a density dependent response will tend to increase fecundity while at the same time the effect of the worsening sex ratio will tend to decrease it. Accordingly one would expect little obvious change in fecundity rates over time, until one or other of these mechanisms became predominant. In the first part of this paper a particular model for the mixing of socially mature males and sexually mature females is proposed and developed. This model, although ignoring much of the rich complexity of sperm whale social life, does contain essential properties that need to be considered; allowing both absolute density and sex ratio to affect fecundity. In the second part, the problem of scaling the parameters of this model is addressed. This involves incorporating the new functional form into the sperm whale model's formalism. Finally the paper presents the results of a preliminary investigation into the effect of the new model on fecundity.

THE MODEL

The model assumes that socially mature males seek out pods of females, moving on when they discover pods with sufficient males. This process occurs for the duration of the breeding season.

Definitions

- $p_1(t)$ = Probability that a female will not encounter a mature male and become pregnant up to time t .
- $p_1(0)$ = 1.
- $p_1(T)$ = p_1 where T is duration of breeding season.
- n_1 = Number of pods of females.
- η = Characteristic pod size.
- N_1 = ηn_1 = Number of females.
- $p_2(t)$ = Probability that a male is still looking at time t .
- $p_2(0)$ = 1
- $p_2(T)$ = p_2
- N_2 = Number of males.

- ϵ = N_2/n_1
- r = $\eta\epsilon = N_2/n_1$ = Number of males/number of female pods.
- $a\delta t$ = Probability that a male will find a given group of females in δt .

Derivation

By definition the total probability that a male will find a female group that does not have sufficient males is $(a\delta t)(n_1 p_1(t))$

Hence

$$p_1(t + \delta t) = p_1(t) (1 - (a\delta t)(N_2 p_2(t)))$$

or in the limit

$$\frac{dp_1}{dt} = -aN_2 p_1 p_2 \quad (1)$$

similarly

$$p_2(t + \delta t) = p_2(t) (1 - (a\delta t)(n_1 p_1(t)))$$

and

$$\frac{dp_2}{dt} = -\frac{aN_1}{\eta} p_1 p_2 \quad (2)$$

By dividing (1) by (2)

$$\frac{dp_1}{dp_2} = \frac{\eta N_2}{N_1} = \eta\epsilon = r$$

hence

$$p_1(t) = r p_2(t) + (1 - r) \quad (3)$$

and substituting for p_2 from (3) in (1) gives

$$\frac{dp_1}{dt} = -(an_1) p_1 (r - 1 + p_1)$$

$$\int_1^{p_1} \frac{dp_1}{p_1(r-1+p_1)} = \int_0^T -an_1 dt$$

$$\frac{1}{r-1} \left[\ln \frac{p_1}{p_1+r-1} \right]_1^{p_1} = - \left[an_1 t \right]_0^T$$

Define $\alpha = an_1 T$

$$\ln \left(\frac{rp_1}{p_1+r-1} \right) = -\alpha(r-1)$$

$$\frac{p_1}{p_1+r-1} = \frac{1}{r} \exp(-\alpha(r-1))$$

$$p_1 = (r-1)/(r \exp((r-1)\alpha) - 1) \quad (4)$$

¹ This study was made with the aid of a grant from the Centre for Environmental Education.

² Department of Biology, University of York, Heslington, YORK YO1 5DD, U.K.

³ Department of Biology, Princeton University, PRINCETON N.J. 08540, U.S.A.

The problem thus now devolves on making an estimate of the parameters r and α for the sperm whale population. This involves formalising the dynamics of the two sex model.

PARAMETER SCALING

Using the functional form of (4) the equations for the dynamics of the socially mature males and sexually mature females may now be written as

$$N_{1t+1} = N_{1t}S + \frac{1}{2}S^k N_{1t-k} (1-p_1) \left[p_0 + Q \left(1 - \left(\frac{N_{1t-k}}{N_1^*} \right)^z \right) \right]$$

at t-k

$$N_{2t+1} = N_{2t}S + \frac{1}{2}S^j N_{2t-j} (1-p_1) \left[p_0 + Q \left(1 - \left(\frac{N_{2t-j}}{N_1^*} \right)^z \right) \right]$$

at t-j

(6)

Where S is yearly survival rate, k age of sexual maturity for females, j age of social maturity for males, p_0 pregnancy rate in unexploited stock (assuming no sex ratio effect), Q a parameter that determines the range of the density dependent response of pregnancy rates, z the density dependent exponent. At equilibrium (unexploited state)

$$N_{1t+1} = N_{1t} = N_{1t-k} = N_{1t-j} = N_1^*$$
$$N_{2t+1} = N_{2t} = N_{2t-k} = N_{2t-j} = N_2^*$$

and substituting in (5) and (6) we obtain

$$N_1^* = SN_1^* + \frac{1}{2}S^k N_1^* (1-p_1)p_0$$
$$N_2^* = SN_2^* + \frac{1}{2}S^j N_1^* (1-p_1)p_0$$

hence

$$p_1 = 1 - (2(1-S)/p_0S^k)$$

and

$$\frac{N_2^*}{N_1^*} = S^{j-k}$$

However $p_1 = (r-1)/(r \exp((r-1)\alpha)-1)$
and at equilibrium $r = \eta N_2^*/N_1^*$
and $\alpha = aTN_1^*/\eta$. Hence it can be shown that

$$aTN_1^* = \frac{\eta}{\eta S^{j-k} - 1} \log_e \left[\frac{\eta S^{j-k} p_0 S^k - 2(1-S)}{\eta S^{j-k} (p_0 S^k - 2(1-S))} \right]$$

(7)

This expression now allows the efficiency of males in finding females to be scaled to the initial female density and hence the overall effect of both male and female depletion on fecundity assessed using the expression for observable pregnancy rate $F = (1-p_1)(p_0 + Q(1-(\frac{N_1}{N_1^*})^z))$.

All other parameters in (7) being assigned values already by previous meetings of the Scientific Committee of the IWC. At its Canberra meeting, these were

$$k = 10$$
$$j = 25$$
$$s = 0.9428$$
$$p_0 = 0.21$$
$$Q = 0.04$$
$$z = 1.4$$
$$\eta = 12$$

at ‘zero’ population level of .25). These parameters were then used to generate levels of pregnancy rate for various levels of depletion of the male and female population, these are given in Table I. What is noticeable is the rapid decay of pregnancy rates once male depletion reaches about 60%.

REFERENCE

Beddington, J. R. and Kirkwood, G. P. (1977) On the mathematical structure of possible sperm whale models. Paper SC/SPC/10 (published in this volume).

Table 1.
Observable pregnancy rates at differing levels of male and female depletion.

		N ₂ %									
		100	90	80	70	60	50	40	30	20	10
N ₁ %	100	0.206	0.204	0.201	0.196	0.188	0.176	0.159	0.135	0.102	0.057
	90	0.212	0.210	0.206	0.202	0.194	0.183	0.166	0.141	0.107	0.061
	80	0.217	0.215	0.212	0.207	0.200	0.189	0.172	0.147	0.113	0.064
	70	0.222	0.220	0.217	0.213	0.206	0.195	0.178	0.153	0.118	0.068
	60	0.227	0.225	0.223	0.218	0.211	0.200	0.184	0.159	0.123	0.072
	50	0.232	0.230	0.227	0.223	0.216	0.206	0.190	0.165	0.129	0.075
	40	0.236	0.234	0.232	0.228	0.221	0.211	0.195	0.171	0.134	0.079
	30	0.240	0.238	0.236	0.232	0.226	0.216	0.200	0.176	0.139	0.083
	20	0.243	0.242	0.239	0.236	0.230	0.220	0.205	0.181	0.144	0.087
	10	0.246	0.245	0.242	0.239	0.233	0.224	0.209	0.186	0.149	0.091

A Note on the Assessment of North Pacific Sperm Whales

G. P. Kirkwood

Division of Fisheries and Oceanography, CSIRO, P.O. Box 21, Cronulla, NSW, Australia

ABSTRACT

The effects on estimates of stock size of North Pacific sperm whales of the inclusion of catches taken prior to 1947 and of differing Asdic factors is examined. In both cases the effects were found to be slight, but since the Western Stock was estimated to be close to MSY level, it is recommended that early catch data be included in future assessments.

Estimates of the total stock size of North Pacific sperm whales obtained at the Special Meeting on North Pacific Sperm Whale Assessments, at Cronulla in 1977 were based on catch data from the 1946/47 season onwards and an Asdic factor of 0.18 for Japanese pelagic operations. It is known that some substantial catches have been taken prior to 1947, and incomplete data are available from 1910 (Ohsumi, 1980). In this note, the effect of including catch data from 1910 on the estimates of stock size is examined. The effect of differing Asdic factors is also discussed.

INCLUSION OF CATCHES TAKEN PRIOR TO THE 1946/47 SEASON

Ohsumi (1979) listed incomplete catch data from 1910 onwards for the Japan and USSR pelagic fisheries, and the Japan, Kuril, Alaska, Canada and USA coastal fisheries. These data contain some missing values, and the sex breakdown of catches is not available for a number of the early years. Full catch data by sex are available only from 1947 onwards.

By inspection of the catches in later years for which the sexes were known, I estimated the proportion of males in the catches to be 50% for Japan coastal and pelagic, 90% for Kuril and USSR, and 100% for Alaska, Canada and USA data where the sex of catch was unknown. Ignoring missing values, a time series of catches from the total North Pacific by sex from 1910 onwards was generated, with catches of combined sexes being split up using the assumed proportions. Using the same parameters and estimation technique as adopted at the Cronulla meeting, the 1910 and 1972 male and female exploited population sizes were estimated, with a male and female age at recruitment of 15 years. The results are compared with those obtained at Cronulla in Table 1.

Table 1

Recruited male and female populations (in thousands)

Initial year	1910	1947
Initial recruited females	210.2	209.2
1972 recruited females	181.7	182.8
Ratio 1972 to initial	0.864	0.874
Initial recruited males	210.2	209.2
1972 recruited males	102.9	105.4
Ratio 1972 to initial	0.490	0.504

As can be seen, there is little difference between the results. No attempt has been made to calculate the effects on quotas. However these effects could be much greater

than appears to be the case from Table 1, as both males and females in the Western Stock were estimated to lie very close to the MSY level. These early catches should be included in future assessments, with an accurate split of catch sex if at all possible.

EFFECTS OF DIFFERING ASDIC FACTORS

The effects of differing Asdic factors were also calculated for the entire North Pacific stock, using four widely ranging values. In addition, initial (1947) and 1972 population levels were calculated using only effort data from 1962 onwards, when Asdic had been fitted to the entire Japanese fleet and so could be ignored. The resulting 1947 and 1972 male recruited populations (15 years of age or more) are shown in Table 2. An Asdic factor of 0.18 was adopted at Cronulla.

Table 2

Estimated recruited male populations (in thousands)

Asdic factor	1947 rect. males	1972 rect. males	Ratio 1972 to 1947
0.10	212.5	108.8	0.512
0.18	209.2	105.4	0.504
0.30	203.2	99.4	0.489
0.75	195.7	92.0	0.470
Not needed	251.5	147.8	0.588

There is a consistent, but slighter than may be expected, trend for smaller estimated initial populations with increasing Asdic factor. The much higher estimate when only effort data from 1962 onwards was used is somewhat surprising, but the estimates no doubt have higher standard errors than those using the larger data set.

The magnitude of the trend shown in these results cannot be generalised to other stocks or sets of catch and effort data. Each set of data needs to be investigated separately. Although in this example it would seem that the estimates are rather insensitive to the Asdic factor, in other cases it is likely that estimates will be quite sensitive. It should be noted that in the latter cases the use of too high or too low an estimate of Asdic factor should be obvious on examination of the residual pattern generated during the estimation procedure.

REFERENCE

Ohsumi, S. 1980. Catches of sperm whales by modern whaling in the North Pacific. Paper SC/SPC/1 (published in this volume).

A Note on the Modelling of Sperm Whale Pregnancy Rates

G. P. Kirkwood

Division of Fisheries and Oceanography, CSIRO, Cronulla, NSW, Australia

ABSTRACT

Equal pregnancy rate contour maps are presented to illustrate the behaviour of the pregnancy rate as a function of relative male and female population levels as currently modelled. A possible method for obtaining a conservative estimate of the reserve male ratio is proposed.

INTRODUCTION

Currently the only biological parameter in the sperm whale model that is assumed to exhibit density dependence is the pregnancy rate, which is assumed to increase with decreasing mature female population levels. However, no data have been presented to date documenting a rise in pregnancy rate in a stock where females have been reduced in numbers. Indeed some time series of gross observed sperm whale pregnancy rates could be taken to suggest that pregnancy rates have declined, and the assumption of density dependence has been criticised (e.g. Fortom-Gouin, 1977). Such criticisms have neglected to take account of, amongst other things, the additional model assumption that pregnancy rates will decline once males have been reduced below a certain level. The purpose of this note is to describe the assumed behaviour of pregnancy rates in response to changes in male and female population levels.

BEHAVIOUR IN THE CURRENT MODEL

In the current sperm whale model, if males are held at their unexploited level, and mature females are reduced to a proportion f of their unexploited level, then using the parameter values adopted for North Pacific sperm whales, the pregnancy rate at level f is

$$p'(f) = 0.20 + 0.05(1 - f^{1.4}) \quad (1)$$

This is illustrated in Fig. 1. In (1), the density dependence exponent is 1.4. The curves corresponding to density dependence exponents of 0.0 and 3.0 are also illustrated in Fig. 1.

The model also assumes that if the females are held at a constant level, then the pregnancy rate will remain constant until the males drop below a certain population level. In particular, if mature females are held at proportionate level f , and mature males reduced to proportion m of their unexploited level, the pregnancy rate is given by

$$p(f, m) = \begin{cases} p'(f) & \text{if } m/f \geq 0.1(1 + R) \\ \frac{10m}{f(1 + R)} p'(f) & \text{if } m/f < 0.1(1 + R) \end{cases} \quad (2)$$

In this equation, R is the reserve male ratio. To illustrate the behaviour of this function, contour diagrams of equal pregnancy rates are presented in Figs 2a–2d for values of R of 0, 0.3, 0.5 and 1.0 respectively. The current estimate of R is 0.3. Also plotted on these figures are the estimated MSY points for $R = 0, 0.3, 0.5$ and 1.0.

We see that if this pregnancy model is correct, only a slight increase in pregnancy rate would be expected if stocks are managed according to IWC rules from commencement of exploitation. In fact this comment will hold for any reasonable pregnancy rate model. Bearing in mind the sampling techniques and sample sizes currently available, any such increase in pregnancy rates would be almost impossible to detect. This highlights the importance of obtaining data from those stocks in which female population levels have been significantly reduced. In particular, if in a stock large numbers of females were taken, and relatively few males (an unlikely occurrence), the pregnancy rate would be expected to show a marked increase.

ESTIMATION OF R

If males are reduced below the critical point, it is clear from the figures that the pregnancy rate should show a

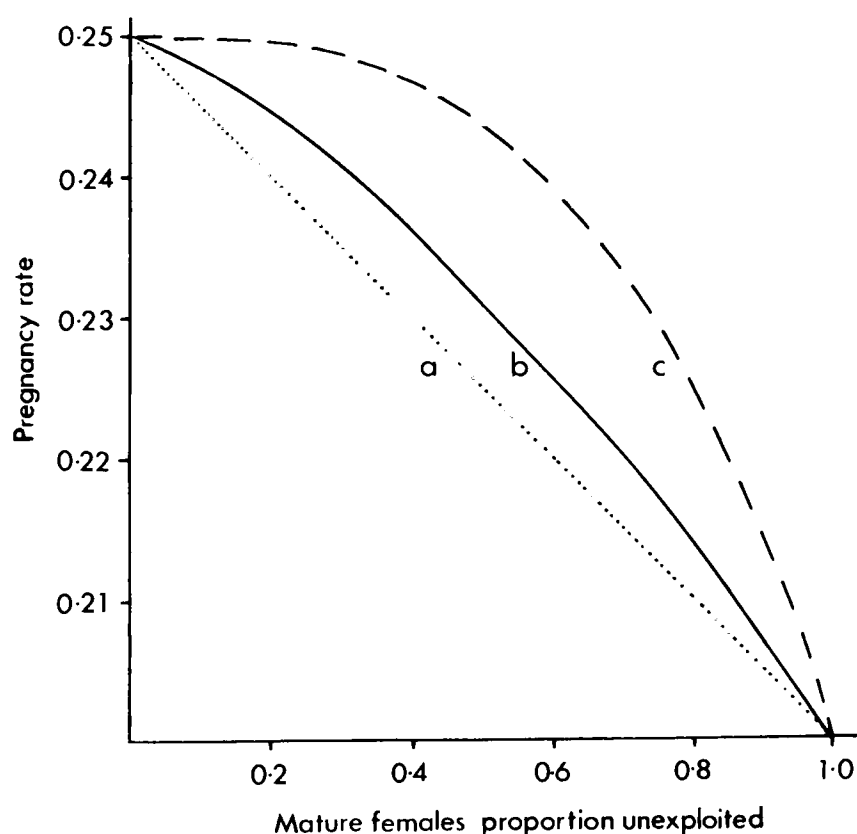


Fig. 1. Pregnancy rates for varying mature female population levels (males held at unexploited level). Density dependence exponents are 0.0 (a), 1.4 (b), 3.0 (c).

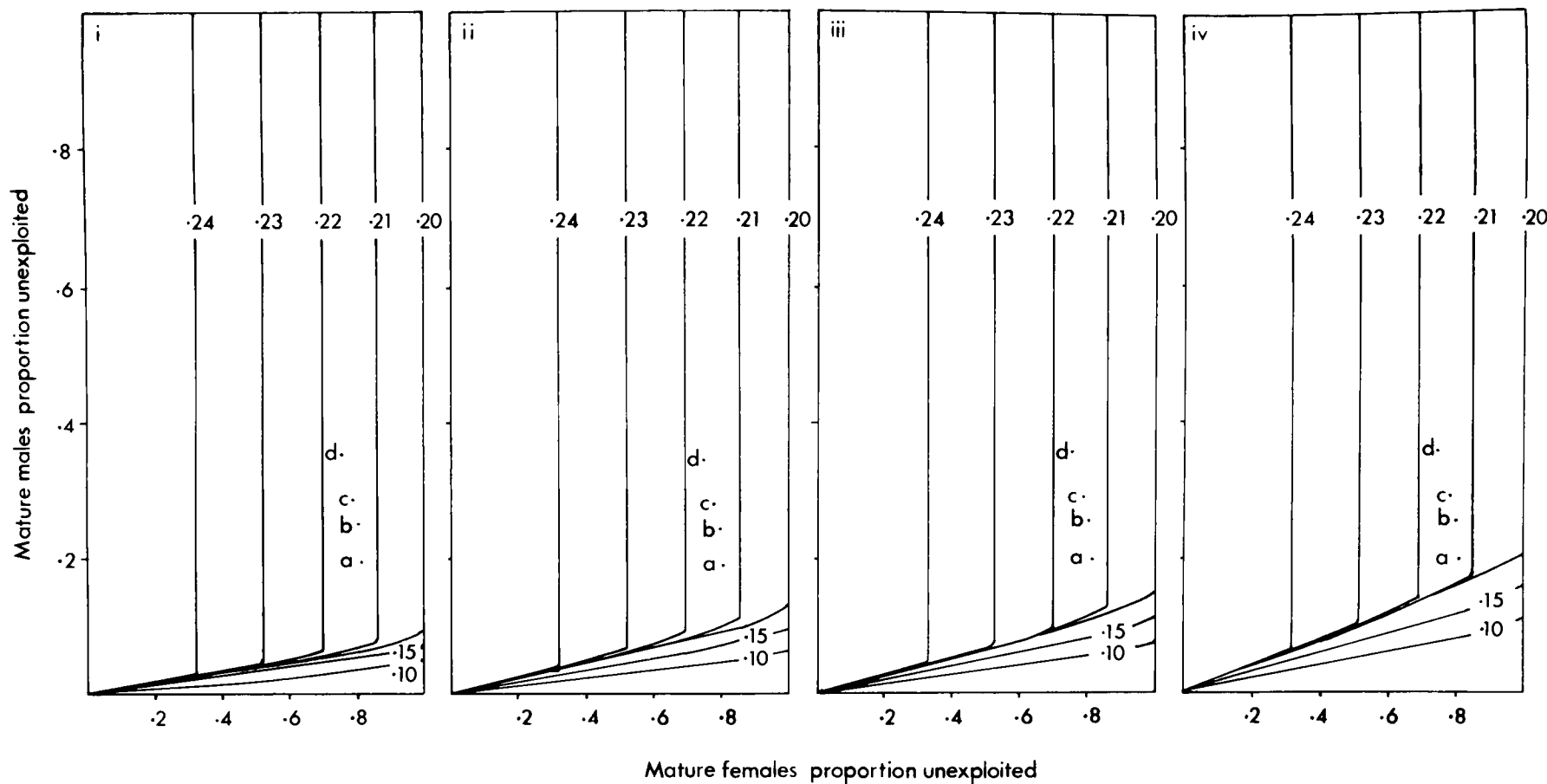


Fig. 2. Contours of pregnancy rates for (i) $R = 0.0$, (ii) $R = 0.5$, (iii) $R = 0.5$, (iv) $R = 1.0$; and MSY points for $R = 0.0$ (a), $R = 0.3$ (b), $R = 0.5$ (c) and $R = 1.0$ (d).

sudden decline. This points to a possible means of obtaining a conservative estimate of the parameter R . If for a stock the lowest relative population levels of mature levels and females were estimated to be m and f respectively, and biological samples suggested that at those levels the pregnancy rate remained at the same level as for higher population levels, then the maximum value of R consistent with this is

$$R = \frac{10\hat{m}}{\hat{f}} - 1 \tag{3}$$

A stock which exhibited a decline in pregnancy rates for mature male population levels below $\hat{m}$ at mature female level $\hat{f}$ would lead to the same estimate (3).

DISCUSSION

Of course, the assumed model is very much an approximation to the “real” process. In particular the model (2)

should almost certainly be replaced by a more gradual curvilinear model. In the figures this would have the effect of replacing the straight lines and “angle bends” by curves. However there seems little point in simply approximating (2) by an arbitrary curvilinear model. The model suggested by Beddington and May (1980) could provide a useful step towards defining a more appropriate model.

REFERENCES

Beddington, J. R. and May, R. M. 1980. A possible model for the effect of adult sex ratio and density on the fecundity of sperm whales. Paper SC/30/Doc 4 (published in this volume).
Fortom-Gouin, J. P. 1977. Changes in the pregnancy rate of the female cachalot in relation with changes in population density or exploitation rate. Paper presented to the Scientific Committee, Canberra, June 1977.

Sensitivity Tests for the Sperm Whale Model

G. P. Kirkwood

Division of Fisheries and Oceanography, CSIRO, Cronulla, NSW, Australia

ABSTRACT

The estimation of both population size and relative MSY statistics employ the current sperm whale model. For a given set of relative abundance data, the sensitivity of the estimated catch limits to changes in various vital parameters is examined.

INTRODUCTION

In the report of the La Jolla Special Meeting on Sperm Whales (IWC, 1977), the sensitivity of estimated MSY levels and catches to differing parameter values in the sperm whale model was reported. These were based on repeated runs of the SPVAP program (Allen, 1977). These results are of interest in themselves, but they fail to address a more important problem. In attempting to recommend catch limits for the various recognised sperm whale stocks, we are faced with a twofold task; first to estimate initial and current population levels using a time series of indices of relative abundance, such as CPUE or sightings indices, and second to determine relative MSY levels and catches, from which catch limits may be estimated. In both these tasks, the sperm whale model is employed, incorporating the best current estimates of the model parameters.

Because many of the model parameters are not known accurately it is important to determine the range of estimated catch limits that may result from varying the parameters of the model, as it is applied to a particular set of relative abundance data. In this note, the results of such sensitivity tests are reported for the five main parameters about which there is most uncertainty, with the other model parameters held at values adopted for Southern Hemisphere sperm whales in Divisions 1–8. The relative abundance data used are a series of aircraft sightings data gathered for the Albany, Western Australia sperm whale fishery.

SENSITIVITY TESTS

A number of the parameters of the sperm whale model are intrinsically measurable, such as ages at recruitment or maturity. However, little or no data exist to allow estimation of the density dependence exponent or the reserve male ratio. Likewise, it is extremely difficult to measure the juvenile and adult natural mortality rates, and availability of data also precludes accurate estimation of pregnancy rates (see Kirkwood, 1980). The estimated catch limits for a range of values of these parameters were obtained.

For each set of parameters, the estimated initial and current population levels were calculated, using the maximum likelihood technique described in Kirkwood (1978), employing the appropriate sperm whale dynamics model. This approach is embodied in a revised version of the POPDYN program. Then, using the SPVAP program, the relative male and female MSY levels and catches were estimated. In each case studied here, the stock fell into the Initial Management category, so that none of the "knife edge" problems inherent in a stock near MSY level were present, and the catch limit was simply 90% of the estimated MSY catch.

Due to the assumption that the population was initially stable at unexploited level, the juvenile and adult natural mortality rates and the pregnancy rate are inextricably entangled in the model. This occurs because the recruitment rate to the mature female population must equal the adult natural mortality rate, regardless of the pregnancy rate, at the unexploited level. The juvenile mortality rate is then calculated from the adult natural mortality rate and pregnancy rate via a balance equation. Consequently the unexploited pregnancy rate was held constant throughout at 0.20, while the adult natural mortality rate was varied between 0.05 and 0.06. Only the range of possible pregnancy rates was varied, upper limits being 0.25 and 0.23.

In addition, three values of the density dependence exponent were used: 0.0, 1.4 and 3.0. These values correspond respectively to female MSY levels (in absence of male exploitation) of 50%, 60% and 67%. Also three reserve male ratios were employed: 0.3, 0.5 and 1.0. These correspond to a requirement of an average of 2.0, 2.25 and 3.0 mature males per breeding school of 15 females.

In each case, the MSY calculated was that providing the maximum total catch in numbers of males and females. The resulting estimated catch limits are presented in Table 1.

DISCUSSION

In the first section of Table 1 we see that as the natural mortality rate (M) increases, the relative female MSY catch increases, while the relative male MSY decreases. However, the estimated initial mature female population level increases also with increasing M , reinforcing the increase in relative female MSY, while compensating to some extent for the decrease in relative male MSY. Thus as M increases the allowable female catch increases markedly, while the allowable male catch stays relatively constant. This effect is also apparent in the second section of Table 1.

Comparing the first two sections of Table 1, we see that decreasing the range of pregnancy rates (p) leads to dramatically reduced female catch limits, but again relatively constant male catch limits. In the third section, there is again a large variation in estimated female catch limits with increasing density dependence exponent (Z), while the male catch limits remain steady. Only in the fourth section dealing with varying reserve male ratio does the male catch limit change markedly, while in this case the female catch limits are relatively unaffected.

Strictly speaking these results apply only to this particular set of relative abundance data. However, the general behaviour is typical of the situation in which catch limits are estimated for a stock for which both males and females have remained lightly exploited. In this case varying M and p affect both the estimates of relative MSY and initial

Table 1
Results of sensitivity tests on the natural mortality rate (M), pregnancy rate (p), density dependence exponent (Z) and reserve male ratio (R)

Parameter value*	Relative MSY statistics**				Estimated init. mat. fem. pop.	Catch limits	
	Female MSYL (%)	Male MSYL (%)	Female MSY (%)	Male MSY (%)		Female	Male
M = 0.050, p = 0.20–0.25	76.3	32.6	5.9	16.0	61.5	327	886
M = 0.055, p = 0.20–0.25	74.9	34.3	6.9	15.8	63.4	394	901
M = 0.060, p = 0.20–0.25	73.5	36.1	7.9	15.5	63.6	452	888
M = 0.050, p = 0.20–0.23	83.2	34.6	3.3	16.1	61.5	183	892
M = 0.055, p = 0.20–0.23	81.1	36.2	4.1	15.8	63.4	234	902
M = 0.060, p = 0.20–0.23	79.1	37.8	4.9	15.3	63.6	280	877
Z = 0.0	90.5	37.2	1.4	16.8	61.5	79	930
Z = 1.4	76.3	32.6	5.9	16.0	61.5	327	886
Z = 3.0	77.0	33.5	8.2	17.0	61.5	454	941
R = 0.3	76.3	32.6	5.9	16.0	61.5	327	886
R = 0.5	75.4	35.1	6.0	15.0	61.5	332	830
R = 1.0	73.2	40.9	6.3	12.7	61.5	349	703

* In this table, parameters in sensitivity test assume the values M = 0.05, p = 0.20–0.25, Z = 1.4, R = 0.3 unless otherwise stated. Other model parameters are those adopted for Southern Hemisphere sperm whales Divisions 1–8 (IWC, 1977).
** MSY statistics presented here are relative to initial population size, with MSY being calculated to maximise total catch numbers of males and females.

population size, leading to stable male catch limits, but varying female catch limits. Because females have only been lightly exploited, and thus little density dependent change in pregnancy rates will have occurred, varying Z will not affect the population estimate, but will lead to stable male and varying female catch limits. Similarly varying R will only affect relative MSY estimates, leading to stable female but varying male catch limits.

If we were to examine the sensitivity of catch limits to changes in parameters for a stock near the lower end of the Sustained Management category, the picture will be confounded by the sharp decline in recommended catch limits for stocks below MSY level. An indication of the likely direction of such effects may be obtained by examining

the relative female and male MSY level columns in Table 1. The consequences are particularly marked when the estimate of the reserve male ratio varies.

REFERENCES

Allen, K. R. 1977. A computer programme to calculate sustainable yields and fishing mortality for sperm whale populations (SPVAP) of variable size. *Rep. int. Whal. Commn* 27: 263.
International Whaling Commission. 1977. Report of the sperm whale meeting, La Jolla, 1976. *Rep. int. Whal. Commn* 27: 245.
Kirkwood, G. P. 1978. Maximum likelihood estimation of population sizes using catch and effort data. Paper SC/30/Doc 12 presented to the IWC Scientific Committee, June 1978.
Kirkwood, G. P. 1980. A note on the modelling of sperm whale pregnancy rates. Paper SC/30/Doc 14 (published in this volume).

Some Comments on Density Dependent Factors in Sperm Whale Populations

Daniel B. Botkin², David S. Schimel², Lilian S. Wu³ and William S. Little, Jr.⁴

ABSTRACT

Previous models of the population dynamics of the sperm whale (*Physeter catodon*) make use of density dependent relationships that have little basis in fact or theory. Competition for food is often given as the mechanism underlying density dependent population regulation, but the search by males for females may also produce density dependent population responses. A new model is presented that takes aspects of such search behavior into account. The model suggests that such factors would require more conservative management policies. Empirical research needed to determine the actual importance of search behavior in population regulation is discussed.

SOME COMMENTS ON DENSITY DEPENDENT FACTORS IN SPERM WHALE POPULATIONS

The lack of knowledge of the population dynamics of the sperm whale (*Physeter catodon*) poses major problems for the management of this species. Of crucial importance to the determining of harvesting rates are knowledge of density dependent mechanisms such as changes in reproduction and mortality with changes in total population size, or with the sex ratio.

It is customary in models now applied to sperm whale management to define the relationship between pregnancy and density by the general equation:

$$p_B = p_0 - (p_0 - p_u)(B/B_u)^{1+n} \quad (1)$$

where p_B is the pregnancy rate at the population level B ; p_0 and p_u the rate at zero and unexploited levels respectively; B_u the population size at unexploited levels and n is defined as a density dependent exponent (Allen and Kirkwood, 1977). B is measured variously as total biomass, total female biomass or mature female biomass. Population number is sometimes used instead of biomass.

The number of males is assumed to have no effect on the pregnancy rate unless the number falls below that required to serve the mature female population (essentially one harem master per pod). If the male population falls below this level, then the relation between pregnancy rate and male population density is assumed to be linear, according to the equation:

$$p' = p_B (MP/MR) \quad (2)$$

where p' is the actual pregnancy rate; p_B the pregnancy rate when the number of males is at or above MR , the minimum level required for the female population and MP is the actual adult male population size (Allen and Kirkwood, 1977).

The assumptions underlining equations (1) and (2) have little basis in observations, nor can they be inferred readily from actual biological mechanisms.

Lacking direct evidence of such density dependent mechanisms, we can gain some insight by making use of our knowledge of the natural history and social behavior of the sperm whale. How might the pregnancy rate change

with the density of adult males, adult females, and the ratio of the sexes? To consider this, we have devised a stochastic model of certain aspects of the social behavior and population dynamics of the sperm whale. This model assumes that the sperm whales are divided into the following social groups: pods made up of adult females and young of both sexes; harem masters associated with specific pods; adjacent males, who remain on the breeding ground during the breeding season, and who can become harem masters if an existing harem master dies; and migrating males, who leave the breeding ground during the breeding season (Ohsumi, 1971).

Analytical solutions can be obtained under certain restricting assumptions (see Appendix II and Beddington and May, 1980).

For those cases that cannot be treated analytically, we have developed a computer simulation (Appendix I). This assumes that the sperm whales are divided into the same social groups as described above. The model represents a portion of the ocean, with the whales distributed in it (see Fig. A). The ocean is defined as a rectangular matrix, with each element containing two probabilities, the first the probability that an adjacent male will move left (or negative) in the X direction, and the second the probability the adjacent male will move down (or negative) in the Y direction. Each individual is defined by its age, sex, social category and location. A pod is defined by a location and the numbers of individuals of each age and sex within it. Each harem master is associated with a pod, while the adjacent males search the breeding ground for pods without harem masters. At daily intervals, each individual is subject to a risk of death, and the adjacent males move within the breeding ground, (with a maximum distance of one unit in each of the X and Y directions).

Since it is known that sounds emitted by sperm whales can be heard for considerable distances (thought to be of the order of 10 or 20 miles under optimum conditions, Mitchell, pers. comm.) the search by an adjacent male for pods is not completely random. Pods serve as 'attractors', and the probability that a male will move toward a pod increases as he nears the pod. Outside of the range of attraction, the probability of adjacent male movement in any direction is 0.5. We also assume that there is a small

¹ The research was supported by the Whale Protection Fund

² The Ecosystems Center, Marine Biological Laboratory, Woods Hole, Massachusetts

³ I. B. M. Thomas, J. Watson Research Center, Yorktown Heights, New York

⁴ Woods Hole Oceanographic Institute, Woods Hole, Massachusetts.

chance that a migrating male will return to the breeding grounds during the breeding season and become an adjacent male.

The dominance of a harem master over a pod is modeled in the following manner. When an adjacent male reaches a pod that has a harem master, the adjacent male is moved 20 miles (two units) away in a direction chosen randomly.

The breeding season is divided into k intervals, and conception of each susceptible female determined stochastically within each period. Whether a conception is successful is determined at the end of breeding season, and depends on whether harem masters were present for a sufficient time (which can be varied by a user of the model) and of course, on the survival of the females. Thus the pregnancy rate is defined by a maximum probability that is decreased according to search success, the time harem masters are present, and the survival of the adult females.

The model assumes that the sperm whales are organized into four social groups, and that search for pods takes place within the breeding grounds by adjacent males according to a matrix of probabilities, and that the ocean is represented by a rectangular matrix of these probabilities. The model is free of both qualitative and quantitative assumptions concerning the form of density-dependent mechanisms. This geographic model allows examination of the effects of searching time by adjacent males on fecundity. It can be used to compare the pregnancy rates as a function of total density, male density, female density (and thus the sex ratio) under the entire spectrum of possible social behaviors that have been discussed above. Although the model is clearly an oversimplification of real social behavior, it is useful for a consideration of certain qualitative shapes of density dependent relationships in spite of our great lack of empirical information about the sperm whale.

For example, one of the crucial ambiguities in our knowledge of the sperm whale social behavior concerns the role of the harem master. If the integrity of the pod depends on the presence of the harem master, then if the harem master dies, the pod might disperse and not reproduce, even if insemination had taken place. On the other hand, if the integrity of the pod is maintained by the females, then the harem master may be necessary only for insemination, and need only be present with the pod for a short time. This leads us to operate the model in two modes. In the first the integrity is assumed to be maintained by the females, and the pregnancies are successful if the pod had a harem master of some minimum time period required for successful insemination. In the second mode, pod integrity is assumed to depend on the harem master, and a pod must have a harem master for most of the breeding season for pregnancies to be maintained.

Parameters open to change by a user of the model include the initial age structure of the pods, the first year and adult mortality rates, ages of maturation, probabilities of movement in any direction from any point by adjacent males, and the probability of migrating male return to the breeding grounds during the breeding season.

We have operated the model making assumptions found in the literature on sperm whales, including a 15-month gestation period and a natural adult probability of annual mortality of 0.05 (Ohsumi and Fukuda, 1972). Initial conditions represent a population with an age structure approximating equilibrium conditions for these probabilities. Pods are randomly located within the breeding grounds. Other parameters are given in Table A.

Figs 1, 2 and 3 show the results of the model as the density of adult males and adult females change. Pregnancy rates are those measured at the start of the breeding season, and are, therefore, the minimum that would be observed during the year. For all simulations, a maximum pregnancy rate of 20% was assumed. Higher maximum rates would raise the curves, but not change their shape. In each trial, the simulation was run for ten years, and the average calculated. Each point on a graph represents the mean of a small number of replicates. (Time constraints prohibited obtaining a larger number of replicates.)

Fig. 1 shows the relation between pregnancy rate (the percent of adult females pregnant at the beginning of the breeding season) as a function of changes in adult female density. The figure shows that the percent pregnancy increases as female density decreases. It is interesting that

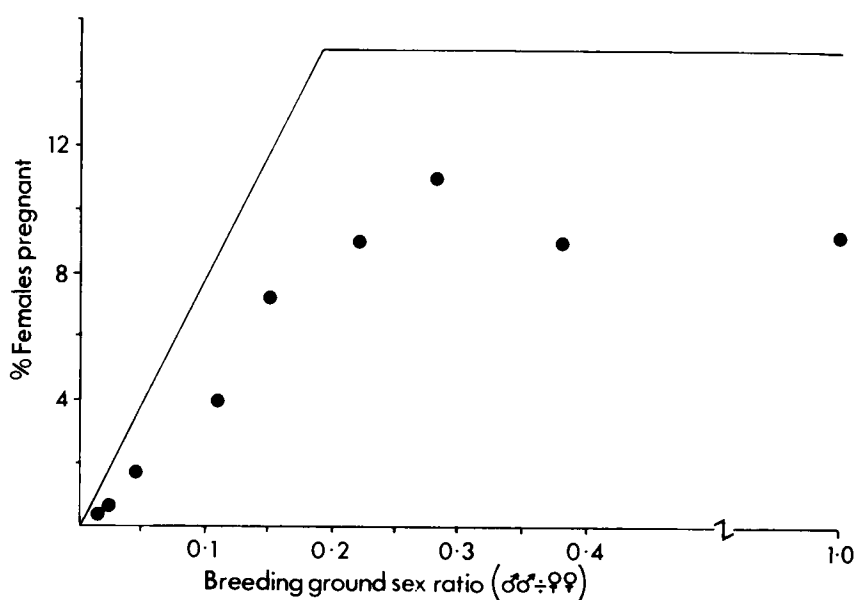


Fig. 1. Effect of changing sex ratio on percent females pregnant. Points represent results of the whale search model. Each point represents an average of three 10 year runs. The maximum pregnancy rate in all runs was assumed to be 20%. The solid line is the prediction of the Allen model, assuming 1.5 males per pod of 10 females. (See equation 2)

this inverse relationship is consistent with observations for some baleen whales, and with the assumptions made in some previous models for sperm whales (Gambell, 1972). However, the usual explanation for this inverse relationship is that food becomes limiting as the population of females increases, resulting in a decline in health status and reproductive success.

Our model shows that another explanation, the search problem, is sufficient to account for such a relationship. As the number of females declines, but the number of adult males remain adequately constant and high, the probability that an individual female will mate increases. To us, food limitation seems an unlikely factor at low population densities, and the search problem a more reasonable explanation, particularly for those populations that have been reduced considerably below the carrying capacity of their environment.

Fig. 2 illustrates the relation between pregnancy rate and adult male density when the female density is maintained constant and high. For this case, our model gives results at variance from the assumptions of equation (2), used in current calculations of allowable catch. In contrast to that

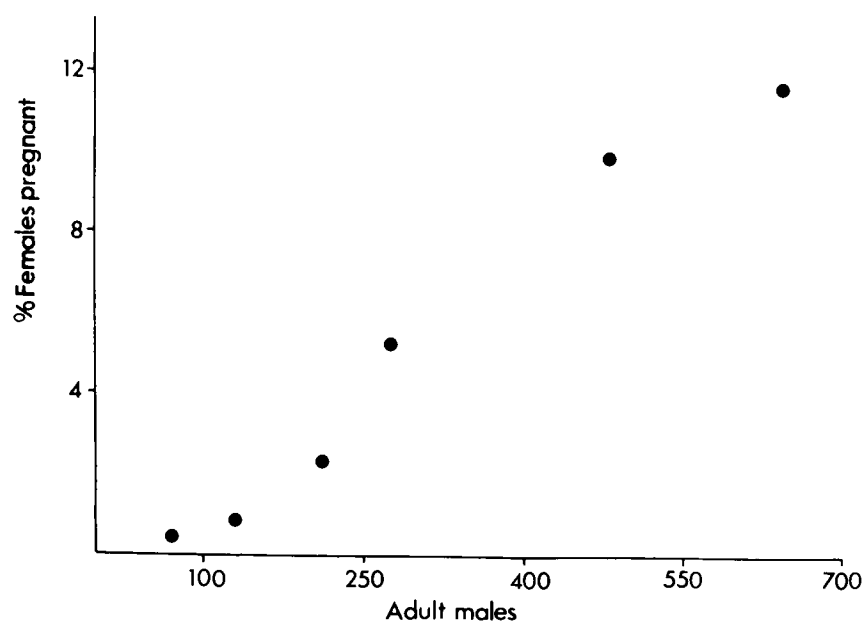


Fig. 2. Effect of total male population size on percent females pregnant. Points represent the average of three 10 year runs. Maximum pregnancy was assumed to be 20%. Initial male population was set at 760 in all runs. Initial female population was varied.

equation, our model indicates a curve resembling a logistic. In terms of the model, this curve has the following explanation. At very low male densities, so few pods have harem masters and so much time is taken up by the adjacent males in their search for pods, that a unit change in male population density has little effect on total pregnancy rate. As the male density increases, a point is reached where the average search success begins to increase rapidly, and the pregnancy rate rises rapidly. Finally, at very high male densities a saturation effect is observed.

II. Implications

The results we have discussed suggest that certain changes should be made in the models currently used by the IWC in determining the allowable catch of sperm whale. The primary qualitative conclusion is that inclusion of the male search problem implies that a more conservative policy (lower quotas) are required.

Although both the model currently used (the Allen Model) and the Whale Search Model imply that the percent pregnancy among adult females increases with decreasing adult female population size, the shapes of the curves in the two models are qualitatively different; one is concave and the other convex (Fig. 3). The Allen Model implies that a density dependent effect would be strong and readily observable at high adult female population levels, and would be asymptotic to a constant value at low population levels. The Whale Search Model implies that the percent pregnancy would fall rapidly with increases in population at low population levels, but would be asymptotic to a constant value above 50% of the maximum population size. Thus above this point, often considered to be the point of maximum sustainable yield (MSY), there would be little change in percent pregnancy with considerable changes in the number of females. According to this model, when density dependent effects were readily observed, the population might be already reduced to levels so that the species might be threatened. The Allen Model implies the opposite: that observation of a density dependent change in percent pregnancy would mean that the population was at a level above one-half of the carrying capacity. The Whale Search Model implies that failure to observe a change in the pregnancy rate would not imply that the population level was constant. The population size might in fact be large, but decreasing rapidly.

Similar differences occur between the two models in regard to the relation between percent pregnancy and the breeding ground sex ratio. The assumptions of the Allen Model imply that no change in the percent pregnancy would be observed until the male population dropped below the number required to service the females (estimated to be approximately a male/female ratio of 0.15). Below this, a linear decrease would be observed.

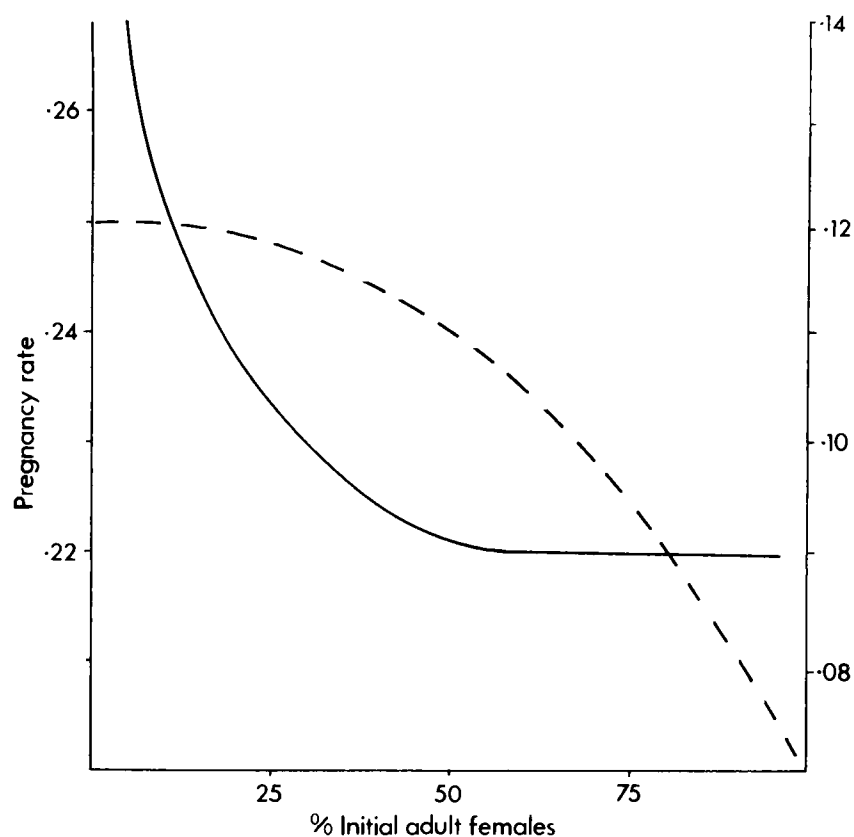


Fig. 3. Effect of decreasing female population on percent females pregnant. Solid line represents the results for the whale search model, and uses the right-hand Y axis. Dashed line represents the results from the Allen model using the relation:

$$\text{Pregnancy rate} = 0.2 - (0.2 - 0.25)(B/B_u)^{1+1.4}$$

(see equation 1)

The Allen model uses the left-hand Y axis. Initial female population was set at 1,200 in all runs. Initial male population was varied.

Fig. 3 suggests that the Whale Search Model gives a more conservative projection, requiring more conservative management. It implies that the pregnancy rate would begin to decrease at much higher ratios, and the pregnancy rate would be lower than that projected by the Allen Model at low male/female ratios.

This model was developed in an extremely short time and has been used to date with a relatively small number of parameter values. Our results suggest that changes in parameters do not change the shape of the curves, or the general qualitative results. However, the model should be operated with many different parameter values to determine the generality of its behavior, and its sensitivity to parameter change.

To date this model has only been used to explore alternate models of whale social behavior. As such, it is useful for examining the consequences of assumptions found in current literature and models. For this model to be realistic more data on sperm whale behavior must be gathered. Two areas, the behavior of the harem masters, and of the adjacent males must be studied. The role of the harem master must be determined. It must be known whether one individual remains with a pod for the entire

breeding season or if there is exchange with the adjacent males. The effect of removing a harem master from a pod must be learned; does the pod often disperse or remain together awaiting a new male? Finally, it must be known to what extent the size or age of the male affects the female's receptivity to him as a mate.

Concerning the role of the adjacent males, one would want to know the rate with which they encounter pods of females. This might be done directly, by observing the frequency of encounters, or indirectly, by knowing the time and distances adjacent males cruise. The (perhaps size dependent) behavior of adjacent males and pods during an encounter must also be known. From such data the effects of searching behavior and the size structure of the population on reproductive rate may be more accurately modeled.

Of particular importance are the following specific observations of the behavior of whales, from which more realistic parameters could be derived. Required observations include: (1) the average time per day spent 'cruising' by adjacent males, as well as the average time spent feeding, resting or in other non-search activities; (2) determination of whether the harem master remains with the same pod throughout the breeding season (requiring techniques to recognize individual whales); (3) the percentage of encounters between a harem master and an adjacent male resulting in (a) the harem master being replaced (b) the adjacent male starting a new search (c) the adjacent male being rebuffed, but remaining near the pod (and the average time occupied by such events); (4) the frequency of

encounters between a pod and adjacent males; (5) the patterns of search behavior by adjacent males; (6) whether (and in what number) migrating males returned to the breeding grounds during the breeding season; (7) a more exact measure of the distance over which sperm whale sounds can be heard.

The behavioral observations require observers who remain near to individual pods and males for extended periods during the breeding season. The studies are non-destructive and adequate results could be obtained in two years.

REFERENCES

- Allen, K. R., and G. Kirkwood. 1977. A sperm whale population model based on cohorts (SPCOH). *Rep. int. Whal. Commn* 27: 268-71.
- Beddington, J., and May, R. 1980. A possible model for the effect of adult sex ratio and density on the fecundity of sperm whales Paper SC/30/Doc 4 (published in this volume).
- Gambell, R. 1972. Why all the fuss about whales? *New Scientist* 54: 674-6.
- Mitchell, E., 1977. Sperm whale maximum length limit. proposed protection of 'harem masters'. *Rep. int. Whal. Commn* 27: 224-5.
- Ohsumi, S. 1971. Some investigations on the school structure of sperm whale. *Sci. Rep. Whales Res. Inst., Tokyo*. 23: 24-25.
- Ohsumi, S., and Fukuda, Y. 1972. A population model and its application to the sperm whale in the North Pacific. *Rep. int. Whal. Commn* 22: 96-110.
- Ohsumi, S., Masaki, Y. and Wada, S. 1977. Seasonal distribution of sperm whales sighted by scouting boats in the North Pacific and Southern Hemisphere. *Rep. int. Whal. Commn*. 27: 308-23.

APPENDIX 1

INTRODUCTION TO WHAL2

WHAL2 is a model of sperm whale population dynamics which incorporates the influence of the sperm whale's social structure and geographic distribution. The model is in two main parts, a geographic model and a population model. A second program W10 is used to initialize the 'map' and population.

Geographic model

The model includes a representation of a portion of ocean, with whales distributed over it. The area modeled is 1,000 miles by 500. The density of whales is set at approximately 1/250 square miles. This figure is derived from Ohsumi *et al.* (1977), and is slightly higher than the figures they give.

The model represents the ocean as a grid of probabilities over which the adjacent males move. Each point on the grid contains two probabilities. The first is the probability of moving left (or negative) in the X direction. This is normally 0.5. The second is the probability of moving down in the Y direction. This is also normally 0.5. Adjacent males will thus move randomly over the grid. The probabilities are, however, altered in the vicinity of a pod. This is to simulate communication between sperm whales by low frequency sound. Standard runs of the model assume a detection distance of 20 miles (Mitchell, pers. comm.). The probabilities of moving towards the pod increase steadily from that distance inwards towards the pod. Adjacent males will thus tend to move towards a pod when they are near one.

If a male reaches a pod which has a harem master it is moved 20 miles away in a direction chosen randomly. This geographic model allows examination of the effects of searching time by adjacent males on fecundity.

Population structure and fecundity

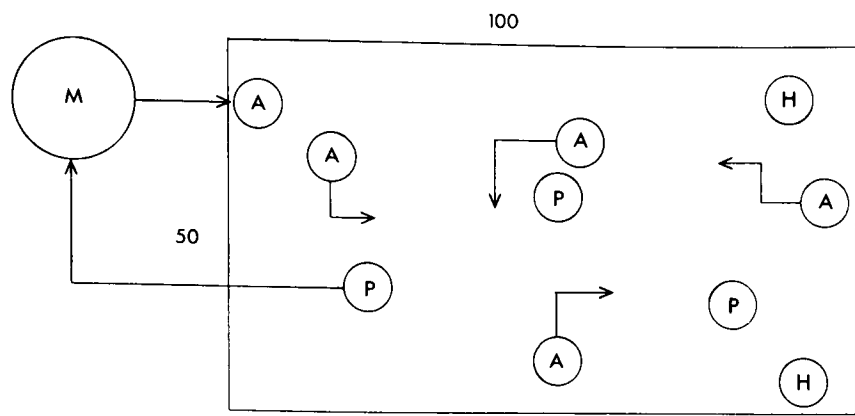
The sperm whale population is divided into three segments in WHAL2. First are migrating males. This is a pool of males not present on the breeding grounds, but with a certain probability of entering the breeding grounds. These males are all over 25 years old and therefore are socially and sexually mature (Mitchell, 1977). Standard runs assume a 0.01 probability/year of return during the breeding season for these males. If they enter the breeding ground they become adjacent males.

Second are the adjacent males. These are males over 25 years. They are distributed over the breeding ground. They move over the geographic grid, and if they encounter a pod without a harem master, they may become the harem master.

Third are the pod members. There are several types of pod members, mature females, pregnant females, harem masters, and immature males and females. The young are assumed to be half male and half female. At age 13 the male young leave the pod and enter the pool of migrating males. The period of gestation is assumed to be 15 months.

Pregnancy is subject to several conditions. Females may not become pregnant until they are thirteen years old,

Fig. A. Game overview



Legend: (P) = pod without a harem master
 (H) = pod with a harem master
 (A) = adjacent male (searching)
 (M) = migrating male (not searching)

each (P) = adult females
 + immature males and females
 + very young males and females (1 year old or less)
 + unborn calves (i.e., pregnancies)

each (H) = same as (P) plus 1 harem master

Motion:

- (1) = (M)'s join the search by becoming (A)'s
- (2) = when immature pod members grow up they join the (M) pool if they are males (50% of the time)
- (3) = (A)'s do a random walk which is biased toward (P)'s and (H)'s by a certain probability field.

although this parameter is easily altered. They may not become pregnant unless the pod of which they are a member has a harem master. The probability of conception is an input parameter. Specifying an appropriate value for the above parameter allows the four year breeding cycle that includes a 15 months gestation, one year lactation and one year rest to be simulated. Standard runs of the program used a probability of 0.2 for conception.

This size and age structure of each segment of the population is controlled at program initialization. The age distribution may be broken down into as many classes as is desired. The number and size of pods can be controlled and several different size ranges of pods may be specified.

Initial distributions and mortality

Different mortalities may be specified for six different segments of the population: migrating males; adjacent males; harem masters; entire pods; adult females; and young. By specifying a probability for whole pods the effect of catcher boats harvesting entire pods can be simulated. The other probabilities allow the simulation of natural mortality or differential catcher-boat induced mortality. In standard runs of the model, first year

Table A
Standard Parameter Values

Annual probability of:	A	M	H	P	F	Y
Mortality	0.05	0.05	0.05	0.0	0.05	0.1
Pregnancy	0.0	0.0	0.0	0.0	0.2	0.0
Entrance to map during breeding season	—	0.01	—	—	—	—

Length of breeding season = 120 days
 Minimum age of pregnancy = 13
 Maximum age of pregnancy = 89

A = adjacent male, M = migrating male, H = harem master, P = pod, F = females, Y = 1 year olds.

Standard probabilities of male movement in the X, Y direction near to a pod are:

.7, .3	.7, .3	N, .3	.3, .7	.3, .3
.7, .3	1., 0.	N, 0.	0., 0.	.3, .3
.7, N	1., N	POD	0, N	.3, N
.7, .7	1., 1.	N, 1.	0., 1	.3, .7
.7, .7	.7, .7	N, .7	.3, .7	.3, .7

Where N means no move in this direction is permitted. A male makes a move in the X and Y direction in each time period.

mortality probability is 0.1, all other age classes = 0.05 and pod mortality = 0.

The initial age distribution was computed for a population with a 0.05 annual mortality. The number of individuals and age distribution can be specified for migrating males, adjacent males and pod members. Experiments were performed by varying the density of various parts of the population.

Program notes on WHAL2 and W10

WHAL2 and W10 run as interactive programs on a DEC PDP-11/34 under RSX-11 V3.0. Both are written in FORTRAN and require a minimum of 32k words of memory. Both programs use several non-standard fortran statements to do file 1/0. These could be easily changed.

Program W10 is used to initialize the probability field used in the geographic model and the population distribution in accordance with parameters found in file WPAR.DAT. W10 writes the initialization data to file WINDAT.DAT from which it is read by WHAL2. WHAL2 is the actual simulation. WHAL2 requires several parameters to be entered by the user interactively. These parameters are listed in Table A. The program also requires a random seed and the number of years to run.

APPENDIX 2

The calculation of probability of pregnancy for a breeding ground population divided into pods, harem masters, and adjacent males as a function of breeding ground sex ratios can be obtained analytically under the following set of assumptions. At the beginning of the breeding season,

1. The fraction of pods without harem masters is known and denoted by $\frac{x}{K}$;
2. The ratio of adjacent males to the number of pods is known and denoted by $\frac{1}{K}$;
3. Adult male survivorship is constant during the breeding season and denoted by S . Note that S is a function of minimum number of days a male is to remain with a pod for breeding to occur;
4. Probability of a susceptible female in a pod becoming pregnant depends only on the presence of a harem master; and
5. No search is involved. The probability of a pod having a harem master depends only on the ratio $\frac{x}{K}$.

Assumptions 1 and 2 imply an adult male to adult female density during the breeding season of

$$\frac{K - x + 1}{K \cdot \text{average adult females in a pod}}$$

We denote the two states of a pod at the beginning of the breeding season, absence or presence of the harem master, by AH and PH. Under the above assumptions, the probability that a pod ϕ is in state AH is $\frac{x}{K}$ and the probability that ϕ is in state PH is $1 - \frac{x}{K}$.

We first calculate the conditional probability of ϕ with a harem master present for the minimum duration needed for insemination (denoted by T) conditioned on ϕ being in

state AH. Let S_i be the conditional probability that there are i harem master positions out of K that are vacant at the end of T (The total number of vacant positions is the sum of x and the number of harem master deaths during T). Then

$$S_i = \left(\frac{K-x}{i-x} \right) \cdot (1-S)^{i-x} \cdot S^{K-i}$$

Hence, the conditional probability that ϕ has a harem master at the end of T conditioned on no harem master at the beginning of the breeding season is

$$S \cdot \sum_{i=x}^K \frac{S_i}{i} = S \cdot \sum_{i=x}^K \frac{1}{i} \left(\frac{K-x}{i-x} \right) (1-S)^{i-x} \cdot S^{K-i}$$

Next we calculate the conditional probability that a pod ϕ has a harem master at the end of T conditioned on being in state PH. Let $\hat{S}_i$ be the conditional probability that there are i , including pod ϕ , harem master positions out of K that are vacant at the end of T . Then

$$\hat{S}_i = \left(\frac{K-x-1}{i-x-1} \right) \cdot (1-S)^{i-x} \cdot (S)^{K-i}$$

This implies the conditional probability that ϕ has a harem master at the end of T conditioned on having a harem master at the beginning of the breeding season is

$$S + S \cdot \sum_{i=x+1}^K \frac{S_i}{i} = S + S \cdot \sum_{i=x+1}^K \left(\frac{K-x-1}{i-x-1} \right) \cdot (1-S)^{i-x} \cdot (S)^{K-i}$$

Finally, the probability of a harem master present for pod ϕ is

$$\frac{x}{K} \left[S \cdot \sum_{i=x}^K \frac{1}{i} \left(\frac{K-x}{i-x} \right) (1-S)^{i-x} \cdot S^{K-i} \right] + \frac{K-x}{K} \left[S + S \cdot \sum_{i=x+1}^K \left(\frac{K-x-1}{i-x-1} \right) \cdot (1-S)^{i-x} \cdot (S)^{K-i} \right]$$

Revised Abundance Indices for Sperm Whales off Albany, Western Australia

G. P. Kirkwood* and J. L. Bannister**

ABSTRACT

Two revised series of relative abundance indices for sperm whales off Albany are proposed, based on aircraft sightings data. The reliability of CPUE based abundance indices for the Albany operation is discussed, and some data are presented on the effect of Asdic.

INTRODUCTION

Sperm whaling operations off Albany, Western Australia have involved co-operative aircraft spotting and catcher operations. Detailed statistics of both the aircraft and catcher operations have been collected since 1962, and summary statistics in the form of series of relative abundance indices have been reported (Bannister, 1975, 1977; see also Australian Progress Reports). Recently the detailed statistics and the methods used to derive the summary abundance indices have been re-examined. As a result, revised series of sightings indices have been obtained and catch per unit effort (CPUE) data have been examined.

SIGHTINGS INDICES

During the years 1962–66, a single engined float plane acted as a spotter for catcher boats operating off Albany. Flying in sight of the catcher boat, the aircraft sought sperm bulls of catchable size (35+ft), and on sighting them, directed the catcher boats to the whales and assisted the catching operation from the air. Effectively, the float plane tended to search the area covered by the catching operation only once. In 1967 a twin engined aircraft with much greater range and speed was introduced, and with the increased capabilities of the aircraft came a change in operational strategy.

Sperm whales tend to concentrate on the continental shelf off Albany, and in the main are found to travel east to west along the shelf, passing through the grounds exploited by the Albany station within 24 hours. Catching operations take place on grounds within a day's steaming of Albany. Consequently, from 1967 spotter aircraft tended to actively search these areas within reach of the catcher boats, flying along a standard grid pattern in search of concentrations of sperm bulls. In general this has resulted in the area covered by the catching operation being searched more than once per day. Once located, the catcher boats were directed to the concentrations, the aircraft sometimes remaining to assist during catching. This mode of operation was further enhanced by the introduction in 1970 of advanced direction finding equipment in the aircraft, enabling much more effective direction of catcher boats to the concentrations of whales. More recently, the area of searching has extended to the south and west of those areas searched in earlier years. The areas searched are illustrated in Fig. 1.

Each single whale or group of whales seen is recorded on an aircraft log sheet, whales seen being recorded only once per day. The aircraft is now operated on two shifts, morning and afternoon. The pilot flying the morning shift briefs the afternoon pilot on the whales he has spotted, ensuring that the whales recorded in the morning are not also recorded in the afternoon.

For the float plane operation, the number of bulls seen per flying unit would have given a reasonable index of abundance of bulls in the area of search, since the area searched was generally covered only once. However, with the twin engined spotter plane, an expanding area was searched more than once, with sightings being logged only once. An index of abundance of bulls seen per flying mile obtained for operations of this aircraft would thus tend to underestimate abundance when compared with indices based on a float plane operation. Thus, taken as a whole, a series of bulls seen per flying mile based on both spotter planes would tend to overestimate true declines in stock abundance. This index was the one previously reported for this operation (Bannister, 1975, 1977).

Two alternative revised sightings indices are now proposed, each based on the assumption that the number of "catchable" (≥ 35 ft) bulls seen per flying day is a reliable index of the abundance of bulls over 35 feet in the area overflown. From examination of the daily flying log sheets, an area that was fully covered each full flying day from 1962 onwards was determined. Spotter operations took place at least during the months April to November inclusive each year. Thus the first proposed index series is the annual average number of bulls over 35 feet seen per flying day in the described area during the months April to November. The second alternative series is simply the annual average number of bulls over 35 feet seen per flying day during April to November, regardless of the area covered. There are disadvantages in each of the proposed indices. The restricted area described encompasses virtually the total area searched in the early years, but makes up only a part of the total area searched in later years. Thus there is a possibility that in later years not all the restricted area was searched daily as thoroughly as it was in the earlier years. The average number of bulls seen per flying day in later years may in consequence slightly underestimate the true abundance. On the other hand, since the area searched has increased over the years, the total area sightings index may underestimate any decline in numbers that may have occurred. The two indices are given in Table 1, and the areas encompassed by spotting activities are shown in Fig. 1.

* Division of Fisheries and Oceanography, CSIRO, Cronulla, NSW, Australia.

** Western Australian Museum, Perth, Western Australia.

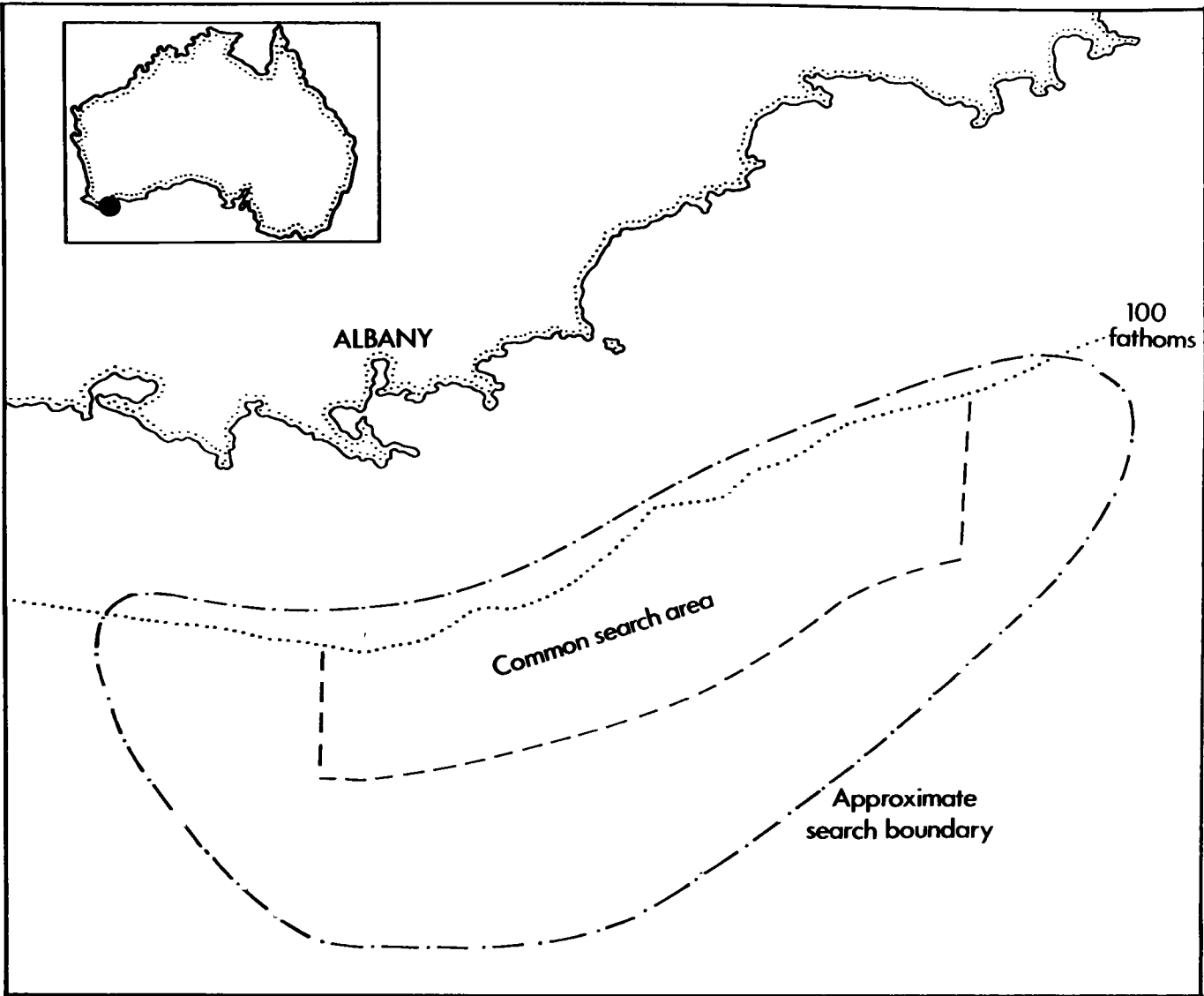


Fig. 1. Aerial spotting search boundaries.

At present no account has been taken of the effects of varying weather conditions on the spotting operations. In particular the tabulations given include all days the spotter plane embarked on spotting activities, even if bad weather conditions on the continental shelf forced an early return to base. Ideally, the indices should include only data for those days when at least the restricted area was searched adequately. This would imply omission of data for those days when either bad weather or the time spent assisting catchers prevented the full restricted area being searched. With regard to the latter point it appears that on average

the time spent assisting catchers is around one half of the time solely spent searching. Table 2 shows the annual proportion of days in which either less than two hours survey, or less than three hours survey in demonstrably bad weather conditions occurred. It is hoped that this effect may be further examined in the future. For the present, however, the low proportion of “ineffective” survey days suggests that any biases are likely to be small.

Table 1
Indices of abundance of “catchable” sperm bulls based on aircraft sightings data between April and November each year

Year	Total seen	No. seen in area	Flying days	Total seen per flying day	No. seen in area per flying day
1962	990	987	116	8.53	8.51
1963	1,345	1,339	138	9.75	9.70
1964	1,484	1,469	153	9.70	9.60
1965	1,173	1,123	138	8.50	8.14
1966	1,185	1,127	146	8.12	7.72
1967	1,174	1,092	132	8.89	8.27
1968	1,521	1,386	128	11.88	10.83
1969	1,717	1,406	153	11.22	9.19
1970	1,670	1,456	141	11.84	10.33
1971	1,673	1,260	151	11.08	8.34
1972	1,753	1,253	174	10.07	7.20
1973	1,317	1,045	140	9.41	7.46
1974	1,246	961	163	7.64	5.90
1975	1,200	1,016	166	7.23	6.12
1976	1,378	1,096	176	7.83	6.23
1977	1,416	954	173	8.18	5.51

Table 2 Average proportions of ineffective searching days (April–November)			
Year	Proportion (%)	Year	Proportion (%)
1963	4.5	1971	4.7
1964	13.3	1972	4.8
1965	5.3	1973	5.3
1966	14.7	1974	4.5
1967	14.4	1975	2.5
1968	11.8	1976	2.3
1969	8.7	1977	6.1
1970	6.0		

It would seem that the appropriate index lies somewhere between the two alternatives proposed. It is suggested that for estimation purposes both indices be used, and a simple average of the estimated initial population sizes be taken as the best estimate. Preliminary studies along these lines suggest that the estimates resulting from use of these two indices are quite close. Due to the change in spotter operations coincident with the commissioning of a new aircraft for the 1967 season, it may also be appropriate to ignore the sightings data for 1962–67 inclusive for estimation purposes, 1967 data being ignored to allow for possible “learning” effects associated with a new aircraft and mode of operation.

CPUE DATA

It appears that in the Albany operation the location of whales subsequently caught is now carried out almost solely by the spotter plane. Because of the nature of the spotting operation, the conventional index of abundance of catch per searching hour is now no longer applicable. We have been unable to devise a reliable index based on catch data for this fishery.

THE EFFECT OF ASDIC

Given the lack of a CPUE-based index of abundance, it is difficult to quantitatively assess the impact of the introduction of Asdic in the Albany operation. However an indication of the effects of Asdic may be obtained from some data on average duration of the period between first sighting of a catchable whale (by the aircraft) and completion of catching and handling of the whale. These data are presented in Table 3.

Table 3
Average catching times

Year	T ₁	T ₂
1963	1.18	1.48
1968	1.37	1.21
1972	1.69	1.10
1977	2.09	1.05

T₁ = time from first sighting by aircraft to first catch for each day (including average handling time).
T₂ = time between ith and i + lth catches during a day for multiple catches from a group of whales.

The dependence of the catchers upon the spotter plane, which now searches often at a considerable distance from the catchers, is illustrated in the first column of Table 3. Despite the introduction of Asdic (1969–71), the average time from first sighting to first catch for each day (including handling time) has increased. This is solely a reflection of increased steaming time to sighted whales in later years over those in the earlier years when the float plane flew closer to the catchers. The added efficiency due to Asdic is seen in the second column of Table 3, where the average time between catches (including handling) from a group of whales has decreased from 1.21 hours to around 1.07 hours between 1968 and 1972–77. The anomalous figure for 1963 may reflect the inexperience of vessel-skipper combinations in the first year of introduction of large catchers into the operation in that year.

Asdic appears to be particularly effective in reducing the catching time of large deep diving bulls. For instance there has been a marked decrease in the number of times the average catching time per large bull has exceeded 3 hours; in 1963 this occurred on 42 occasions but only 9 in 1977 (although the 1963 figure is likely to be higher than expected because of inexperience in handling the newly introduced vessels in that year).

The authors wish to acknowledge the assistance of Miss Helen Sutherland, who carried out some of the basic analyses of the data presented herein.

REFERENCES

Bannister, J. L. 1975. Relative abundance of sperm whales off Western Australia, 1962–73. *Rep. int. Whal. Commn* 25: 90–4.
Bannister, J. L. 1977. Sperm whales off Albany, Western Australia. *Rep. int. Whal. Commn* 27: 355–8.

Pregnancy Rates in Sperm Whales off Durban¹

Peter B. Best

Sea Fisheries Branch, Cape Town, South Africa

ABSTRACT

The incidence of females in early pregnancy in a sample of sperm whales examined at Durban from 1973 to 1975 was higher than in a sample examined about ten years previously. This effect was mainly the result of increased reproductive activity in older females, coincident with a period of intensified exploitation of this sex. The need for large samples in order to adequately monitor changes in the sperm whale pregnancy rate is illustrated.

INTRODUCTION

The model currently used by the IWC to simulate the population dynamics of the sperm whale includes the assumption that the pregnancy rate will increase as the population of mature females is reduced in size (Allen and Kirkwood, 1977). At the 29th meeting of the IWC some questions were raised concerning the appropriateness of this assumption, particularly as there had apparently been no direct evidence of an increase in pregnancy rate in a sperm whale population following exploitation (IWC, 1978).

The sperm whale population off Durban, South Africa, has been subjected to one of the longest histories of continuous exploitation this century in the Southern Hemisphere. Whaling at Durban started in 1909 and ended in 1975, although pelagic fleets still continue to take animals probably belonging to the same stock (Division 3), both north and south of 40°S. Throughout this period female sperm whales have been a regular feature of the catch, and total removals of this sex for Division 3 from 1946/47 to 1974/75 amounted to about 16,600 animals. This exploitation, however, was at a comparatively low level until quite recently: the total annual female catches only exceeded 400 twice prior to 1961/62 and 75% of the total post-war take was removed after 1961/62. According to the IWC assessments, the stock of mature females in Division 3 was at 84% of its initial (1946/47) size in 1977/78, and as such was the fourth most reduced stock of females in the Southern Hemisphere (IWC, 1978).

Extensive collections of biological material have been made at Durban from the 1962 season onwards, and these provide a useful basis to examine whether the intensified exploitation has produced any compensatory change in the pregnancy rate of the sperm whale.

MATERIAL AND METHODS

Under the provisions of the Schedule of the International Convention for the Regulation of Whaling, 1946, member nations are instructed to collect certain statistical information relating to each whale taken by their industry, including 'if it contains a foetus, the length and sex, if ascertainable, of the foetus'. For many years, therefore, whaling companies have provided details of the foetuses found during their operations. However, the stipulation to

collect such information in a systematic manner (i.e. to inspect every female for the presence of a foetus) is not specified in the Schedule, and hence most whaling companies in the past have interpreted this provision by simply recording those foetuses that were revealed accidentally during the dismemberment of the carcass. Although some nations (particularly those who employed biologists as inspectors) were more meticulous than others in collecting and recording such details, the tendency was for only the larger foetuses to be recorded, and many pregnant females went unrecorded. Pregnancy rates calculated from such 'official' statistics would therefore if anything tend to be underestimates. Temporal trends in the recorded pregnancy rates could also be affected by changes in the management of the whaling company and in the personnel employed as inspectors: the effect of biologists working on the flensing platform also usually had the effect of boosting the number of pregnant females recorded. For these reasons the 'official' statistics on the incidence of pregnant females must be interpreted with caution.

From 1962 to 1967, material and information was collected from whales landed at the Durban factory by scientific personnel of the National Institute of Oceanography, UK. This included observations on the incidence of pregnant and other reproductive categories in 1,029 mature female sperm whales (Gambell, 1972). Starting in 1968, responsibility for the collection of material was taken over by the Sea Fisheries Branch of the South African Department of Industries. Whaling inspectors were instructed *inter alia* to record systematically the incidence of pregnant females in the catch. However it was soon clear from the statistics rendered that the number of pregnant females recorded was unrealistically low. Consequently from 1973 onwards inspectors were instructed to collect both ovaries from every female sperm whale landed, and they were informed of the fact that the presence of a corpus luteum in one of the ovaries usually indicated that the animal was pregnant in that horn of the uterus. It was hoped that this would both increase the frequency of reported foetuses and allow some correction to be made for unreported foetuses by inspecting the ovaries collected for the presence of a large corpus luteum. In all, pairs of ovaries were available from 1,127 mature females landed at Durban in the 1973, 1974 and 1975 seasons. After fixation in 10% formolsaline, these were sectioned on a commercial meat-slicing machine and examined as described previously (Best, 1967).

¹ (Revised since the June 1978 meeting)

PREGNANCY RATES CALCULATED FROM OFFICIAL STATISTICS

When interpreting official catch statistics for pregnancy rates it is necessary (in the absence of any direct information) to make some assumption regarding the proportion of the catch that was sexually mature. In this paper it has been assumed that all females 29 feet or more in length were mature, as the body length at which 50% of female sperm whales are estimated to reach sexual maturity is 28 feet (Best, 1968). Because pregnancy in the sperm whale exceeds one year in duration it is also necessary to make a distinction between animals that conceived at the current breeding season (i.e. those in early pregnancy) and those that conceived at the previous breeding season (i.e. those in late pregnancy). In the case of the Durban records this has been done by classifying animals carrying foetuses 9 ft (2.74 m) or more in length from February to July inclusive as in late pregnancy, and all other animals carrying foetuses as in early pregnancy: from an inspection of Fig. 34 in Gambell (1972) this division appears to make an adequate distinction between the two 'year-classes' of foetuses.

The pregnancy rates obtained from official statistics for the years 1968 to 1975 show great variation from year to year and from month to month (Fig. 1). This confirms the reservations expressed above regarding the validity of the data from this source. Some of the variability, for instance, is probably due to extraneous factors: in 1973, where the pregnancy rates appear consistently high, new instructions for the collection of ovaries and the recording of pregnancies were issued to the inspectors, and this almost certainly led to greater care in searching for and recording foetuses.

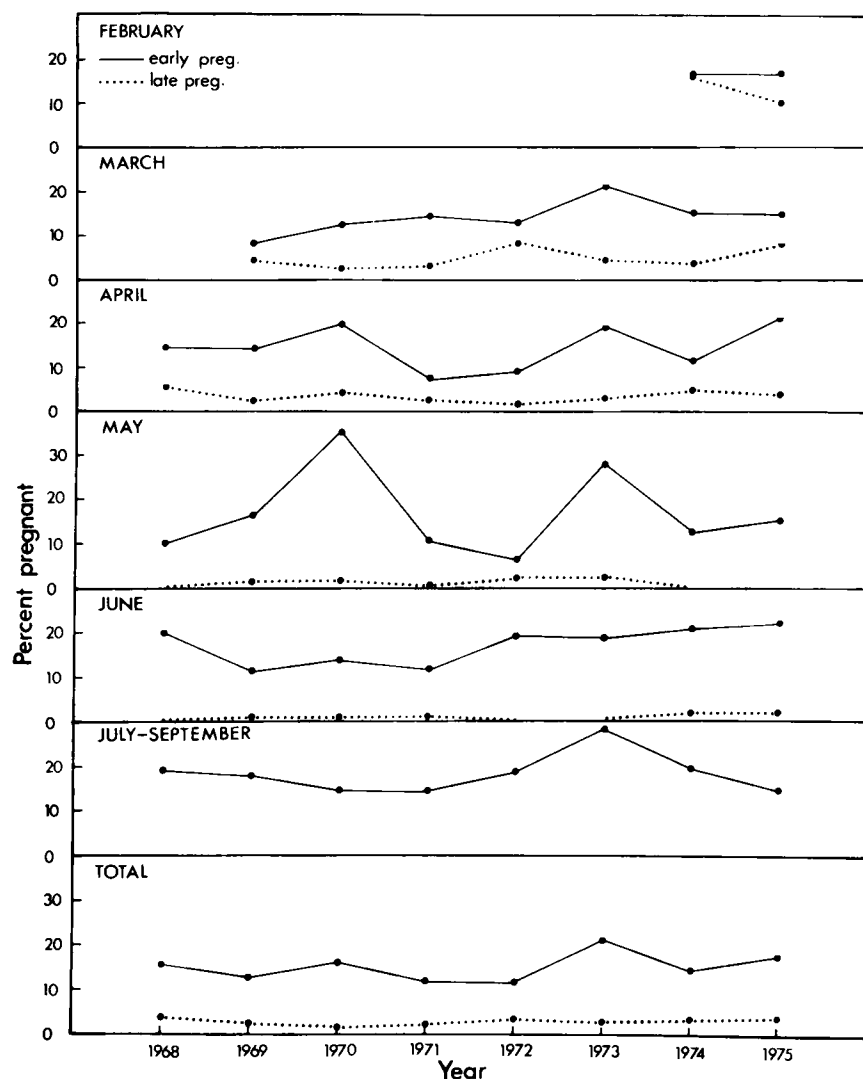


Fig. 1. Pregnancy rates in Durban sperm whales from official statistics.

PREGNANCY RATES CALCULATED FROM BIOLOGICAL COLLECTIONS

In analysing pregnancy rates for animals from which reproductive material has been collected, the criterion of sexual maturity used has been whether the whale has ovulated at least once, irrespective of whether it subsequently conceived successfully. Consequently all animals with one or more corpus luteum or albicans in the ovaries are considered mature. The division used in this paper to distinguish females in early and late pregnancy has been described above: it is assumed that Gambell (1972) used a similar approach although he does not specifically state it.

A comparison of the data collected at Durban in 1962/65 + 1967 and in 1973/75 shows that in every month the proportion of females in early pregnancy was greater in the latter period than in the former (Table 1), although not to a statistically significant extent (chi-square test, $p > 0.05$ for each month). The trend for animals in late pregnancy is not so clear, and although the proportion of such animals is much higher in February in Gambell's data, in subsequent months the proportions do not differ markedly between the two periods.

The pregnancy rates calculated for 1973/75 could also be underestimated. Most of these animals were not examined by biologists so that some foetuses may have been missed or the pregnancy not recognised as such. Several ovaries were in fact collected which bore a corpus luteum but for which no associated foetus was recorded: these animals have not been included as pregnant in Table 1. In an attempt to distinguish between which of these might represent animals that had recently ovulated and which might actually represent pregnant animals, the size of the corpus luteum has been taken as an indicator. The mean size of the corpus luteum of ovulation in sperm whales is given as 5.55 ± 0.95 (S.D.) cm by Best (1967) and 6.11 ± 0.18 (S.E.) cm by Gambell (1972), while these authors give the mean size of the corpus luteum of pregnancy as 7.49 ± 0.86 cm and 7.51 ± 0.06 cm respectively. A value of 6.5 cm seems to exclude most of the ovulating females (Best, 1967, Fig. 7), so that any female with a corpus luteum 6.5 cm or more in diameter but from which no foetus was reported is considered likely to have been pregnant. These animals are entered separately in Table 1, from which it can be seen that they were most prevalent in February and March. As this corresponds in time with the peak of the calving season off Durban (Gambell, 1972), it is conceivable that the majority of these females had either given birth shortly before being killed, or had aborted their near-term foetuses at death or shortly thereafter – Risting (1928) stated that blue whales in advanced pregnancy could lose their foetuses while being towed to the factory. This would suggest that pregnancy rates calculated for animals in late pregnancy may be biased downwards.

In calculating the overall pregnancy rate for the Durban population, Gambell (1972) combined data from females in late pregnancy in February with that from females in early pregnancy in subsequent months, giving an overall pregnancy rate of 18.8%. A more logical method of estimation might be to consider the early and late-pregnant animals separately, particularly as it seems likely that the data from animals in late pregnancy may be biased. Animals in early pregnancy will be considered first. As conceptions can occur as late as May (Gambell, 1972), a correction factor is needed in the early months of the season to account for animals that have still not conceived in the

Table 1.
Monthly incidence of female sperm whales in early and late pregnancy at Durban, based on ovarian examinations.

Month	1962-65 + 1967 ¹				1973-75			
	No. of mature females examined	% in early pregnancy (corrected)	% in late pregnancy (corrected)	% with corpus luteum ≥ 6.5 cm but no foetus	No. of mature females examined	% in early pregnancy (corrected)	% in late pregnancy (corrected)	% with corpus luteum ≥ 6.5 cm but no foetus
February	78	10.3 (11.4)	28.2 (34.9)	9.0	63	20.6 (22.8)	14.3 (17.7)	7.9
March	256	19.1 (19.7)	5.9 (11.6)	2.7	257	20.2 (20.8)	6.2 (12.2)	10.1
April	295	15.6 (15.7)	1.7 (8.2)	1.4	432	19.9 (20.0)	1.9 (9.2)	5.8
May	218	21.1 (21.2)	1.4 (22.2)	1.4	176	22.7 (22.8)	1.1 (17.5)	3.4
June	130	15.4	0.8 (57.1)	1.5	102	22.5	0	2.9
July	52	19.2	0	0	97	19.6	0	5.2
August								
September								
Total	1,029	17.4	4.5	2.2	1,127	20.7	3.1	6.2
Mean (corrected)		(17.1)				(21.4)		

¹ From Gambell (1972 and pers. comm.).

current breeding season. It is suggested that the most appropriate method for achieving this is by using the distribution of conceptions over time calculated for Durban sperm whales (Table 2). The cumulative percentage of conceptions (at the mid-point of each month) will then indicate what proportion of the actual pregnancy rate has been achieved each month. Given the observed pregnancy rate (P') in a particular month (t), the corrected pregnancy rate (P) can then be calculated simply as

$$P_t = \frac{P'_t}{\Sigma_{c_t}}$$

where Σ_{c_t} = cumulative percentage of conceptions at mid-point of month t . These corrected pregnancy rates, using the data for Σ_{c_t} in Table 2, are shown in Table 1. Differences from the observed rates are slight, because 90% of conceptions have occurred by mid-February. A similar, although cruder method for adjusting pregnancy rates was used by Ohsumi (1965).

Similar calculations can be made in an attempt to adjust the proportion of animals in late pregnancy in the catch, using the distribution of births over time. In this case, however, the cumulative percentage of foetuses remaining at the mid-point of each month has been used as the correction factor (Table 2). The corrected pregnancy rates so obtained generally tend to fluctuate widely, and (particularly in the 1973/75 sample) to be lower than those calculated for females in early pregnancy. This could reflect either the bias caused by lost foetuses mentioned above or the sensitivity of the corrected rates to the correction factor used: for months in which a great many births occur (February to early May) a bias may be introduced if the distribution of observations does not fall evenly around the mid-month. Consequently greater confidence must be

placed in the pregnancy rates calculated from females in early pregnancy.

It has been shown above that for individual months there is no statistically significant difference between the observed proportions of females in early pregnancy in the 1962/65 + 1967 and the 1973/75 samples. A more powerful test, however, would be to compare the overall corrected pregnancy rates between the two samples. This has been done by calculating the corrected number of females in early pregnancy in each month and then summing them, producing overall totals of 181 out of 1,029 animals in 1962/65 + 1967 and 235 out of 1,127 animals in 1973/75. These proportions are not significantly different (chi-square test, $0.1 > p > 0.05$). However this is a two-tailed test, and while it is theoretically possible that the pregnancy rate can decline under exploitation if the male:female ratio becomes too disturbed, in a polygynous species such as the sperm whale it seems more reasonable to assume (given the intensive exploitation of females from 1962 to 1975) that the pregnancy rate during this period would have increased rather than decreased. Hence a one-tailed test is considered applicable. Under these circumstances the difference in pregnancy rates is significant ($0.05 > p > 0.025$).

Data in Table 1 also indicate that the 1973/75 sample contained a higher proportion of animals with a large corpus luteum but in which no foetus was found than did the earlier sample (which had been examined by biologists). It is therefore possible that the actual difference in the proportion of pregnant females in the catch between the two samples was greater than was tested above.

AGE-SPECIFIC PREGNANCY RATES

Trends in the pregnancy rate with age for Durban sperm whales have been illustrated by Gambell (1972). Using the

Table 2.
Half-monthly distribution of sperm whale conceptions and births off Durban and the factors necessary to adjust observed pregnancy rates.

Month		% conceptions	Cumulative % conceptions at mid-month	% births	Cumulative % foetuses remaining at mid-month
August,	early	0	0	0	100
	late	0		0	
September,	early	0	0	0	100
	late	0.4		0	
October,	early	0.9	1.3	0	100
	late	3.1		0	
November,	early	7.6	12.0	0	100
	late	13.9		0	
December,	early	15.7	41.6	0	100
	late	16.6		0.9	
January,	early	17.0	75.2	1.3	97.8
	late	9.4		7.6	
February,	early	5.8	90.4	9.4	80.8
	late	4.0		12.6	
March,	early	2.7	97.1	17.5	50.7
	late	1.3		15.2	
April,	early	0.9	99.3	14.8	20.7
	late	0		9.0	
May,	early	0.4	99.7	5.4	6.3
	late	0		2.2	
June,	early	0	(100)	2.7	1.4
	late	0		0.4	
July,	early	0	(100)	0.4	0.6
	late	0		0.4	
August,	early	0	(100)	0	(0)
	late	0		0	

accumulation of ovarian corpora albicantia as an index of relative age, it has been shown that the proportion of animals pregnant in the population is lower in newly mature females than in those somewhat older, but falls to its lowest level in the oldest females. This tendency for the pregnancy rate to be strongly age-specific means that changes in the age composition of the population could produce corresponding changes in the overall pregnancy rate without there being essentially any reproductive response on the part of the population. Thus, for instance, if the oldest females were to be selectively removed, there would be a corresponding slight increase in the overall pregnancy rate of the surviving population, even if fertility, etc. remained constant.

In order to investigate whether the apparent increase in the pregnancy rate off Durban could be attributed to changes in the age composition of the catch or to a reproductive response of the population, the total count of corpora lutea and albicantia in the ovaries has been taken as a relative index of age (Best, 1970), and the proportion of pregnant females at each ovarian corpus number for the period 1962/65 + 1967 has been compared with equivalent data for 1973/75 (Table 3). Apart from the first three corpora numbers, where pregnancy rates in the 1973/75 data are either close to or below the values for the earlier period, thereafter at 10 out of 13 corpora numbers the pregnancy rates for 1973/75 exceed those in the earlier period. This tendency is particularly noticeable in corpora counts above 7: the mean pregnancy rate for animals with 8 to 15 corpora is 14.1% from Gambell's data and 20.6% for 1973/75. This suggests that there was a reproductive

response from the females (and particularly the older individuals) during the intervening period.

The age compositions of the two samples (using the total

Table 3. Age-specific pregnancy rates in Durban sperm whales.				
Age (corpora count)	1962-65 + 1967		1973-75	
	Number examined	% pregnant	Number examined	% pregnant
1	48	20.8	43	20.9
2	60	21.7	72	19.4
3	93	31.2	97	20.6
4	95	20.0	100	27.0
5	85	24.7	115	23.5
6	88	23.9	118	30.5
7	83	30.1	130	26.2
8	82	17.1	80	31.3
9	71	21.1	82	24.4
10	54	18.5	74	18.9
11	51	15.7	52	26.9
12	29	6.9	43	18.6
13	30	13.3	31	19.4
14	18	11.1	24	25.0
15	22	9.1	9	0
16	16	5.7	17	10.5
17	9		5	
18	8		6	
19	3		5	
20	4		2	
>20	13		3	
Total	962		1,108	

corpora counts in Table 3) have been compared in a 2 × k contingency table. If all animals with more than 18 corpora are combined into a single class, the two age distributions are homogeneous (chi-square test, 0.1 > p > 0.05, 18 df). This result indicates that there was essentially no change in the age composition of the sampled population between the two periods.

CONCLUSIONS AND DISCUSSION

The evidence presented here suggests that an increase in pregnancy rate occurred in female sperm whales off Durban between the extremes of 1962 and 1975, corresponding to a period of intensified exploitation for this sex. This increase appears to have been mainly the result of a reproductive response on the part of older females, although the mechanism for this change is still not clear.

In an animal with a very similar social organisation, the African elephant, there is also a tendency for fecundity to be markedly age-specific, and it is apparent that the ‘menopause’ in elephants is density- or habitat-dependent (Laws, Parker and Johnstone, 1975, pp. 226–7).

However the conclusions of this paper should be interpreted with some caution. The values for pregnancy rate are obtained solely from the proportion of that reproductive class in the catch. There is the possibility therefore that observed changes in the pregnancy rate may reflect changes in the composition of the catch rather than in the population, although in this instance I have no reason to suppose that selectivity for or against one or other reproductive class might have changed during the period under consideration. Nevertheless, the absolute values found for pregnancy rates in the catch may not reflect the true rates in the mature female population as a whole, due to consistent segregation of or selection against a particular reproductive class.

A further point of interest arising out of this analysis is that, in order to detect changes in the pregnancy rate of the order expected, large numbers of females must be examined. The sample sizes used in this report (of just over 1,000 animals each) were only adequate to distinguish a pregnancy rate difference of about 3% at the 5% level in a one-tailed test. In many instances, however, a two-tailed test may be needed, for which even larger samples are required to detect differences of the same level of significance.

Monitoring of the pregnancy rate may become an essential part of the IWC’s management of sperm whales. If females are to continue to be harvested, and their only density-dependent response anticipated is an increased pregnancy rate (IWC, 1978), it is obvious that considerable

Table 4.

Sample sizes required in order to detect changes in pregnancy rates of a given order, at the 5% level of significance.

Pregnancy rate in first sample (p ₁)	Pregnancy rate in second sample (p ₂)	Sample sizes required (N)	
		One-tailed test	Two-tailed test
0.20	0.21	8,821	12,517
	0.22	2,245	3,186
	0.23	1,015	1,441
	0.24	581	824
	0.25	378	536
0.20	0.19	8,496	12,056
	0.18	2,082	2,955
	0.17	907	1,287
	0.16	500	709
	0.15	313	444

effort must be expended to ensure that this parameter is monitored adequately. Alternatively, if female harvesting is to stop and male exploitation allowed to continue, it is equally clear that some monitoring of the female reproductive rate will be necessary to ensure that the efficiency of fertilisation is maintained when relative male abundance is reduced. In both situations it is necessary to know the sample sizes required to detect changes in the pregnancy rate of the expected order, given a certain level of probability.

From the chi-square test for a 2 × 2 contingency table, using a two-tailed 0.05 significance level, the required sample size is calculated as

$$N > 1.920 \frac{(p_1 + p_2) (2 - (p_1 + p_2))}{(p_1 - p_2)^2},$$

where N = sample size
p₁ = pregnancy rate in first sample
p₂ = pregnancy rate in second sample.

This function assumes that the two samples are equal in size. For a one-tailed test the equivalent sample sizes can be calculated as 0.705N.

The results indicate that in order to detect significant differences of as much as 5% in the pregnancy rate, samples of about 450–550 animals are required for a two-tailed test (Table 4). Given the order of the anticipated changes in pregnancy rate (from about 20% in an initial stock to 23% at 60% of its initial size), it seems that adequate monitoring would require even larger sample sizes. A possible minimum would be 1,500 animals, which would enable detection of a 3% difference in either direction.

ACKNOWLEDGEMENTS

Collections of ovarian material at Durban were made by K. Botes, J. F. Groenewald, H. S. Huysamen, P. C. B. Jurgens, I. Muir and W. E. van Zyl, with the assistance of B. Mbonambi and P. Mthembu and under the supervision of P. van der Byl. M. A. Meÿer was responsible for sectioning and examining all the material and for sorting and analysing the data from it. P. D. Shaughnessy undertook the statistical analysis for the sample size requirement. To all of these gentlemen I am most indebted. Original data for the earlier Durban sample was kindly supplied by R. Gambell.

REFERENCES

Allen, K. R., and Kirkwood, G. P. 1977. Further development of sperm whale population models. *Rep. int. Whal. Commn* 27: 106–12.

Best, P. B. 1967. The sperm whale (*Physeter catodon*) off the west coast of South Africa. 1. Ovarian changes and their significance. *Investl Rep. Div. Sea Fish. S. Afr.* 61: 1–27.

Best, P. B. 1968. The sperm whale (*Physeter catodon*) off the west coast of South Africa. 2. Reproduction in the female. *Investl Rep. Div. Sea Fish. S. Afr.* 66: 1–32.

Best, P. B. 1970. The sperm whale (*Physeter catodon*) off the west coast of South Africa. 5. Age, growth and mortality. *Investl Rep. Div. Sea Fish. S. Afr.* 79: 1–27.

Gambell, R. 1972. Sperm whales off Durban. *Discovery Rep.* 35: 199–358.

International Whaling Commission, 1978. Report of the Scientific Committee to the 29th meeting of the Commission. *Rep. int. Whal. Commn* 28: 38–92.

Laws, R. M., Parker, I. S. C., and Johnstone, R. C. B. 1975. *Elephants and their habitats. The ecology of elephants in North Bunyoro, Uganda.* Clarendon Press, Oxford. 376 pp.

Ohsumi, S. 1965. Reproduction of the sperm whale in the north-west Pacific. *Sci. Rep. Whales. Res. Inst., Tokyo* 19: 1–35.

Risting, S. 1928. Whales and whale fetuses. Statistics of catch and measurements collected from the Norwegian Whalers’ Association 1922–25. *Rapp. Proc.-Verb. Réunion.* 50: 1–122.

A Rationale for Modifying Effort by Catch, using the Sperm Whale of the North Pacific as an Example

Charles W. Fowler

Department of Wildlife Science, Utah State University, Logan, Utah 84322¹

INTRODUCTION

A commonly used index of population size in fisheries and marine mammal studies is the catch per unit effort (CPUE). It is widely recognized that a good measure of the effort needed to derive this index is difficult to obtain. Additional experience and new technology often add greater effectiveness to the original unit of effort (Rothschild, 1977).

Little attention has been paid to the effect of the catch itself as an influential factor in determining the effectiveness of effort. Basic predator-prey theory often involves the assumption that the rate a predator encounters prey is proportional to prey density and searching time—all else being equal. This paper is an examination of how a similar assumption influences the interpretation of data representing the catch and effort from a fishery by using the sperm whale of the North Pacific as an example.

THE SPERM WHALE CATCHING OPERATION

The Japanese sperm whale fleets consist of factory ships and a group of catcher boats. Historically, the measure of effort for a particular area has been the catcher days worked determined as the sum of the number of days spent working by each catcher boat in that area. The CPUE has then been calculated on the basis of the total catch in the area of question divided by the CDW (catcher days worked) modified by factors to compensate for size of boat, weather, etc. (IWC, 1980).

A more realistic measure of effort would be the number of hours spent searching for whales as modified by other appropriate factors. Ignoring the influence of other factors for the purpose of the argument being developed here, we can develop a simple model of the number of hours spent searching in the following manner. Consider the average 24-hour day spent whaling by the average catcher. This day may be divided into:

- T_R = time spent resting (anchored, etc.)
- T_S = time spent searching
- T_H = time spent handling (various activities associated with turning the whale over to the factory ship)
- T_T = time spent transporting the whale to the ship, and
- T_P = time spent pursuing whales.

From these definitions:

$$\begin{aligned} T_S &= 24 - T_R - t_H C - t_T C - t_P C \\ &= (24 - T_R) - C(t_H + t_T + t_P) \end{aligned} \quad (1)$$

where:

t_H , t_T , and t_P are the average time *per whale* spent in the activities defined above, and C is the average catch per day (whales) per catcher vessel.

As a simple example of the effect of such an adjustment, assume that resting time is a constant (say 9 hours) and that the total whale-specific operating time is 1 hour. We see that if $C = 6$:

$$T_S = (24 - 9) - 6(1) = 9,$$

whereas if $C = 2$

$$T_S = (24 - 9) - 2(1) = 13,$$

an increase in effective effort (as measured by searching time) of a factor of over 1.44!

AN EFFORT MODIFIER

If an average working day is T_W hours in length ($T_W = 24 - T_R$) the appropriate effort modifier to be used in correcting historical data is (again assuming rest time is constant):

$$M = \frac{T_W - C(t_H + t_T + t_P)}{T_W} \quad (2)$$

a linear function of C (Fig. 1). Since this value is always less than one (for any positive t_H , t_T or t_P) all CPUE data used in the past will be adjusted upward by the application of (2). The degree to which they are increased will depend on the catch, the larger the catch the greater the increase. This produces the conclusion that stocks which have been shown to have declined to some fraction of their unexploited levels (or any previous point of reference) (Tillman, 1977) may have actually declined even more than previously thought.

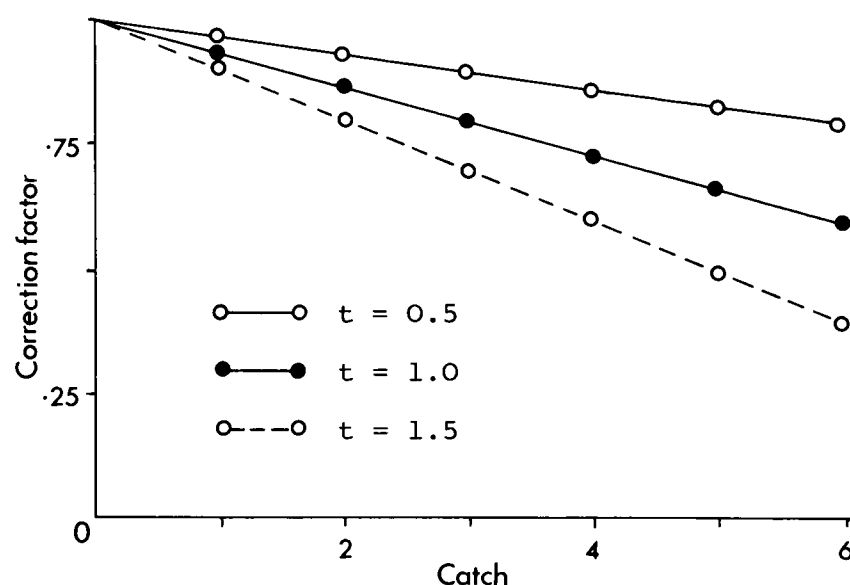


Fig. 1. The correction factor which must be applied to effort as determined by the catch in whales per day per catcher boat as it varies with t (the mean time required to capture an individual whale).

¹ Present address: National Marine Mammal Laboratory, NWAFC, 7600 Sand Point Way N.E., Bldg. 32, Seattle, Washington 98115.

To examine the extent to which this may have happened we may utilize information collected from the Japanese whaling operation in 1977 (Ohsumi, 1980). From these (Japanese) data the following means may be derived:

$$\begin{aligned} T_R &= 9 \\ t_C &= 0.59 \\ t_H &= 0.33 \\ t_T &= 0.2 \end{aligned}$$

for a total of 1.14 hours per whale. Assuming that this value applies across time (i.e., no other additional modifications to increase efficiency) the modifier to be applied for each measure of effort in units of CDW is:

$$M = \frac{15 - 1.14C}{15} \tag{3}$$

The catch per unit of effort for the Central Asian males in 1956 was about 6 whales per CDW and 1972 it was about 2 whales per CDW (Fig. 2). Applying the above correction factor (to make effort have units of catcher-boat-search-time) we estimate about 11.0 whales per unit searching time (15 hours) in 1956 and about 2.3 in 1972. Whereas the former data indicate a decline to about 33% of the former levels the corrected data indicate a drop to 21% (Fig. 2). This is an extreme example. Using data for male sperm whales from Ohsumi, 1980 Fig. 8 (for the entire North Pacific) we see a drop to about 33% (approximately 3 per CDW to approximately 1 per CDW) from 1959 to 1976 (Fig. 3). Applying the correction (3) we would obtain an estimated decline to 28% of the original population.

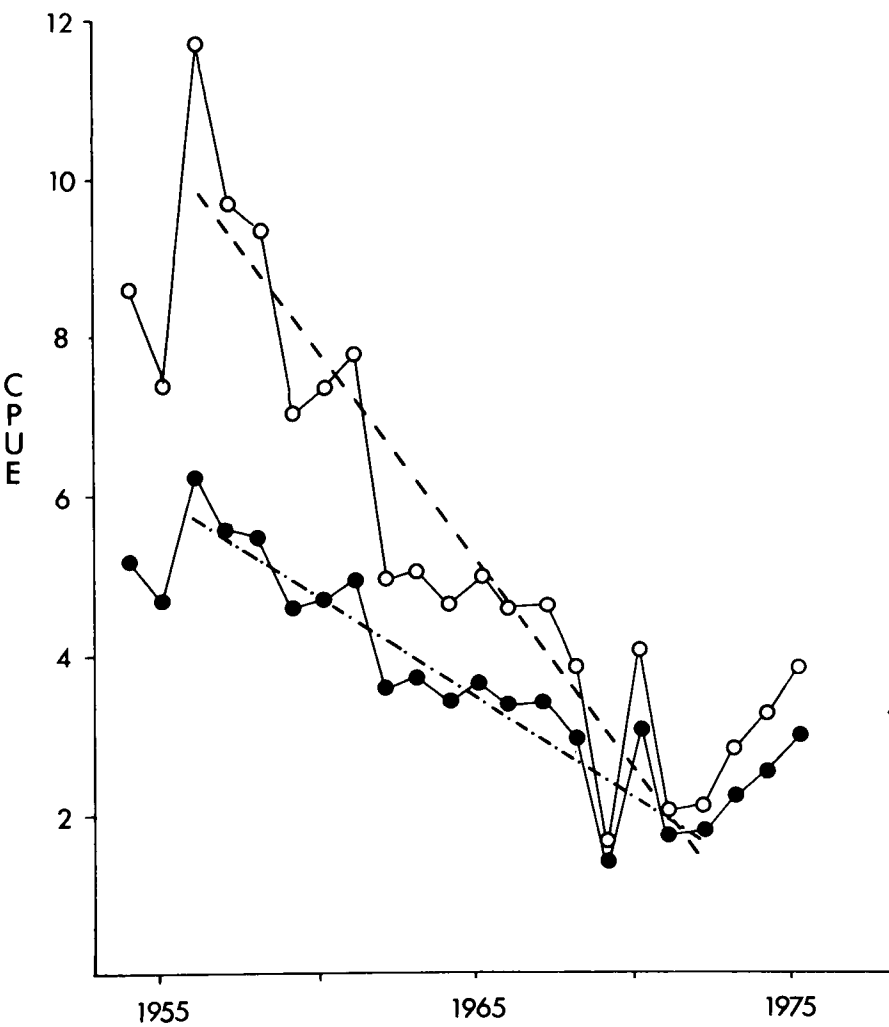


Fig. 2. Catch per unit effort for male sperm whales of the Central North Pacific (Tillman, 1977). The lower plot is Tillman's data and trend as found by regression. The upper plot is for the same data corrected to reflect catch per unit search time.

Fig. 1 is a plot of the correction factors to be applied to measured effort (CDW) as a function of catch (C) for various whale-specific capture times ($t = t_H + t_T + t_P$). As many be noted (and as would be expected) the larger values

of t produce more need for correction when large catches are involved.

An examination of Figs 2 and 3 and the calculations above indicate that the ratio of CPUE at low levels ($CPUE_L$) to that at high levels ($CPUE_H$) as corrected to reflect units of effort in search time will depend on the magnitude of the original ratio as well as the catch. To examine the interaction of catch at various levels, the ratios of CPUE at these levels, and the expected changes in these ratios as a function of whale-specific operating times consider the following:

$$\text{Let } \frac{CPUE_L}{CPUE_H} = R$$

where CPUE is calculated on the basis of CDW uncorrected for catch. This might be, for example, the ratio of current populations ($CPUE_L$ = current low levels) to unexploited populations ($CPUE_H$ = previous higher levels). The corrected value of R is found by the equation:

$$R' = R \frac{15 - t(CPUE_H)}{15 - tR(CPUE_H)} \tag{4}$$

The correction to be applied to R is shown in Fig. 4 as a function of $CPUE_H$ for various values of t and R . As will be noted the correction required becomes more pronounced with increases in t , $CPUE_H$, and with decreases in R . This means that where original indices indicate large historic populations and small current populations the situation may actually be much worse than we think.

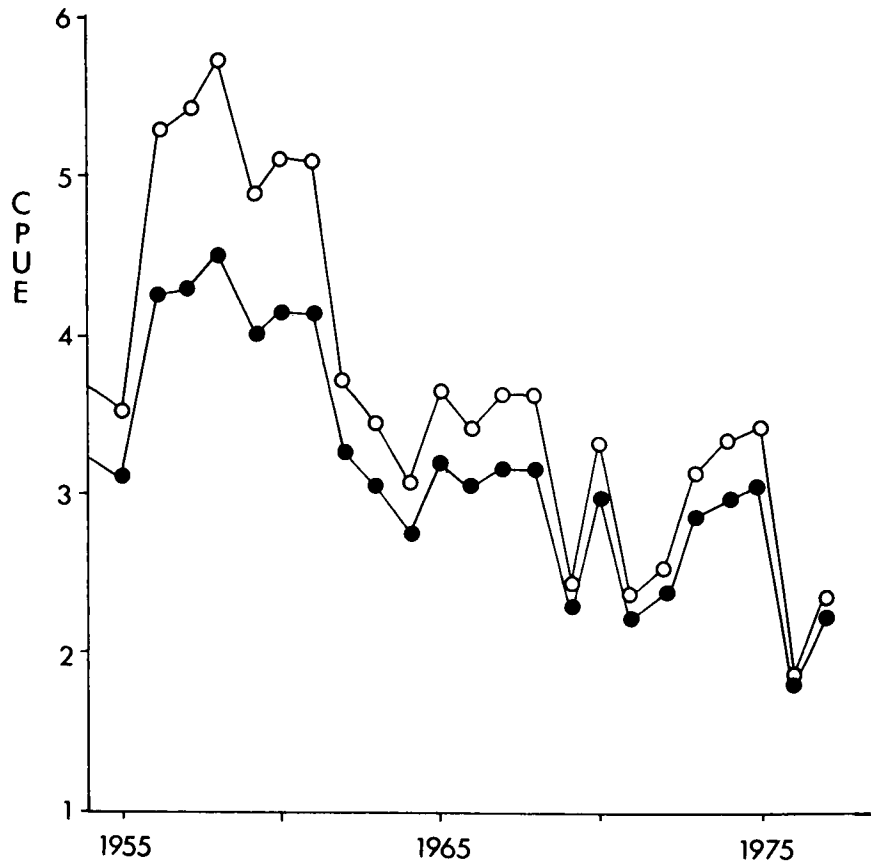


Fig. 3. Catch per unit effort for male sperm whale of the North Pacific taken from Ohsumi, 1979 (bottom) and the same data corrected for catch to reflect catch per unit search time (top).

The application of this kind of modification to CPUE data as shown in Fig. 2 shows that declines may be accentuated. What does the application of this kind of correction do to population estimates? The DeLury method and modifications of it (Chapman, 1974; Allen, 1977), for example, are often used in estimating population levels and in obtaining information for estimating current population levels. To address the question we may examine Fig. 5. This figure contains a plot (straight solid line) of the regression

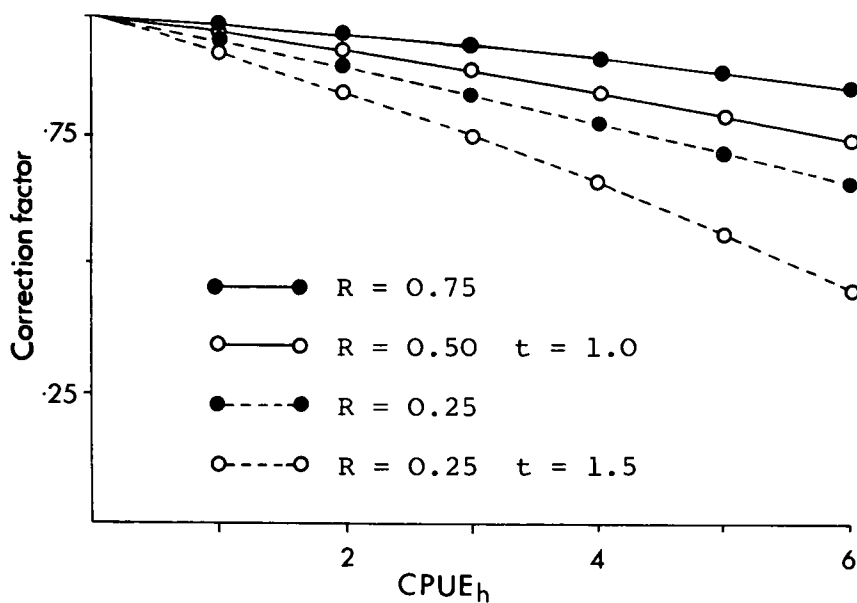


Fig. 4. The correction factor to be applied to the ratios of indices of sperm whale population levels as measured in catch per unit effort (whales per CDW) as a function of the larger value for various initial ratios and whale-specific capture times.

equation found by Tillman (1977) for what he defines as the central stock of male sperm whales of the North Pacific. From this equation it is estimated that there were about 78,775 whales in this stock in 1956.

We may apply the correction for catch (using $T_R = 9$ and $t = 1.14$ in equation 2) to this line to obtain the curved solid line in Fig. 5. The correction indicates (as would be guessed from an examination of Fig. 1) that the greatest effect is seen at high levels of catch. The basic assumption of a linear relationship between CPUE and adjusted cumulative catch may still apply as per the original assumptions of the DeLury technique. Regressions fit to corrected CPUE data, then, will obviously be different from the original. The dashed line of Fig. 5 is an example. This line was fit to the portion of the corrected curve centered at an adjusted cumulative catch of 20,000 whales. Although this is only a crude approximation, such a change obviously creates a reduced estimate of the original population and an increased slope (negative catchability coefficient). In this case the original (1956) population estimate is reduced to about 80% of Tillman's estimate and estimates of 1972 populations are reduced to about 58% of his estimated levels. The corresponding ratios of 1972 population levels to 1956 levels are about 33% for Tillman's approach and about 24% when corrected to reflect catch per unit search time.

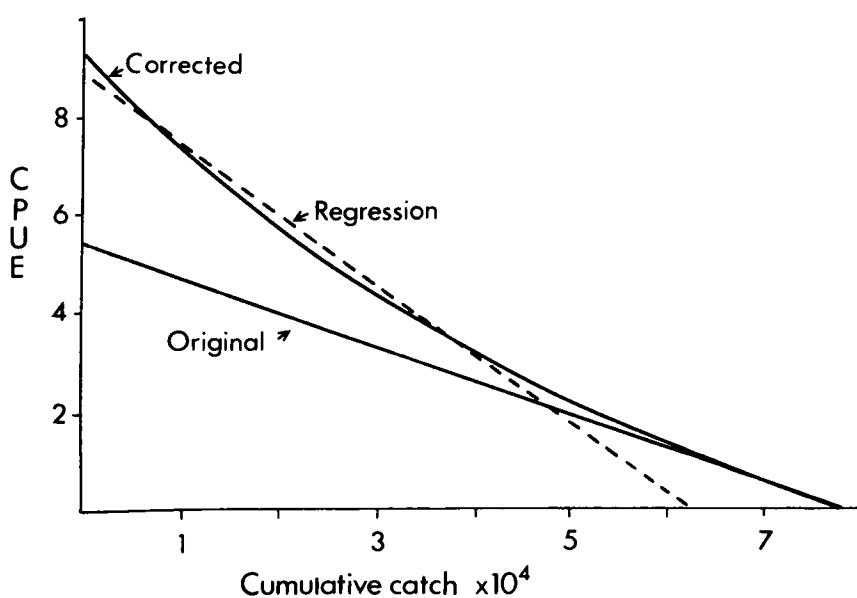


Fig. 5. Changes expected in the application of the modified DeLury method to population data. (See text for details).

Further examination of Fig. 5 shows that the location of the bulk of the CPUE data along the catch axis will determine, to an extent, how different resulting estimates will be (from standard approaches) when corrected for catch. Essentially the slope of the dashed line will be expected to be close to the tangent of the curve at the midpoint of the data. Data concentrated to the left will accentuate changes as discussed above. Data to the right will create less marked differences. Located to the left, CPUE data will indicate lower initial population estimates (through a smaller intercept on the X axis) and lower populations for which the original CPUE is smaller. This happens in the DeLury technique on the basis that the estimates are:

$$\hat{N}_0 = b_0/\hat{q} \text{ and} \quad (5)$$

$$\hat{N}_i = \frac{\text{CPUE}}{\hat{q}} + 1/2c_i, \quad (6)$$

where b_0 is the y axis intercept and q is the negative of the regressive slope. It is not obvious that N_0 will be reduced through correction for search time since b_0 increases. An examination of Fig. 5 shows, however, that increases in q more than compensate for increase in b_0 . Increases in q are also responsible for decreased estimates of the population at later times through (6).

DISCUSSION

That correction for catch is a valid approach to obtaining a realistic measure of effort is intuitively appealing. If no searching occurs no whales will be caught. At a fixed level of searching effort we would expect to see (and hence catch) more whales where they are more abundant. On the other hand, very little search time would be available for populations which are especially dense (and hence giving rise to large catches); most catcher boat time would be involved in catching and delivering the whales it caught. In such cases catcher boat days would be a gross over estimate of real effort. These relationships are all taken into consideration in the approach described here.

If we define the actual catchability coefficient (a) as that derived on the basis of the work presented here then the measured value (q) will be:

$$q = \frac{a}{1 + at \frac{N}{T_w}} \quad (7)$$

where N is the population size (and other parameters as defined earlier). This means q is a decreasing function of the population size (and original CPUE). Allen (1972) presents data for fin whales (Table 2) which when plotted show the general relationship expected from equation (7). Similar decreases have been observed for menhaden (Schaaf and Huntsman, 1972), cod, (Pope and Garrod, 1975) and sardine (MacCall, 1976). Further effects and implications of such relationships are being investigated by the latter author.

Whaling data such as those used here must also be interpreted in view of other factors. Many whaling operations catch species other than those being used for analysis. The catch of these whales should also be used in calculating the effective effort measured in units of search time. It will obviously accentuate the estimated decline in stocks since the early operations took more whales of other

species than are currently being taken. Catches of other whales also take time. As a result, this time is not available for searching.

Other factors which influence the efficiency of effort should also be considered. This is especially true of such advances as the use of Asdic for whaling. This factor creates a decrease in chase time (t_p) and hence will make even more pronounced the estimated declines produced on the basis of data from the fishery. The analysis and estimation of the degree of this change can be handled quite well using equation (2) since it and the subsequent modifications of effort are based on time.

Equation (2) may be written in a general form:

$$M = a - bC \quad (8)$$

Equation (8) may appear to be a first approximation to corrections to be applied to measures of effort for *any* application involving CPUE data. Based on the time-budget approach for sperm whale it would appear both realistic and markedly influential. It obviously can produce marked changes in results obtained from the estimation of population through techniques such as the modified DeLury.

In fisheries involving fish caught by nets it would seem that similar principles would be expected to operate. Unloading nets, restacking, cleaning nets, etc. would all seem to be time consuming activities which would increase with catch thus subtracting from the time available for searching (as for tuna) or towing (in fisheries involving trawls, etc.). These problems (as well as the sperm whale example) are the same as, or highly related to, the problems of 'saturation' as discussed by Rothschild (1977). If (8) is found to hold true in any general sense a great number of fisheries (as well as marine mammal populations) may be (or have been) more overfished than previously believed.

CONCLUSIONS

The approach to modifying measures of effort as outlined above give rise to the following:

1. Considering the number of observed declines in catchability coefficient as functions of population size and/or

CPUE and the intuitively appealing nature of an effort modifier, as described in this paper, may, when implemented, remove some of this stock-related bias. It seems necessary to consider this or similar modifications in the analysis of population data.

2. When the correction described in this paper is applied to the sperm whale of the North Pacific (for which there is data to make first approximations for such adjustments) some very marked changes are indicated relative to the interpretation of these data.
3. Taken as a whole the approach being presented here would indicate that many populations probably do not exist at levels which compare well with the estimates we now have. Many stocks and populations may be at levels substantially lower than we think.

REFERENCES

- Allen, K. R. 1966. Some methods for estimating exploited fish populations. *J. Fish. Res. Bd Can.* 23: 1553-74.
- Allen, K. R. 1972. Further notes on the assessment of Antarctic fin whale stocks. *Rep. int. Whal. Commn* 22: 43-53.
- Chapman, D. G. 1974. Estimation of population size and sustainable yield of sei whales in the Antarctic. *Rep. int. Whal. Commn* 24: 87-90.
- International Whaling Commission. 1980. Report of the Special meeting on North Pacific sperm whale assessments, Cronulla, 21-26 November 1977, (published in this volume).
- MacCall, A. D. 1976. Density dependence of catchability coefficient in the California Pacific sardine (*Sardinops caerulea*) purse seine fishery. *Calif. Coop. Oceanic Fish. Invest. Rep.* 18: 136-48.
- Ohsumi, S. 1980. Criticism of Japanese fishing effort for sperm whales in the North Pacific. Paper SC/SPC/Doc 2 (published in this volume).
- Pope, J. G. and Garrod, D. J. 1975. Sources of error in catch and effort quota regulations with particular reference to variation in the catchability coefficient. *ICNAF Res. Bull.* 11: 17-30.
- Rothschild, B. J. 1977. Fishing effort, pp. 96-115 In: J. A. Gulland (ed.) *Fish Population Dynamics*. John Wiley & Sons, 372 pp.
- Schaff, W. E. and Huntsman, G. R. 1972. Effect of fishing on the Atlantic menhaden stock: 1955-1969. *Trans. Amer. Fish. Soc.* 101: 290-7.
- Tillman, M. F. 1977. Trends in abundance of sperm whale in three areas of the North Pacific. *Rep. int. Whal. Commn* 27: 343-50.

Intraspecies Structural Data of Sperm Whales in the North Pacific

G. N. Veinger

Whale Investigation Laboratory of the Pacific Institute of Fishery and Oceanography (TINRO)

ABSTRACT

The possible existence of separate populations of sperm whales in the North Pacific has been discussed by several authors. A study of external morphology, in this case using the shape of the fluke notch as a distinguishing character, indicates the presence of at least three populations in the North Pacific.

Within the limits of their particular waters, whales are found in groups of various structure and size. Some of these groups are termed "populations" in spite of our insufficient knowledge of their boundaries, dynamics and the causes of their isolation. This ignorance is a very real hindrance to the organisation of rational harvesting. Investigation of the physical characteristics of whales, and especially of those species harvested by the industry, is also necessary because of the lack of general biological knowledge on this subject.

The possible existence of separate populations of sperm whales in the North Pacific has long been of interest to researchers and several authors have expressed different opinions as to the number and location of such populations. According to Sleptsov (1952), those sperm whales migrating along the Asiatic and American coasts of the North Pacific represent a single population, various stocks of which mingle in the north as well as in the south near the equator. Other authors including Zenkovich (1937) and Tomilin (1960) hold the opinion that in the North Pacific there are two populations of sperm whales: Asiatic and American, each having separate summer and winter waters. Omura (1957), while agreeing to this in principle, considered that in the summer the two populations mingle in their feeding grounds in the higher latitudes, and are only separate in winter, when each returns to its native waters. Klumov (1955) considered that both the Asiatic and American populations of sperm whales are themselves divided into two independent populations, each with its own territory.

Analysis of whaling data for sperm whales in the 1950s amongst other data enabled Rovnin (1969) to postulate the existence of an independent "Hawaiian" population in the central Pacific. Berzin (1971), after examining all points of view, concluded that three populations inhabit the North Pacific: the Asiatic or Western, the Central and the American or Eastern populations.

The conclusions of practically all these authors were based on observations of large groups of whales and were not consolidated by morphological data.

The decrease in population density of sperm whales in the temperate zone combined with unfavourable harvesting conditions has led to the change in whaling operations to the moderately warm waters of the North Pacific, their breeding grounds. In this connection it has been possible to use phenotypic research methods well known in the research of other mammals but never before used in studying sperm whales.

The development of this research trend was aided by studies of the polymorphism of sperm whale characters, particularly colour, and statistics showing the population

character of this polymorphism (Veinger, 1969, 1974a, 1974b; Clarke, Aguayo and Paliza, 1968; and others). The study of the exterior morphology of sperm whales from the point of view of finding phenotypic characters as markers led to the production of a special listing of possible variations in a rather large number of features subject to polymorphism (Berzin *et al.*, 1975). From 1974, research groups of Soviet whaling fleets have regularly collected data on these features. Our experience in collecting and analysing such data has shown that not all the initially chosen features can be used equally well for population analysis. For instance, it was found to be too laborious and complicated to determine the polymorphs of internal organs, such as the spleen and the liver; without X-ray equipment, it was impossible to collect substantial data on the structure of the first finger; the determination of the type of fastening of the sternal ribs, which depended on the technology of processing the whale, was found to be too subjective. However, it was established that good results in distinguishing populations can be given by the use of only one character, if all the numerous forms of this character are easily assembled into a small number of types and if assigning each whale to a particular type does not depend on subjective judgements. The character which best fitted these demands was the shape of the notch of the flukes.

The first investigations using phenotypic methods have shown considerable differences in the structure of whale groups in the various whaling regions, with the whales of the eastern region showing the most marked variations. The differences between whales of the central and western regions were not as great, but were clearly distinguishable. These data confirm the opinion that the sperm whales of the North Pacific can be divided into at least three independent populations.

In 1976, in addition to the traditional northern, central and eastern regions, whaling was carried out to the north of the Philippines, where the whaling fleet *Vladivostok* harvested sperm whales for two months. The sexual composition of the groups found, the physiological condition of the whales in the groups and their behaviour differed from those for whales of the nearby western region.

Table 1 shows the structure of whale harvest in three regions for 1974–75 and in the Philippine Sea in 1976 in terms of the shape of the fluke notch.

One of the most essential features present in populations of any species of animal is the stability of the gene pool (Mair, 1974). The structure of the population in terms of any polymorphic features which are part of the gene pool must also be stable. As can be seen from Table 1, only the Eastern Population fulfils these requirements, which undoubtedly indicates its degree of isolation. The stability

Table 1
Frequency of occurrence (%) of three types of fluke notch for sperm whales in the North Pacific

Year	Type 1	Type 2	Type 3
Western (Asiatic) Region			
1974	60.2	10.7	28.8
1975	52.6	9.1	38.1
1976	49.4	22.8	27.8
Central Pacific Region			
1974	—	—	—
1975	43.2	10.8	45.9
1976	35.7	17.4	46.9
Eastern (American) Region			
1974	30.2	17.6	52.2
1975	36.9	14.4	48.7
1976	36.5	15.5	48.0
Philippine Sea			
1976	49.2	30.4	20.4

of the Eastern Population may also serve to confirm the correctness of our determination of its boundaries.

The basic grouping of sperm whales has its own genetic fund which is smaller than the gene pool of the total population. Therefore, the general genetic fund (as expressed by the phenotype) of a harvested stock will depend on how evenly the harvesting effort is distributed throughout the population. Yearly changes in the proportions of the fluke notch types in the Western and Central populations noted in Table 1 may be explained, in my opinion, by the fact that the harvesting effort was concentrated on different parts of these populations in different seasons, largely by chance.

In 1976 the data for the Central and Eastern populations are quite similar. However, taking into account the considerable differences shown in the previous season and the presence in the catch of males from the south of unknown origin, I am inclined to consider this a chance similarity.

The absence of any visual physical boundaries between the populations means that only conditional lines can be drawn between them especially as the boundaries may change from season to season for various reasons, e.g. oceanographic conditions.

It is not impossible, therefore, that the real frequency of any characters in one population may be concealed by migrating sperm whales from other populations. On the other hand, the data might be used for determining the level of genetic bonds of the populations, i.e. their degree of isolation.

As has been mentioned, sperm whales harvested in 1976 in the Philippine Sea differed in some traits from sperm whales of the neighbouring Western population. Table 1 shows that the structure of this group with respect to fluke notch type differs markedly from the Central and Eastern populations but is similar to the Western population in that year. At present, this similarity does not provide a basis for considering this group as an independent population which suggests that genetic isolation of the Philippine sperm whales, i.e. their separation from the Western population, has occurred comparatively recently, and they have not yet attained population status. However, the appearance of certain distinctive differences will have caused a structural change in the Western population as a result of the latter harvesting seasons and the practically non-existent whaling in the Philippine area. Nevertheless, taking into account the

possible isolation of sperm whales in the Philippine Sea and aiming at the preservation of the gene pool, I consider it reasonable to regard the Philippine Sea as a whaling area with an independent quota. It is also necessary to increase population research in this area.

Although the present work is at an intermediate stage, the analysis of the results of many years of whaling, confirmed by special genetic research, has enabled us to propose that the North Pacific be divided into three whaling areas, the Western, Central and Eastern, corresponding to the three basic populations of sperm whale inhabiting these regions, and to advance the Philippine Sea area as an independent subregion of the Western area. The population boundaries for all highly mobile animals are naturally approximate and the sperm whale is no exception. Therefore, the boundaries shown in Fig. 1 and given below are only approximate and may vary from season to season. However, they are very far from the centres of the populations and correspond to the whaling districts of the North Pacific.

Western Region

- Southern boundary: along the 24° N line of latitude
- Northern boundary: shoreline of the Asian continent as far as 170°E
- Western boundary: shoreline of the Asian continent
- Eastern boundary: along the 170°E line of longitude.

Central Region

- Southern boundary: along the 24°N line of latitude.
- Northern boundary: along the 50°N line of latitude.
- Western boundary: as eastern boundary of Western Region
- Eastern boundary: a line through 24° N, 137° W and 54°N, 160°W.

Eastern Region

- Southern boundary: along the 18° N line of latitude
- Northern boundary: along the shoreline of the American continent as far as 160° W
- Western boundary: as eastern boundary of Eastern Region
- Eastern boundary: shoreline of American continent.

CONCLUSIONS

An analysis of sperm whale fisheries for many years shows that the whales are irregularly distributed in the North Pacific. The alternation of areas of high whale density with those of low or zero density is not accidental but regular.

Concentrations from the Western, Central and Eastern parts of the North Pacific can be separated by age and sexual structure. Recent investigations have shown obvious differences in these concentrations for a number of polymorphic features. All this suggests that no less than three independent sperm whale populations exist each inhabiting its own area. The North Pacific area was conventionally divided into three fishing regions based on the described populations and boundaries. Only the boundary between the West and Central areas can be extended to the north of the regions suggested. It should be drawn from Bering Island to the north-west as far as Cape Kamchatsky of the Kamchatka peninsula.

The available data confirm the southern boundaries for the three sperm whale populations to be at 20° N. Other populations are further south, the areas of their distribution crossing the equator. If the conventional formation of fishing areas is required for the North Pacific as far as the

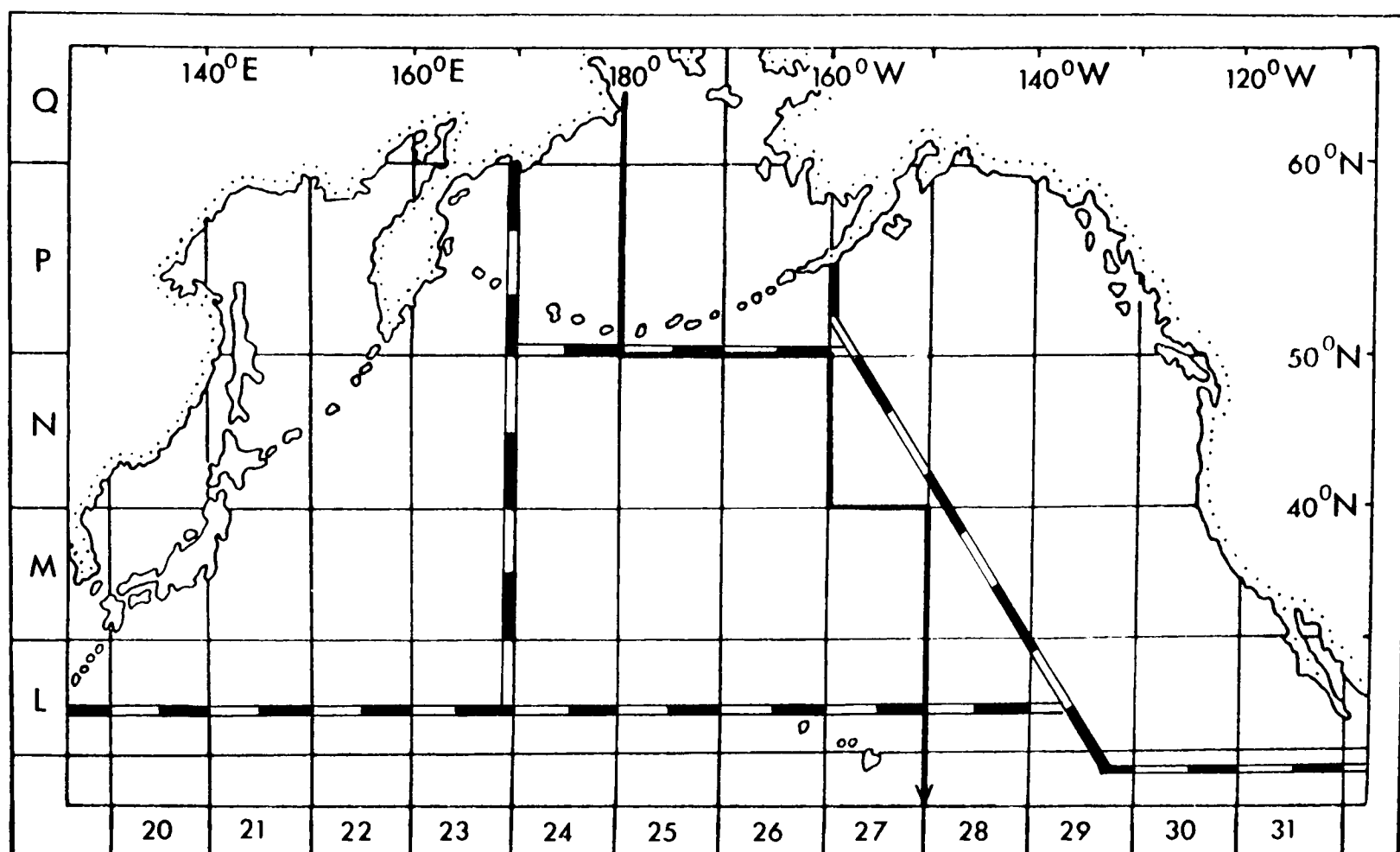
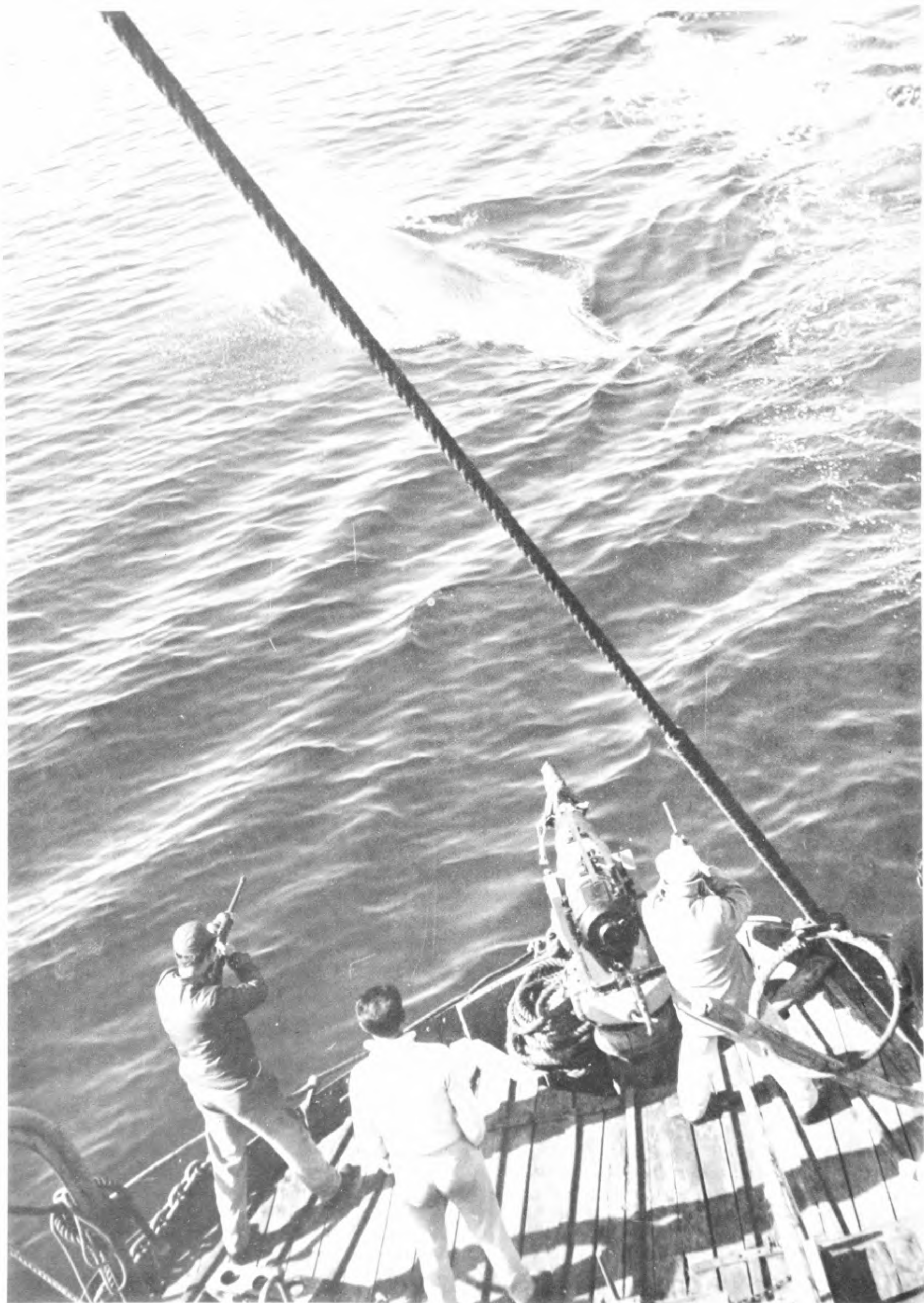


Fig. 1. Proposed new stock boundaries (approximate) for North Pacific sperm whales. — old boundary, - - - new boundary.

equator, then the boundary lines between the Western, Central and Eastern regions should be extended to the equator in the same direction.

REFERENCES

- Berzin, A. A. 1971. *The Sperm Whale*. Pishchevaya Promyshlennost, Moscow. 367 pp. (In Russian.)
- Berzin, A. A. 1974. Actual problems on studies of Cetacea (Cetacea of Pacific Ocean). *Vertebrate Zoology* 6: 158-89. (In Russian.)
- Berzin, A. A., Lagerev, S. I. and Isakov, G. I. 1975. Data on sperm whale population morphology of the Pacific Ocean. Proceedings of the VIth All-Union Conference on Marine Mammals, Part 1, Kiev: 28-30 (In Russian.)
- Clarle, R., Aguayo, A. and Paliza, O. 1969. Sperm whales of the Southeast Pacific. *Hvalråd. Skr.* 51: 1-80.
- Klumov, S. K. 1955. Location of whale herds. *Tr. Inst. Okeanol.* 19 (18). (In Russian.)
- Mair, E. 1974. *Population, Species and Evolution*. Mir Priorody, Moscow, 460 pp. (In Russian.)
- Omura, H. and Kawahami, I. 1956. Japanese whale marking in the North Pacific. *Norsk Hvalfangsttid.* 45: 555-63.
- Rovnin, A. A. 1969. Distinctiveness of whale stocks in Northern Pacific IV the All-Union Meeting on Marine Mammals, summary papers, Moscow: 119-124. (In Russian.)
- Sleptsov, M. M. 1952. Whales of far eastern seas. *Izv. TINRO* 38: 1-166. (In Russian.)
- Tomilin, A. G. 1960. Migrations, geographic races, thermal regulation and effect of environmental temperature on whale distribution. In: *Animal Migrations*, Iss. 2, AN USSR, 1-198. (In Russian.)
- Veinger, G. M. 1969. What the colour of sperm whales tells us. *Nature* 4: 71-3.
- Veinger, G. M. 1974a. Determination of population structure of sperm whales on the basis of colour analysis, pp. 153-64. In: *Issledovaniya po Biologii Ryb i Promyslovoi Okeanografii*. Iss. 5, Vladivostok. (In Russian.)
- Veinger, G. M. 1974b. The morphological character of skin of the sperm whale *Physeter macrocephalus* L. and its colour variation as a population character. Aftoref. dis. Vladivostok. (In Russian.)
- Zenkovich, B. A. 1937. Migration of whales in the North Pacific. *Izv. TINRO* 10: 3-18. (In Russian.)



Marking sperm whales from the whale catcher *Indus XIV* on 30th November 1964.

Photograph by courtesy of Robert Clarke.

Report of the Special Meeting on Sperm Whale Assessments 27 November to 8 December 1978

1. INTRODUCTION

At its 30th Annual Meeting held in June 1978, the International Whaling Commission instructed the Scientific Committee to hold a special meeting to consider North Pacific and Southern Hemisphere sperm whale stock assessments prior to a Special Meeting of the Commission, to be held in December 1978 to set catch limits for North Pacific sperm whale stocks.

By kind invitation of the Government of the United States of America, the meeting was held at the National Marine Fisheries Service Southwest Fisheries Center, La Jolla, California, 27 November to 8 December 1978. The participants were welcomed to La Jolla by Mr John Carr, Deputy Director of the SWFC.

Those attending were:

K. R. Allen	}	Australia
J. L. Bannister		
G. P. Kirkwood		
R. J. Lomax		
E. D. Mitchell		Canada
T. Doi	}	Japan
Y. Fukuda		
S. Ohsumi		
J. Tedorii		
M. Maeda		
W. Bergmans		Netherlands
J. P. Fortom-Gouin		Panama
P. B. Best		South Africa
N. N. Argunov	}	U.S.S.R.
R. G. Borodin		
V. M. Zemsky		
J. W. Horwood		United Kingdom
J. M. Breiwick	}	U.S.A.
R. L. Brownell		
D. G. Chapman		
T. Garrett		
W. Perrin		
T. Smith		
M. F. Tillman		
R. Storro-Patterson		
S. J. Holt		UNEP
J. R. Beddington		IUCN
G. Donovan	}	IWC
R. Gambell		

Invited Participants

R. Clarke
R. M. May
K. Ralls
J. Valdivia

Observers

J. Gordon Clark	FOE
P. Spong	Greenpeace
R. W. Keller	Project Jonah

2. MEETING ARRANGEMENTS

Bannister, as Convenor of the Sperm Whale Subcommittee was elected Chairman for the relevant part of the meeting. Donovan was appointed Rapporteur.

The Agenda adopted is shown in Annex A.

3. REVIEW OF DOCUMENTS AND STATISTICAL MATERIAL

Statistical material on pregnancy and size composition data by 10° square provided by Soviet scientists was available for the Southern Hemisphere from 1972–73 to 1977–78 and for the North Pacific from 1973–78. Age composition data by 10° square for the Southern Hemisphere from 1976/77 to 1977/8 and in the North Pacific in 1976 and 1977 were also provided by Soviet scientists. Japan provided a computer tape detailing individual biological records to sperm whales as described in SC/SP78/20. Kirkwood and Breiwick ensured that detailed North Pacific catch, effort and length data from North Pacific forms for 1947 to the present were available on the computer as well as catch and effort data by 10° squares for the Southern Hemisphere for 1946–47 to the present.

The documents available to the meeting are shown in Annex B.

4. EFFORT MODIFIERS

The Committee had before it the following documents, SC/SP78/2, 3, 5, 6, 7, 9 and 13. As in Cambridge, the Committee decided to obtain the appropriate unit of effort — catcher searching hour — from the appropriate values for each fishery of the daylight hours spent chasing, handling and towing, and allowing for changes in day length and female catch (see p. 108). The Committee reviewed a proposal in SC/SP78/6 that searching during other operations should be taken into account but believed this could not be quantified for the current sperm whale operations.

Chasing time:— SC/SP78/2 provided information on the effect of Asdic on the killing interval (time between successive kills by a catcher on the same day and in the same location) which suggested that the introduction of Asdic on the Durban catchers had no discernible effect. This contradicted earlier analyses for this area which had attributed an increased catching power of the fleet, by 2.3 times, completely to the effect of Asdic. It was felt that at least some of this increase could be due to an increased interest in taking sperm whales during the period of introduction of Asdic. Some members felt that the facts that most of the data in SC/SP78/2 referred to small sperm whales and that the nature of the analysis excluded data for

the first whale killed each day and totally unsuccessful chases, could have introduced biases into the method so as to minimise an Asdic effect. The data from SC/SP78/9, together with additional data provided by Ohsumi (reanalysed in SC/SP78/23) led to the corrections allowing for additional time chasing for operations when Asdic is not used as given in Table 1.

Best and Ohsumi said that Asdic is not used immediately when chasing whales, especially in a school, as it frightens the animals, causing the breakup of the school. Some members of the Committee believed that Asdic would increase the likelihood of catching whales when the school had been broken up. SC/SP78/23 showed that for the available data for large males from the Southern Hemisphere the ratio of sperm whales lost to those caught is 2.5 times greater for those boats without Asdic than for those boats with Asdic.

Data on the chasing time for Soviet operations in the North Pacific are given in SC/SP78/31. However, the 'taking' data listed in the time budget did not include the time spent chasing whales subsequently lost which should be included for use in the model. The corrected value of

2.34 hours (the average of the values where $p = 0.4$ and $p = 0.28$ where p is the proportion of whales chased but lost) was adopted for the average chasing time per whale. A similar correction was required for the Southern Hemisphere Soviet chasing time and a value of 1.38 hours was adopted.

SC/SP78/23 estimated the Japanese pre-Asdic chasing time for males in the Southern Hemisphere to be 1.38 hours and this was accepted by the Committee.

The Peruvian land station is owned by a Japanese company and has both a Japanese captain and gunner. Accordingly it seems reasonable as a first approximation to take the time budget from Japanese coastal whaling data. SC/SP78/9 tabulates these data for the Nippon Whaling Company in the 1969 season and the Nitto Whaling Company in the 1977 and 1978 seasons.

However, the Peruvian operation catches whales up to 200 miles from the coast, whereas the Japanese operate up to 250 miles from the coast. Hence, the Japanese towing time is likely to be proportionally greater per whale caught than the Peruvian. As a first approximation it was agreed to estimate the towing time for Peruvian operations by

Table 1a
Time Budget Data – North Pacific

	Japanese pelagic		Japanese coastal		Soviet pelagic	
	value	source	value	source	value	source
Handling time (hr)	0.33	Report of the sub-committee on sperm whales, (Annex E) June, 1978, (published in this volume).	0.3	SC/SP75/9 weighted mean for two operations in 1962 and one in 1969.	0.33	SC/SP78/31
Towing time (hr)	0.22	As above	1.1	as above, but half of the towing assumed to be taking place at night (Ohsumi, pers. commn)	0.7	SC/SP78/31
Chasing time with Asdic (hr)	0.59	As above	0.4	SC/SP78/9 weighted mean for two operations in 1962 and one in 1969	–	Asdic was not used in the Soviet operations studied
Chasing time correction (hr)	+0.26	As above	+1.57	Annex E, Cambridge June, 1978	–	
Chasing time without Asdic	–		–		2.3	SC/SP78/23 Appendix 1
Total time/female	0.96	sum of mean handling and towing times and chasing time for females (see SC/SP 78/10)	1.8	sum of mean handling, towing and chasing times	3.53	sum of mean handling, towing and chasing times

Table 1b
Time Budget Data – Southern Hemisphere¹

	Japanese pelagic		Soviet pelagic		Peruvian coastal (Division 9)	
Handling time (hr)	0.21	Weighted mean from SC/SP78/9	0.24	SC/SP78/31	0.3	As for Japanese coastal except for the towing time (see text)
Towing time (hr)	1.45		0.89		0.88	
Chasing time with Asdic (hr)	0.98	SC/SP78/23	–	Asdic was not used in Soviet operations studied	0.4	
Chasing time correction (hr)	0.4	SC/SP78/23	–		+1.57	
Chasing time without Asdic (hr)	–		1.38	SC/SP78/23 Appendix 1	–	
Total time/female	2.64	sum of mean handling, chasing and towing times	2.51	sum of mean handling, chasing and towing times	1.58	

¹ SC/SP78/2 gave information on South African coastal time budgets from Durban:
Handling time + Chasing time = 0.77 hours, Towing time (in daylight hours only) = 0.37 hours.

multiplying the Japanese value by 200/250 i.e. 0.8, with the following results:

Nippon	2.40 hr
Nitto	3.48 hr
Average	2.94 hr

Schooling effects. The Committee received the report (Annex C) from the sub-group which was set up as the result of a discussion on SC/SP78/3. The Committee considered that a schooling factor could be important in determining indices of abundance but that at present only very limited data were available and it was therefore not in a position to consider this in the assessments at the present meeting. It was agreed that an effort should be made to obtain as many data as possible on the present situation. The best data on school size and composition may come from scouting vessels, but in order to examine the relations between C, V and S (where C is the expected catch per CDW and V is the number of catchers involved in taking a catch from a school of size S, where S is the number of males in a school), it will be essential to have data, including school sizes from catcher vessels. It is also essential that the data recorded on school size, (total and catchable), should be compatible between scouting and catching vessels.

Details of the values adopted for the above and other effort modifiers are given in Table 1.

5. STOCK IDENTITY

The Committee had two papers before it concerning stock identity, SC/SP78/12 and 16. Ohsumi believed that while the biochemical (genetic) and marking data in SC/SP78/12 suggested that more than two stocks exist in the North Pacific, at present it is extremely difficult to determine the actual boundaries. He therefore proposed that for assessment purposes it would be more practical to deal with the North Pacific as a whole. Some members, however, felt that in the light of Sharp's paper (Paper ACMRR/MM/SC/88, Scientific Consultation on Marine Mammals, Bergen, 1976), the sample sizes in the biochemical analyses were too small to yield any significant results. In addition, the absence of detailed data at the meeting on the numbers of whales marked made the marking data difficult to analyse.

The division of the North Pacific into two management areas as adopted at the meeting in Cambridge, June 1978, was given some support by the pregnancy data in SC/SP78/8.

The historical study of SC/SP78/16 concluded that on the basis of discontinuous distributions of sperm whales during the peak breeding season, the Western Division can be divided into at least two, and possibly three stocks in the band between 20°–40°N, at 180° and 140°E. The Committee agreed that while these may represent biological stocks they could not, at this meeting, be separated for assessment purposes outside the breeding season, and that the assessments should be made for the present Western and Eastern Divisions. However, because of mixing of animals from these areas outside the breeding season and north of 40°N, it felt it would be impossible at present to attempt division of yields on the basis of such sub-units.

Mitchell expressed a different view, reflected in Annex H.

6. BIOLOGICAL PARAMETERS

Chapman expressed the view in SC/SP78/30 that the Committee was increasingly finding itself in the position of having to offer advice to the Commission based on less than

complete data in the form of 'best' or 'more conservative' or 'more reasonable' estimates. Some members of the Committee thought that in these circumstances the reasons for deciding between one or more alternatives were sometimes not based solely on scientific evidence. It was felt that it would be more scientific to present the Commission with a range of options and a clear indication of the weaknesses in the data which prevented a firm recommendation being given.

Some members of the Committee considered that it had been attempting to base its advice under the New Management Procedure on the biologically most likely principles and that it would not be scientifically sound to provide the Commission with a range of options between which the Committee itself could not judge on biological grounds. However, it was recognised that fuller reporting of the difficulties faced in arriving at parameter values based on limited observations and greater recognition of the urgent need for work to be carried out to provide such data, should be given in the Committee reports. The Commission should also be made more fully aware of the difficulties under which the Scientific Committee has to operate in providing stock assessments as required under the New Management Procedure, given the current state of knowledge, the lack of a firm data base, and the relatively few people undertaking data analysis between meetings.

Pregnancy Rates

The Committee had before it SC/SP78/4, 5, 8 and 22 on pregnancy rates as well as SC/SP78/1 giving data from South Africa regarding the timing of oestrus within schools. SC/SP78/8 presented a detailed analysis of apparent pregnancy rates in the North Pacific, by Zone and Division, and the author stated that the data as presented indicated a constant apparent pregnancy rate in the Western Division following exploitation, with annual fluctuations, and not an obvious decline as had been determined by analysis in Cambridge (see P. 000). It did show a different pattern of change between the Eastern and Western Divisions. On the other hand, SC/SP78/29 presented a statistical analysis which does indicate a significant decline in the Western Division although it is recognised that there are problems because of the change of operations and hence of samples from high to low latitudes over the time period concerned.

Fukuda stated that the means of monthly rates for each year seem to be at a somewhat lower level for the years in and after 1973 when the minimum size limit was lowered, and that the regressions by Chapman and Beddington may be confounded by the effect of lowering the minimum size with the inevitable inclusion of more younger mature females, supposedly with a lower pregnancy rate, although he could not provide any detailed analysis during the meeting.

SC/SP78/5 from Southern Hemisphere Division 9 proposed that a comparison of pregnancy rates from Paita, Peru, between 1959–61 and 1975–77 showed a decline in the pregnancy rate, believed to be associated with a marked decline in the proportion in the catch of males of harem master size. However, a further analysis of data for Paita from 1959–64 and 1976–78 in SC/SP78/21 shows no significant difference between the two periods (see SC/SP78/35) with an overall pregnancy rate in the two periods of 0.306. This may contain a small number of small foetuses but otherwise is not biased by selection against lactating females in the catch. The Committee noted the

high pregnancy rate value indicated by comparison with the rest of the Southern Hemisphere which may be due to the environmental conditions of the Peru Current and/or to the response of the stock to heavy exploitation in the past.

Data from British Columbia (SC/SP78/22) also suggested a high true pregnancy rate. Some members thought that because the sample was taken from northern latitudinal waters it could be expected to be biased towards late pregnancies and thus be unrealistically high. The Committee noted that Rice (1963, *Norsk Hvalfangsttid.* 52 (7): 181–7) had obtained similarly high values in a smaller sample for probably the same stock off California.

The Committee noted that exploitation of females could lead to an increase in the pregnancy rate but exploitation of males could eventually lead to a decrease in pregnancy rate. These two effects work in opposite directions and while it is necessary in the final analysis to consider the resultant of the two effects, it is useful to consider the response mechanisms separately. The first of these two response mechanisms, that is the response to the reduction in the number of females, has been discussed extensively by the Committee at many special and regular meetings. Most members believe that while there is little conclusive evidence for an increase in pregnancy rates in sperm whales due to this mechanism, mainly because few if any female stocks have been sufficiently reduced, it is biologically reasonable as the only density dependent factor in the model. Relative to this question the data on changes in pregnancy rate in female sperm whales caught off Durban between 1962–1965, 1967 and 1973–75 (given in SC/30/Doc 33 revised) were discussed and reanalysed to provide information in the form and range of the density-dependent response. It was noted that the increase in pregnancy rate in the data is not statistically significant at the 5% level. (However, if it is considered that the only valid alternative to no change is an increase in the rates between the two time periods, then the change is significant at the 5% level.) The increase in pregnancy rate appeared to be greatest in the older females. It was further noted that the data indicate that pregnancy rates themselves are age-specific; after a small increase, the rate then decreases with age.

Holt (SC/SP78/25 and 27) showed that some increase in average pregnancy rate could be explained by a change in the age structure of the mature females resulting from exploitation. Horwood (SC/SP78/26) reanalysed the data and concluded that on this basis there could be an increase of the average pregnancy rate from 0.20 to 0.23 for the Durban data. Taking this factor into account and noting the density-dependent response shown in baleen whales (up to 100% increase in average apparent pregnancy rate) and in some terrestrial large mammals, the Committee agreed to use the same values and specifically the same range (0.20–0.25) as in Cambridge (June, 1978) for all sperm whale stocks except for Division 9. This is consistent with a change from a 5-year to a 4-year breeding cycle; the unexploited rate accords with observations from lightly exploited stocks of between 0.19 and 0.23 (Schevill, W. E. (ed.) 1974. *The Whale Problem, a status report.* Harvard University Press, Mass., 419pp.) the upper limit of 0.25 represents the large amount of change that could be expected without affecting juvenile mortality. Shortening the cycle to 3 years, it was considered, would cause a significant reduction in the length of lactation, which has generally been accepted as lasting 2 years, and hence might change the post-weaning survival rates.

Natural Mortality Rates

The Committee had before it SC/SP78/17 and 18. In the former, the likelihood and consequences for assessments of natural mortality rates differing by sex were examined. In the latter, examples were given from other mammals, indicating that where marked sexual dimorphism occurs, differences in mortality rates can be expected, with the smaller sized sex having a lower mortality rate. It was agreed that the observed values for each sex should be adopted in the sperm whale model rather than the pooled value applied to each sex as has been previously used. It was noted that the observed values were obtained from catch curve data. The data for the North Pacific are summarised in Annex D, giving mean values of 0.066 for males and 0.055 for females. Ohsumi however thought that the observed difference between the two values may be the result of differences in the exploitation of the two sexes and that the actual values of the natural mortality rates would not be so different. It was also agreed that the juvenile mortality rate (from birth to 2 years) obtained from the balance equation could be applied to males as well as females.

Density Dependent Exponent

The Committee discussed the evidence for the exponent being greater than zero and concluded on the basis of an analysis in SC/SP78/26 that this was likely. It was however unable to determine by how much the value might exceed zero. Some members felt that an exponent value of 1.4 as adopted at Cambridge and representing an MSY level (MSYL) of 60% for females was valid but others believed there was little evidence to determine where the value should lie between zero and infinity, i.e. MSYL 50%–100%. Best felt that an MSYL of 60% should be considered as a minimum, given that a value of 60% had been adopted for baleen whales, and that sperm whales in general feed at a higher trophic level than baleen whales. It was also noted that the theoretical level in a predator was likely to be skewed more to the right than the value for its prey (Beddington *et al.*, in prep). After considerable discussion the Committee agreed that it was unable, on biological grounds, to determine the most appropriate level and that it would undertake assessments with a range of values equivalent to MSY levels of 50%, 70% and 90%. The Committee noted, however, an unpublished study of the situation in large mammals (Charles Fowler, Utah State University, pers. commn.) which indicates that in the female sperm whale the value might lie between 85% and 90%.

Age at Recruitment

For males this was determined by analysis using the CPOP program of age distributions based on the Japanese 'ideal' age-length key *Rep. int. Whal. Commn* 27: 295–300) for both Divisions of the North Pacific for each year (see Figs 1 and 2). Inspection of the results indicated little change in the period from 1956–72 in either Division for both the Japanese and Soviet data. There was similarly little annual difference after the change in the minimum size limit for either set of data for the Eastern Division. The values used in the assessments are shown below since integer values are needed.

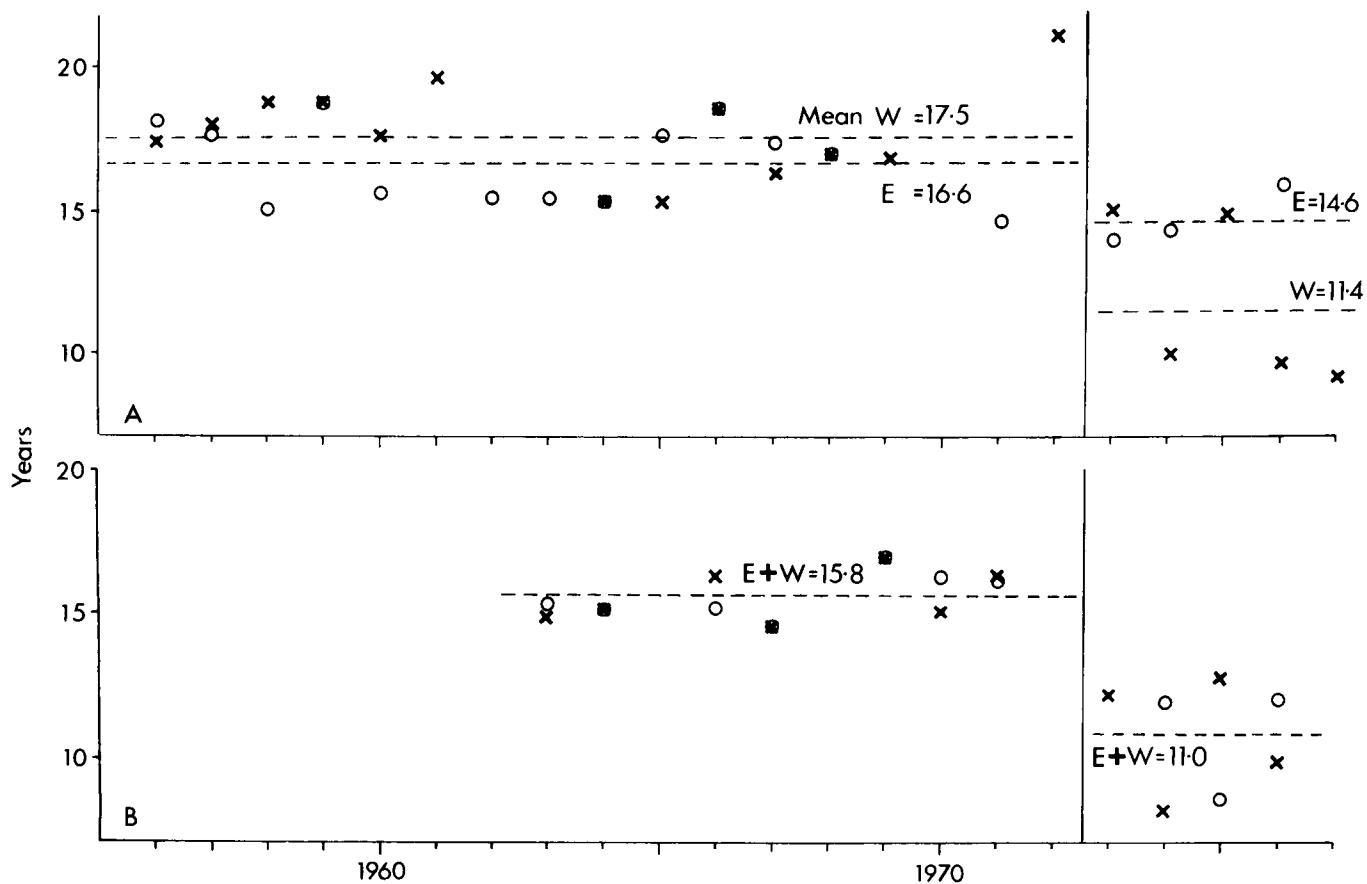


Fig. 1 North Pacific whaling – age at recruitment.
(A) From Japanese data: ○ Eastern Division; × Western Division
(B) From Soviet data: ○ Eastern Division; × Western Division

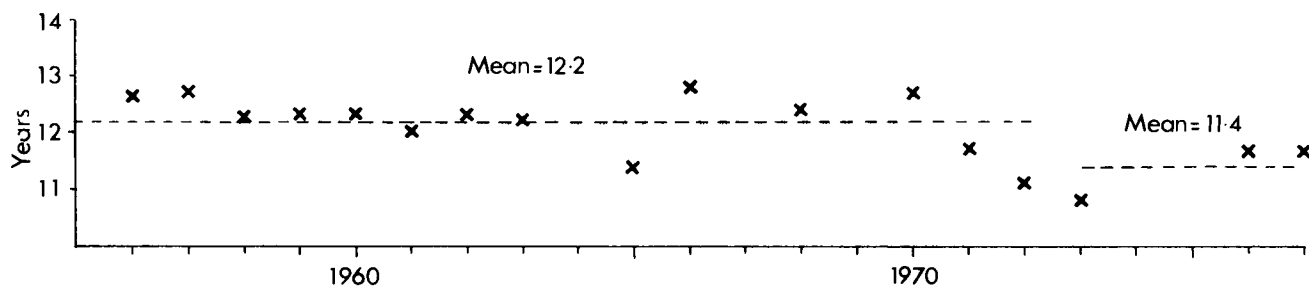


Fig. 2 Japanese coastal whaling – age at recruitment.

Values for the Japanese coastal data were obtained in the same way.

		<i>Pre 1972</i>	<i>Post 1972</i>
Japan	E	17 (years)	14 (years)
Pelagic	W	17	12
Coastal		12	11
USSR	E	16	11
Pelagic	W	16	11

For females the same values as used at the Cambridge meeting were adopted (IWC/30/4, Annex E).

The Committee recognised that it faced a major difficulty in agreeing on the set of parameters which define the dependence of recruitment rate on female density. This arises from the fact that recruitment cannot be estimated directly for this species. Thus, the only estimates available are indirect ones from a very few observations of apparent pregnancy rates and the changes in these – changes in which density and sex ratio effects may be confounded – and calculations of theoretical pre-recruit mortality rates derived from a balance equation. The reason recruitment cannot be estimated directly is that adequate age-length keys are still not available; many large samples of teeth remain unread. Without these data the Committee is not in a position to examine possible changes in absolute age-specific pregnancy rates and in age at female maturity.

A summary of the biological parameter values adopted is given in Table 2.

7. POPULATION MODELS

Kirkwood reported that the model used in Cambridge in June 1978 had been modified to allow for estimation of annual numbers of animals at each age and is thus able to take account of changing ages at recruitment. As at Cambridge, population estimation was carried out using a maximum likelihood technique comparing actual and observed catches with known effort.

A modified form of the May-Beddington model was presented in SC/SP78/14. This model describes changes in pregnancy rate arising from a reduction in population and in its revised version has two specific parameters:

α is the ratio between the length of the breeding season and the typical time to encounter a pod.

β is the ratio between the length of the breeding season and the average time a male spends with a pod.

A preliminary comparison of the pregnancy rates predicted using the May-Beddington model and the current pregnancy model with the Western Australian data on observed pregnancy rate changes in Division 5 was carried out. Using a value of α close to unity in the May-Beddington model, and the parameter values adopted in Cambridge in the Allen-Kirkwood population model, the predicted pregnancy rates shown in Table 3 were obtained using the Western Australian sightings data as an index of abundance.

Table 2
Biological Parameters

		North Pacific		Southern Hemisphere	
		value	source	value	source
Average age at recruitment	♂	see Table in text		20	Annex E, Cambridge, June 1978
	♀			13	
Average age at maturity (social maturity)*	♂*	25	Annex E, Cambridge, June 1978	25	as North Pacific
	♀	10		10	
Natural mortality	♂	0.066	see Annex D and text	0.066	
	♀	0.055		0.055	
Juvenile mortality (both sexes 0–2 years)		0.0926	from balance equation (and see text)	0.0926	as North Pacific
Mean number of mature females available to a school master		10	Annex E, Cambridge, June 1978	10	as North Pacific
Reserve male ratio		0.3	As above (and see text)	0.3	as North Pacific
Pregnancy rates	unexploited	20	(and see text)	Div 9 25	see text
	exploited	25		Rest 20	
				30	
Density dependent exponent (n)		range of values n = 0, n = 1.39 n = 4.04, n = 33	see text		as North Pacific

Both models predict lower rates than observed. The results do not indicate which model is better at describing the observed situation, although the May-Beddington model predicts an earlier reduction in pregnancy rate than the current pregnancy model. Unfortunately there are no earlier observations to allow this feature to be investigated. The Committee decided that the best course of action in the time available was to fit the May-Beddington model to the observations by finding an appropriate value of α which would then, in effect, be a curve generating parameter. This conclusion was arrived at following considerable discussion of the alternatives available to the Committee in the absence of data which would permit estimation of the pregnancy rate change, the reserve male ratio and the density-dependent exponent to be obtained in the current pregnancy model. The Committee saw that it had three alternatives:

- (1) To use the current model and retain the reserve male ratio used in Cambridge.
- (2) To retain the current model but replace the step function which describes the effect of the reserve male ratio on the pregnancy rate by a smooth curve obtained by fitting an appropriate power function.

- (3) To use the May-Beddington model, altering the value of α to fit the observed data.

Most of the Committee felt that there was biological justification for smoothing the step function and it was agreed that this might appropriately be done by using the May-Beddington model with a value of α which would fit the observed Australian data and then testing the result against the Division 3 Durban data on changes in pregnancy rate as reported in SC/30/Doc 30. The Committee considered that there was some biological justification in increasing α as this would reflect the likelihood that there are surplus males available which do not take part in searching activity during the breeding season.

The Committee recognised that in the time available it would not be possible to do further analysis than that outlined in the previous paragraph. It was agreed that if alternative (3) above did not provide an improved fit, the reserve male ratio would be held at 0.3 as at the Cambridge meeting and in that event the assessments at this meeting would have to be carried out using the Allen-Kirkwood model and parameter values as for the Cambridge (June, 1978) assessments but with some changes already described.

The results of these fitting exercises are shown in Table 4. On reviewing this, the Committee decided that adjusting α in the May-Beddington model did not satisfactorily explain the observed changes in pregnancy rates at Durban. However, the Committee then requested additional exploration of predictions with reserve male ratios in the range of 0.2 to 0.5. The results gave the Committee no reason to change the value of 0.3 as adopted at Cambridge.

CPUE Analysis

The Committee reviewed an analysis of index of abundance in North Pacific data in SC/SP78/10 and agreed that the use of direct CPUE data within the North Pacific is confounded by geographical variations in density of whales, both seasonal and annual changes in availability, and shift of

Table 3

Division 5, Western Australia pregnancy rates predicted and observed

Season	May-Beddington	Current	Observed (apparent)
1947	0.20	0.20	—
1955	0.193	0.20	—
1964	0.161	0.20	0.376
1965	0.152	0.201	0.293
1973	0.084	0.119	0.282
1974	0.078	0.107	0.222
1975	0.071	0.096	—
1976	0.066	0.088	0.125
1977	0.062	0.081	0.226

Table 4
Western Australia predictions of pregnancy rate

	May-Beddington model		Allen-Kirkwood model	Observed (apparent)
	$\alpha = 5.0$	$\alpha = 13.5$		
1961	0.20	0.20	0.20	
1962	0.19	0.20	0.20	
1963	0.18	0.20	0.20	
1964	0.17	0.19	0.19	0.376
1965	0.15	0.16	0.17	0.293
1966	0.10	0.10	0.13	
1967	0.05	0.06	0.10	
1968	0.03	0.03	0.08	
1969	0.03	0.03	0.08	
1970	0.02	0.03	0.07	
1971	0.02	0.02	0.06	
1972	0.02	0.02	0.06	
1973	0.02	0.02	0.05	0.282
1974	0.01	0.01	0.05	0.222
1975	0.01	0.01	0.04	
1976	0.01	0.01	0.04	0.125
1977	0.01	0.01	0.03	0.226

whaling grounds with time. It believed the methodology developed in SC/SPC/10 was valid but that data coverage is insufficient to attempt such an analysis. It was therefore decided to use the approach using CPUE data as adopted at the Cambridge meeting.

The trend in catch per unit effort in the Japanese coastal fishery is an increase with time (SC/SP78/7), while the pelagic CPUE shows the reverse trend. In order to combine these two trends adjustment is required that allows for the different densities and areas of the two sectors.

The relative areas of operation of the coastal (within 250 nm from the stations) and pelagic (between 25° and 55°N and 159°E) fleets was calculated as 1:7.78.

Assuming that CPUE measured as catch per searching hour is an index of density and that all age groups are evenly distributed within each of the coastal and pelagic areas, the following algorithm performs the appropriate pooling of the catch and effort to produce the required adjusted effort from known catches.

$$\begin{aligned} \text{CPUE}_c &= \text{CPUE coastal (catch/searching hour)} \\ C_c &= \text{total catch from known effort coastal} \\ \text{CPUE}_p &= \text{CPUE pelagic (catch/searching hour)} \\ C_p &= \text{total catch from known effort pelagic} \\ I &= \text{adjusted CPUE for area effect} \\ I &= \text{CPUE}_c \times (\text{proportional area coastal}) + \\ &\quad \text{CPUE}_p \times (\text{proportional area pelagic}) \\ \text{Total catch } C &= C_c + C_p \\ \text{Adjusted effort } E &= C/I. \end{aligned}$$

The algorithm uses total catch and adjusted effort to produce the adjusted time series.

DOIPOP

SC/SP78/11 detailed an assessment method based on changes in age distribution resulting from catches during the available time series and independent of effort data. The Committee agreed that results from such an analysis were useful in giving estimates of overall population levels. However, the method cannot be used to extrapolate beyond that series for prediction of future trends in population levels. The Committee also felt that a comparison of the observed and expected age distributions should be made over a longer time series and used with an objective criterion, for example a least squares fit. The programme was re-run using the parameter values agreed at this meeting for the North Pacific.

8. POPULATION ASSESSMENTS

North Pacific: DOIPOP

The results of estimates obtained using the DOIPOP estimation technique for both Divisions of the North Pacific are given in Annex E.

The Committee concluded that the model might give some insight into approximate levels of exploitable females in 1910. In the Western Division a value of about 150,000 appeared to give the best fit to the single comparison for the 1977 catch data by age. In the Eastern Division a minimum value of between 100,000 and 150,000 was suggested. The Committee noted that both DOIPOP and the Allen-Kirkwood population model predict a decline in pregnancy rate in the Eastern Division and no decline in the Western Division although pregnancy rate data from the Western Division show a statistically significant decline (SC/SP78/29). Some members believed that the low pregnancy rate for the Eastern Division although obtained from a small sample size is supported by DOIPOP and the Allen-Kirkwood population model.

It was also noted that the relative abundances of the Eastern and Western Divisions obtained from DOIPOP are not in accord with data presented in SC/SP78/10 and it was suggested that this may be due to problems of allocating the age distribution by Division.

North Pacific: Allen-Kirkwood Population Model

Assessments were undertaken for the Eastern and Western Divisions. At Cambridge, effort data in the form of hours searched were calculated from catcher days worked by subtracting the time spent handling, chasing and towing the sperm whales taken. The Committee recognised that the time spent handling, chasing and towing any baleen whales taken in addition to the catch of sperm whales should also be subtracted to correctly obtain searching hours. In the North Pacific, Japanese catch and effort data were not available in sufficient detail to allow these additional times to be accurately determined. The Committee agreed to use Japanese catch and effort data for the two stock Divisions only for those areas and months when the catch solely consisted of sperm whales. It was pointed out that the time series of Japanese pelagic catches for searching hours for the Western Division show a smaller decline than the corresponding time series used at Cambridge. This effect occurs because of the relatively higher catches of baleen whales in the later half of this time series. Soviet catch and effort data were not used in the assessments as the series of catches per searching hour for the Western Division did not show a decline.

The results are shown in Annex F. Calculations were made for each stock with the range of density dependent exponent (n) values already agreed. Figures were obtained both for the catch limits of males and females as well as for the catch limit for males if no females were taken.

Southern Hemisphere: Allen-Kirkwood Population Model

Assessments were carried out using this model for Divisions 5, 7, and 9. Lack of time made it impossible to carry out assessments for the other Divisions. Division 5 was given priority because of the information in SC/SP78/4 indicating that using the Cambridge parameter values, males should be protected: for Division 7 there was a series of pregnancy rates from Soviet data which could be compared with model predictions over the same time span. Reasonably complete catch and effort statistics were now available for Peru for Division 9 to allow assessments to be compared

with those undertaken earlier showing both sexes in that area to be Protection Stocks.

For Division 5 data used were Albany sightings, Japanese pelagic outside the baleen whale season and USSR pelagic north of 40°S. For Division 7, Japanese pelagic outside the baleen and USSR north of 40°S data were available, as also were Japanese pelagic data north of 40°S, but these contained only 4 data points and assessments based on them were considered to be unreliable.

The results are given in Annex G.

9. CLASSIFICATION AND CATCH LIMITS

North Pacific (see Annex F)

Based on the results given in Annex F for the Allen-Kirkwood model, stocks of males and females in both Divisions would be classified under the New Management Procedure as either Sustained Management or Initial Management Stocks. As previously discussed (Section 6) the Committee was unable to recommend between estimates obtained for the range of values of the density dependent exponent.

However, the Committee calls to the attention of the Commission the inconsistencies in the computer model estimates between the North Pacific and Southern Hemisphere as well as the large change between the new computer estimate for the Western Division as contrasted to those previously obtained by several methods.

In particular the Committee faced two problems in considering the population estimates and assessments in Annex F. In the Eastern stock, pregnancy rates were predicted by the model to have fallen from 1969 reaching a minimum in 1974 and by 1978 the number of surplus males was still zero. Projection of the predictions into the future implied reduced recruitment to the population over the next decade. Although available data on pregnancy rates in the Eastern Division provided by Ohsumi (SC/SP78/9) showed no such decrease, it was based on very limited samples.

In the Western stock the model predicted no such drop in pregnancy rates; however, analysis of data for the Western stock indicated a statistically significant decline (SC/SP78/29).

Accordingly the most conservative view to take would be that both stocks would be expected to show a decline in recruitment. Appropriate management strategy in such a case would be to protect the female stock and ensure that males are harvested below their replacement yield. Unfortunately because of the considerable variation in stock estimates, little confidence could be placed in an estimate of replacement yield.

The Committee also notes the uncertainty over the pooling of pelagic and coastal catch per effort data in the model, its inability to assess the consequences of the latitudinal shift of effort in the Western Division, the lack of information or the reliability of the estimates and on the reliability of a procedure resting solely on CPUE data. It further recalls the unresolved problems concerning pregnancy rates in both Divisions of the North Pacific. Additional examination of the pooling procedure and of the effects of differential distribution, and additional sensitivity analyses should be carried out. Alternative estimation procedures should be developed, as well, in particular, as further studies along the lines developed by the sub-group set up to advise on research needs (Annex H).

In view of substantial scientific uncertainty on both the population estimates, and the validity of the assumptions

on the population response, most members of the Committee recommend that the Commission sets male quotas conservatively, certainly not higher than 1978 quotas, and that it reduces female quotas to zero as proposed in SC/SP78/30 and 33.

Mitchell expressed reservations, reflected in Annex H.

Horwood agreed with the recognition of the problems outlined above but considered that they were pertinent to the analysis of the 'western' division. In the Eastern Division, however, this area is considered to have one biological stock, unlike the 'western' division and is more suitable for such an analysis. The analysis of this division has been consistent over the past few assessments and there has been no decline observed in the pregnancy rates which would cause a concern. Consequently, he considered that the Eastern Division analysis was competent, and was in agreement with the DOIPOP results.

Storro-Patterson proposed that a zero quota be set for males as well as females in the North Pacific until the difficulties with the current attempt at assessment and further analyses of available raw data and biological material can be 'read' and assessed.

The Japanese scientists could never agree to such majority recommendations in the light of the discussions during the last two weeks. They recommended, following the criteria in Cambridge:

	<i>Western Division</i>	<i>Eastern Division</i>
Male	IMS 4672	IMS 1317
Female	IMS 1813	IMS 552

Fortom-Gouin and Lomax wished to point out that hunting on nursery schools (also called harem schools when associated with breeding males) can be expected to greatly reduce the reproductive capacity of the nursery groups hunted for the following reasons:

- (1) reduction of the mature females,
- (2) negative effect of the removal of successful breeding males,
- (3) possible increase in the juvenile and/or adult mortality due to the social dislocation created by the removal of several adults from a stable social grouping,
- (4) possible negative effect of hunting the family groups of large-brained animals.

As any positive effect on the nursery groups not hunted is purely speculative at the present reduced level of the sperm whale stocks, any hunting on nursery groups should also be prohibited.

Holt, Beddington, Lomax, Fortom-Gouin, Bergmans and Storro-Patterson wished to record the following view:

- (1) There is no direct evidence for a density-dependent increase in the rate of recruitment with decrease in the abundance of female sperm whales. Even if such dependence is necessary for the stability of the assessment model used, the Committee has no means of estimating the necessary degree or form of the dependence. There is very little evidence regarding the density dependence of pregnancy rate and none of any accompanying changes in the survival rate from the pre-natal period to the age of recruitment. In these circumstances it is impossible to say whether the 'true' combined MSY by number is closer to any of the estimates of combined MSY given by the model than to the sustainable 'surplus' of males if females are unexploited.

The assessments show that the sacrifice of sustainable yield, by number, by taking only males, is a small

percentage of the theoretical estimates of combined MSY, for possible values of the exponent of density dependence of pregnancy rate. Furthermore, if the great difference in size between males and females is taken into account there would be a gain rather than a sacrifice. Accordingly, a strategy for management of sperm whaling in the present state of scientific knowledge would therefore be to protect all females and to continue to exploit males provided they are not so reduced that the pregnancy rate falls; such a strategy was suggested in SC/SP78/30. It would not be incompatible with the new management policy since there is no reason to suppose that the sustainable male catch so obtained would be further from the true combined MSY than any of the theoretical estimates of the latter quantity. (2) It is essential that the parameter values adopted for the model lead to predictions of changes in pregnancy of about the same degree and at the same time as any observed changes. Hence, if a 'catch males only' policy was adopted (supplemented preferably by protection of nursery schools) the question must arise of the need to monitor the pregnancy rates. It would not, however, be responsible to recommend in response to that question, as has been suggested, that substantial catches of females should regularly be taken under scientific permits for this purpose until the following conditions, at least, are satisfied:

- (a) It is determined, by examination of existing data, that the sample sizes necessary to detect significant declines in pregnancy rates without reasonable doubt, and sufficiently promptly, would not be such that the recruitment would likely be adversely affected by the sampling process;
- (b) indices of recruitment are determined and nursery schools are observed so that any large changes in prenatal and juvenile mortality rates can be identified;
- (c) most of the *existing* biological materials, especially samples of teeth, have been examined, the age-size data from them incorporated in the data base, and new assessments have been made utilising those data. (It is quite possible that if more age-data were available it would be possible to examine directly changes in recruitment rates and possibly in ages at maturity.)

(3) Experience has shown that statistical determination of trends in pregnancy rate is difficult. It would, therefore, be necessary to set a mature male population level relative to their initial level (or a mature male/female sex ratio, if this could be estimated) below which males would be protected in any case. An appropriate level, which would not be in conflict in the light of analyses so far made, might be 50%. As to the level of the male catch from stocks above the 50% males level, and in which pregnancy rates had not been observed to decline, this might be determined from a conservative estimate of the MSY or of some forward projection of the replacement yield.

Southern Hemisphere (see Annex G)

Division 5. Over the range of values for the density dependent exponent, males all fall into the Protection category while females are Sustainable in most cases. The overall conclusions corroborate those in SC/SP78/4 that pregnancy rates have fallen in this Division and hence that

stock levels will continue to fall irrespective of whether catches continue to be taken. The Committee therefore recommends that on the basis of the current analysis males should be protected; and even though females are classified as largely a Sustained Management Stock under the current management policy the Committee believes the Commission may wish to protect the female stock.

Division 7. Both sexes are largely Sustained or Initial Management Stocks except in the less reliable Japanese north of 40°S data where males fall into the Protection category. The two sets of Japanese data indicate a decline in pregnancy rate from about 1967 to 1977 but the data on pregnancy rates from whales sampled in the area indicate a slight but not statistically significant increase in the pregnancy rate for samples of late pregnant animals and early pregnant plus ovulating animals.

Division 9. The Committee recognised that the results were only preliminary since some catches were unaccounted for in the early years. Both sexes fall within the Sustained Management category except for females at the lowest levels of density dependent exponent which fall within the Protection category. For this Division particularly the Committee believes that assessments should be made with more complete data as soon as possible.

10. OTHER BUSINESS

10.1. SCAR

The Scientific Committee of the IWC has been invited to nominate a scientist to take part in the BIOMASS Technical Group on Data, Statistics and Resource Evaluation. The Committee welcomes the opportunity to cooperate actively in this important research program in the Southern Ocean, and recommends that the Commission should provide any necessary financial support to send Dr Gambell to such meetings as are arranged.

The Committee also notes that SCAR will probably invite it to send observers to meetings or other groups connected with the BIOMASS programme and recommends that a suitably qualified scientist should be asked to attend as its representative on such occasions.

10.2. Budget Requirements for Data Processing

The work of the Scientific Committee has become totally dependent on the availability of a large computer system to store and retrieve the large amounts of data involved and to carry out many highly complex analyses. At present this need is being barely met by members of the Committee, in particular one Australian scientist, to establish and operate the service at each meeting.

This does not provide for the necessary continuing activity of updating the records and vigorously collecting from national and other sources the new data required by expanding analytical methods. It is essential that this work carries on continuously and that the essential tabulations are prepared in advance so as to be available at the beginning of each Committee meeting.

The present system could also break down completely if certain key people were not available at each meeting.

The Scientific Committee, therefore, considers most strongly that unless the Commission makes immediate provision for the establishment and staffing within its organisation of facilities to provide these services it faces a serious possibility that the Scientific Committee will become unable to provide the Commission with the advice which it is required to give.

The matter is discussed in more detail in Annex I and it is estimated that essential costs are:

Establishment	Preliminary design study (Consultant)	£1,000
	Consultant to set up the system-one time cost	15,000
	Design computer operating	9,000
	Computer hardware – establishment cost	5,000
	Initial data assembly and storage	20,000
		£50,000
Operating	Scientist to direct/operate service	
	Salary, etc (annual)	£10,000
	Travel (annual)	3,000
	Computer operations and other running costs	8,000
		£21,000

The Committee strongly recommends that steps be taken to initiate this system in advance of the June 1979 meeting, although it would still be impossible to have it fully operational by that time.

10.3. Schedule Amendment for Data Reporting Requirements

The Scientific Committee recommends that the second part of the present schedule paragraph 26 be amended to read as the following:

New Paragraph 27

‘Notification shall be given in accordance with the provisions of Article VII of the Convention with regard to all factory ships and catcher ships of the following statistical information.

- (a) The name and gross tonnage of each factory ship.
- (b) For each catcher ship attached to a factory ship or land station.
 - (i) The dates on which each is commissioned and ceases whaling for the season.
 - (ii) The number of days on which each is at sea on the whaling grounds.
 - (iii) Where possible, the time spent each day on different components of the catching operation.
 - (iv) The gross tonnage, horsepower, length and other characteristics of each; vessels used only as tow-boats should be specified.
 - (v) Any modifications of the above measures or data from other suitable indicators of fishing effort for “Small-type whaling” operations.
- (c) A list of the land stations which were in operation during the period concerned, and the number of miles searched per day by aircraft, if any.

The information required under paragraphs (b) (iii) to (b) (v) should be recorded in the log book format shown in Appendix A’.

The log book format is shown in Annex J of this report.

10.4. Special Meeting on Sei Whales

Japan has indicated that it is not satisfied with the analyses and results of the meeting of the Scientific Committee held in June 1978 and the ensuing decisions of the Commission, concerning Southern Hemisphere sei whales. It has therefore requested that a special meeting of the Scientific Committee should be held to go further into this matter.

The Scientific Committee agreed that it would be least difficult to hold this special meeting immediately preceding the June 1979 meeting. It emphasised that it will be essential to have all necessary data and analyses for this meeting submitted well in advance of the starting date together with early distribution of the documents to be considered.

Horwood was appointed as Convenor of the meeting.

10.5. CITES

The Secretary outlined the UK proposals forwarded from the CITES Secretariat concerning the listing of cetaceans in the CITES Appendices. The full documentation supporting these proposals will be circulated to Commissioners and members of the Scientific Committee by the IWC Secretariat as soon as possible for comment prior to the next meeting of the parties to the CITES. Since several species of small cetaceans are proposed to be listed in the Appendix, the small cetaceans subcommittee will attempt to prepare a review of the proposals to be sent to the Secretary before the deadline.

It was suggested that it would be useful for copies of the criteria for listing stocks and species under the CITES to be distributed to the Committee for reference. It was also suggested that the Secretary of the IWC should discuss with the CITES Secretary the classification systems of the two Conventions.

10.6. Arrangements for June Meeting

A possible timetable for the meeting of the Scientific Committee next June was discussed. In the expectation that the 31st Annual Meeting of the Commission will be held in London in the week beginning 9 July, it was agreed that the Special Meeting on Sei Whales should be held from Monday 18 to Thursday 21 June; the Scientific Committee should meet from Friday 22 June to Tuesday 3 July. The Management Working Group could meet during 4–6 July, although it might wish to meet earlier in order to prepare proposals in time for discussions by the Scientific Committee. All these meetings will be in Cambridge.

10.7. Aboriginal/Subsistence Whaling

The Scientific Committee had insufficient time at this meeting to develop any ideas on the agenda or to define research papers to be requested for the proposed workshops on Arctic whales and subsistence whaling, but will include this item on its agenda next June.

However, it urged very strongly that any scientific evidence arising from the proposed meeting of specialists to be held in February 1979 should be adequately documented and made available to the Scientific Committee for review and study. It was hoped that consideration of questions of aboriginal and subsistence whaling will not be confined to the Arctic.

10.8 Press Reports

On 6 December the Committee’s attention was drawn to an article in the *San Diego Union* of that morning, headlined: ‘Safe whale kill called Uncertain’. This purported to describe a proposition and the ensuing discussion in the Committee, based on information presumably derived from a person attending the meeting. In addition to obvious errors of fact in the article, there were implications which the Committee strongly felt should be reported to the Commission.

The Scientific Committee has always attempted to operate in an atmosphere of confidentiality in order to

preserve its freedom to discuss the many and complex matters on its agenda. Only with this freedom can such discussion be wide ranging and productive so that ideas can be freely expressed, hypotheses developed and various alternatives explored, many of which may ultimately be rejected. The atmosphere of confidentiality is necessary not to create an aura of secrecy in its deliberations but to allow for free and open discussion without fear of misrepresentation. Press reports of the kind that appeared in the *San Diego Union* reduce the effectiveness of the Committee's work.

The Committee recognises that individual members are responsible to their own governments or organisations, but it also recognises a code of ethics which does not condone

statements to the media concerning details of its decisions. The Committee wishes to draw the Commission's attention to its serious view of the matter.

ACKNOWLEDGEMENTS

The Committee wishes to record its deep appreciation to the many members of the staff of the Southwest Fisheries Center who supported the meeting through general assistance and typing, copying, computing, and numerous other ways.

It also wishes to express its thanks to Dr G. P. Kirkwood for once again carrying the main burden of the computer work.

Annex A

Agenda

1. Opening Remarks
2. Election of Chairman
3. Appointment of Rapporteurs
4. Adoption of Agenda
5. Review of Documents and Statistical Material
6. Effort Modifiers
7. Stock Identity
8. Biological Parameters
9. Population Models
10. Estimates of Initial and Present Population Sizes, and MSY
11. Classification and Catch Limits, Including 10% Allowance
12. Proposals for Further Research
13. Any Other Business
 - 13.1. SCAR – Representation on Technical Group on, 'Data Statistics and Resource Evaluation'
 - 13.2. Budget Requirements for Data Processing (Comm. Agenda 13.5)
 - 13.3. Schedule Amendments for Data Reporting Requirements (Comm. Agenda 8)
 - 13.4. Special Meeting on Sei Whales (Comm. Agenda 9)
 - 13.5. CITES – Secretary's Report
 - 13.6. Arrangements for June Meeting
14. Recommendations to the Commission

Annex B

LIST OF DOCUMENTS

SC/SP78/

- 1 BEST, P. B. and BUTTERWORTH, D. S. Timing of oestrus within sperm whale schools.
- 2 BEST, P. B. Operational time budget of whale catchers from Durban, South Africa, with observations of the effect of Asdic on the killing interval for sperm whales.
- 3 ALLEN, K. R. The influence of schooling behaviour on CPUE as an index of abundance.
- 4 KIRKWOOD, G. P., ALLEN, K. R. and BANNISTER, J. L. An assessment of the sperm whale stock subject to Western Australia catching.
- 5 CLARKE, R., AGUAYO, A. and PALIZA, O. Pregnancy rates of sperm whales in the southeast Pacific between 1959 and 1962, and a comparison with those from Paita, Peru between 1975 and 1977.
- 6 RØRVIK, C. J. Biases in time budget model for modern whaling.
- 7 OHSUMI, S. Sperm whale catch by Japanese coastal whaling in the Sanriku Region.
- 8 OHSUMI, S. Examination of the pregnancy rate of the sperm whale in the North Pacific.
- 9 OHSUMI, S. Time budgets of sperm whaling operations by Japanese whaling.
- 10 OHSUMI, S. Index of abundance of the male sperm whale in the pelagic whaling ground of the North Pacific.
- 11 DOI, T., OHSUMI, S. and TEDORI, J. Theoretical aspects analysed by introducing age-specific maturity and age-specific availability into population analysis—III. Sperm whales in the North Pacific.
- 12 WADA, S. On the genetic uniformity in the North Pacific sperm whale.
- 13 DOI, T. What good will it do to use CPUE?
- 14 MAY, R. and BEDDINGTON, J. The effect of adult sex ratio and density on the fecundity of sperm whales.
- 15 BANNISTER, J. L. Logbook records of the 19th century American sperm whaling: Progress report for the first 3 months of study, July–October, 1978.
- 16 BANNISTER, J. L. and MITCHELL, E. D. North Pacific sperm whale stock identity: distributional evidence from Maury and Townsend charts.
- 17 HOLT, S. J. Two concerns about the sperm whale model.

- 18 RALLS, K., BROWNELL, R. L. and BALLOU, J. Differential mortality by age and sex in mammals, with specific reference to the sperm whale.
- 19 Withdrawn.
- 20 OHSUMI, S. Individual biological records of sperm whales taken by Japanese expeditions in the North Pacific and Southern Hemisphere from 1966–77.
- 21 VALDIVIA, J. List of sperm whale data available for Peruvian waters.
- 22 MITCHELL, E. D. Comments on sperm whale pregnancy rate, British Columbia, 1954–67, from data collected by G. C. Pike. A summary of this is Annex L to the Report.
- 23 HORWOOD, J. W. Asdic corrections in the Antarctic.
- 24 ALLEN, K. R. Relation between catch per CDW and indices of abundance allowing for non-searching time and operation on schools.
- 25 HOLT, S. J. Calculations from Best, Table 3 — Apparent pregnancy rates.
- 26 HORWOOD, J. W. Relative increases in population pregnancy rate of sperm whales.
- 27 SC/SP78/25 Continued.
- 28 KIRKWOOD, G. Some considerations of the May–Beddington pregnancy model.
- 29 CHAPMAN, D. G. and BEDDINGTON, J. R. Statistical evaluation of apparent pregnancy trends over time in the western North Pacific.
- 30 CHAPMAN, D. G. An alternative procedure for the Scientific Committee's recommendations with respect to sperm whale management.
- 31 Soviet time budget data. This is Annex K to the Report.
- 32 FOWLER. Telegram.
- 33 FORTUM-GOUIN, J. and HOLT, S. J. Four good reasons for recommending zero female catch limits.
- 34 CHAPMAN, D. G. Comparison of pregnancy and recently ovulated rate at Paita, 1959–64 versus 1976–78. This is Annex M to the Report.
- 35 ANONYMOUS. Pregnancy rates in Southern Hemisphere sperm whales. This is Annex N to the Report.
- 36 SMITH, T. Catches of sperm whales by 1° square by the Japanese pelagic whaling fleet from 1966 to 1977.
- 37 GARRETT, T. Pelagic whaling off the 'Coast of Peru', 1936–54. Statistical material. This is Annex O to the Report.

Annex C

SUBCOMMITTEE TO CONSIDER THE EFFECTS OF SCHOOLING ON CPUE

Members: K. Allen
J. Beddington
J. Horwood
J. Lomax
S. Ohsumi

The subcommittee considered SC/SP78/3, 24 of this meeting and SC/30/Doc 3 (*Rep. int. Whal. Commn* 29: 149–54).

To compensate for the various time elements and the response of the fleet to school size, the catch per catcher day needs to be converted to an index of stock density and an expected catch/CDW. SC/SP78/24 gives these expressions as:

$$C = \frac{qEAPC(sv)(1 - T_w - \sum b_j h_j)}{S + qEAP(C(sv)h + (v-1)g)}$$

and

$$R = \frac{SI}{E C(sv)(1 - T_w - \sum b_j h_j) - I(C(sv)h + (v-1)g)}$$

where I is the catch per CDW
C is the expected catch per CDW
R is an index of abundance
E is the relative efficiency of catcher finding schools
 T_w is the time wasted by 1 catcher in 1 day
q is an 'encounterability' coefficient for schools
A is to modify q as school size varies
P is stock size (i.e. what we are estimating)
S is the average number of male whales in a school
C(sv) is the catch of males from a school of size S males

h is the handling time of males of v vessels
v is the number of catchers involved in taking a catch from a school of size S
g is the time the boats take to get to the boat that found the school
 b_j is the number of females and other species taken
 h_j is their handling times.

The subcommittee agreed that it was very desirable to take into account the effect of school size and number of vessels used on the proportion of the schools taken since this influences the relation between population size and catch per searching hour. This had not been done in previous analyses although Beddington (SC/30/Doc 3) had allowed for it in his formulation. Data in SC/SP78/24 indicated that the proportion of the school caught decreased with school size, possibly asymptotically but increased with the number of vessels cooperating in an attack. There was also a tendency to use more vessels on larger schools.

The subcommittee considered the data available at this meeting to obtain the values and functions needed to define the parameters above. Some are obtained from the time budget information and catch data (h, h_j , b_j , g).

Information is particularly required on three problems:

- (a) The relation between number of vessels used and school size in the various fisheries. This may have varied over time.
- (b) The relation between school size, number of vessels and catch. This also may vary between fleets, by locality and over time. A special problem arises from the fact that sometimes both sexes and sometimes males only are being caught from mixed schools.

(c) The variation in school size and composition with time and locality. While in general it appears to be agreed that schools become smaller and contain a higher proportion of males as latitudes become higher, the data available showed that the situation is very complex. The proportion of males also changes with area and possibly season and needs careful study. g might be obtained from logbook data or from typical distances between boats in a fleet, assuming steaming time.

The principle data available to the subcommittee were in Ohsumi (1971, *Sci. Rep. Whales Res. Inst., Tokyo* 23:1–25) which provides information on school size particularly for the North Pacific, north and south of 50°N and off the coast of Japan, and in Tables 1 and 2 provided for the meeting by Japanese scientists. There are also some data for 1948 in SC/SP78/9. Ohsumi (1971) also provides some data on the ranges in size of whales in schools of different numbers. From these an approximation to the proportions of animals over a certain size (e.g. takeable

Table 1

Catches of sperm whale schools by cooperative operation of catcher boats of Japanese pelagic whaling fleet in the North Pacific in 1977 and 1978.

School size	Number of catcher boats operating cooperatively																	
	1			2			3			4			5			6		
	N	C	C/N	N	C	C/N	N	C	C/N	N	C	C/N	N	C	C/N	N	C	C/N
1	51	48	0.9															
2	12	18	1.5	9	18	2.0												
3	5	10	2.0	5	17	3.4	3	9	3.0									
4	7	14	2.0	1	4	4.0	6	24	4.0	1	1	4.0						
5	6	12	2.0	1	3	3.0	7	31	4.4	1	5	5.0	2	10	5.0			
6	1	2	2.0	1	3	3.0	5	27	5.4	1	6	6.0	1	5	5.0			
7	1	6	6.0	3	18	6.0	4	22	5.5	2	16	8.0	1	7	7.0			
8	1	2	2.0	3	17	5.7				2	15	7.5						
9							2	17	8.5	2	18	9.0						
10	6	21	3.5	7	41	5.9	3	27	9.0	4	32	8.0	1	6	6.0	1	13	13.0
11				1	10	10.0	1	11	11.0	2	20	10.0						
12							2	14	12.0	1	12	12.0	3	33	11.0	1	12	12.0
13				1	8	8.0												
14										2	27	13.5	2	28	14.0			
15				2	7	3.5	4	36	9.0	5	65	13.0	1	12	12.0			
18													2	34	17.0	1	18	18.0
20	1	2	2.0				1	5	5.0	3	34	11.3	3	52	17.3	3	51	17.0
24							1	17	17.0									
25										4	58	14.5				3	60	20.0
30				1	8	8.0	1	19	19.0	2	17	8.5	3	56	18.7	3	76	25.3
40																3	98	32.7
45																1	40	40.0
50				1	8	8.0	1	17	17.0							1	26	26.0
Total	91	135	1.5	41	186	4.5	41	286	6.98	32	329	10.3	19	248	13.1	17	394	23.2

Remarks: N: Numbers of cases, C: Total catch.

Table 2

Japanese coastal whaling, 1973, 1977

School size	Number of vessels								Mean catch		
	1		2		3				1	2	3
	Case	Catch	Case	Catch	Case	Catch					
1	10	10							1.0		
2	4	5	1	1					1.3	1.0	
3	1	1	1	2					1.0	2.0	
5	7	10	4	7	1	2			1.4	1.8	2.0
7–8	2	2	3	12					1.0	4.0	
10	18	80	3	14					4.4	4.7	
15	18	80	5	31	2	20			4.4	6.2	10.0
20	26	187	10	88	2	19			7.2	8.8	9.5
30	26	216	15	190	6	70			8.3	12.7	11.7
50	8	63	14	247	9	190			7.8	17.6	21.0

males (?) over 38 ft) is obtained. Discussion of these data emphasised the need to distinguish clearly as to whether it is the total number in the school or the number of takeable animals which is being counted or estimated. Apparent differences in practice in this respect produced very conflicting results for lower latitudes. If possible, both numbers should be recorded.

The subcommittee recommends strongly that this line of inquiry should be pursued. The primary need is to obtain as many data as possible on the present situation. The best data on school size and composition may come from scouting vessels, but in order to examine the relations between C, V and S, it will be essential to have data, including school sizes from catcher vessels. It is also essential that the data recorded on school size, total and catchable, should be compatible between scouting and catching vessels.

Annex D

ESTIMATES OF NATURAL MORTALITY RATE – NORTH PACIFIC

D. G. Chapman

Author source	Year of reference	Sex	Location	Method	Year of data	Estimate
Ohsumi	1966	Male	Coastal	Age length	1960–64	0.081
		Male	Aleutian	Key [= Z]	1961–62	0.071
		Female	Coastal	Age sample	1960–64	0.073
Ohsumi, et al.	1963	Female	Coastal	Age sample	1960–61	0.053
Shimadzu	1970	Male	Pelagic (ave)	Age length key	1967	0.064
		Male	Pelagic (ave)	Age length key	1968	0.060
		Female	Pelagic	Age sample	1967–68	0.058
		Female	Coastal	Age sample	1968	0.053
Chapman	1977	Male	Coastal	Age length key [= Z]	1946–50	0.069

Average of five estimates for male M is 0.069. If coastal estimate which may include emigration factor is omitted, average of four estimates for males is 0.066. Average of four estimates for female M is 0.059; if first estimate is omitted since it may include some fishing mortality, the average of the remaining three estimates is 0.055. The first two and last estimates for males are based on the numbers of older animals and hence should be free of this bias.

Annex E

RESULTS FROM THE DOIPOP ESTIMATION PROCEDURE

Table 1

Summary of estimated available number, number of mature animals and replacement yield for the Western Division.

Situation		10 × 10 ⁴			15 × 10 ⁴			20 × 10 ⁴			25 × 10 ⁴		
		Total available mature (%)			Total available mature (%)			Total available mature (%)			Total available mature (%)		
Female	1910	20.9	10.0	12.3	31.4	15.0	18.4	41.8	20.0	24.6	52.3	25.0	30.7
	1946	20.2	9.6	11.8	30.6	14.6	18.0	41.1	19.6	24.1	51.5	24.6	30.3
	1960	19.4	2.3	11.4	29.9	3.5	17.5	40.3	4.8	23.7	50.8	6.1	29.8
	1970	18.2	2.1	10.8	29.0	3.3	16.9	39.4	4.6	23.1	49.7	6.9	29.2
	1973	17.0	8.3(83)	10.4(80)	28.5	13.5(89)	16.5(90)	38.9	18.3(92)	22.7	49.4	23.3(93)	28.9(94)
	1977	14.4	7.8(78)	9.8(80)	27.6	12.8(85)	16.0(87)	38.0	17.8(89)	22.1(90)	48.5	22.8(91)	28.3(92)
Male	1910	18.1	8.0	3.3	27.1	12.1	5.0	36.1	16.1	6.6	45.1	20.1	8.3
	1946	17.3	7.7	3.1	26.4	11.7	4.8	35.4	15.7	6.4	44.4	19.7	8.1
	1960	15.0	6.3	2.1	24.0	10.7	3.7	33.1	15.1	5.4	42.1	18.5	7.0
	1970	12.9	4.4	1.0	22.2	8.6	2.7	31.2	12.7	4.3	40.3	16.8	6.0
	1973	11.5	4.4(55)	0.6(18)	21.6	8.8(73)	2.3(46)	30.6	13.2(82)	3.9(59)	39.7	17.6(88)	5.6(67)
	1977	9.6	4.4(55)	0.5(15)	21.3	8.8(73)	2.2(44)	30.4	13.3(83)	3.8(58)	39.4	17.7(88)	5.5(66)
Catch available		X											
Harem condition		△											
Pattern check					Acceptable			Acceptable					
RY	♀				600 – 1,300			900 – 1,800			0 – 1,100		
	♂				3,100 – 3,600			3,300 – 4,000			2,700 – 3,500		

X : rejected by negative age composition or pattern check
△ : harem condition is less than 1.5 × 1.3
‘Available (exploitable)’ were affected widely due to change of legal size limit.

Table 2
Estimated replacement yield in next 10 years in each situation for the Western Division

Situation	Sex	Present available number at the end of 1977	Rate of exploitation %	Replacement yield
10	F			
	M			
15	F	127,120	0.5–1.0	600–1300
	M	89,025	3.5–4.0	3100–3600
20	F	177,121	0.5–1.0	900–1800
	M	133,007	2.5–3.0	3300–4000
25	F	227,122	0 –0.5	0–1100
	M	176,988	1.5–2.0	2700–3500
	F			
	M			
	F			
	M			

Table 3
Comparison of actual catch with calculated available number in 1977 for the Western Division

Age interval	Catch	Situation 10		Situation 15		Situation 20		Situation 25	
		Available (exploitable)	Adjusted catch	Available (exploitable)	Adjusted catch	Available (exploitable)	Adjusted catch	Available (exploitable)	Adjusted catch
15–19	804			23,444	804	32,948	804	42,452	804
20–24	485			14,469	496	21,302	520	28,134	533
25–29	271			7,640	262	12,552	306	17,463	331
30–34	160			4,167	143	7,698	188	11,229	213
35–39									
40–44									

Table 4
Summary of estimated available number, number of mature animals and replacement yield for the Eastern Division

Situation		5 × 10 ⁴			10 × 10 ⁴			15 × 10 ⁴			20 × 10 ⁴		
		Total available mature (%)			Total available mature (%)			Total available mature (%)			Total available mature (%)		
Female	1910	10.5	5.0	6.1	20.9	10.0	12.3	31.4	15.0	18.4	41.8	20.00	24.6
	1946	10.5	5.0	6.1	20.9	10.0	12.3	31.4	15.0	18.4	41.8	20.0	24.6
	1960	10.4	1.3	6.1	20.9	2.6	12.2	31.3	3.8	18.4	41.8	5.1	24.6
	1970	8.5	1.1	5.8	20.2	2.4	12.0	31.0	3.7	18.1	41.4	5.0	24.0
	1973							29.8	10.6(71)	18.0(98)	41.3	14.3(72)	24.2(98)
	1977							27.6	10.5(80)	17.9(97)	41.0	14.2(71)	24.1(97)
Male	1910	9.0	3.8	1.7	18.1	7.6	3.3	27.1	11.4	5.0	36.1	15.2	6.6
	1946	8.9	3.6	1.5	17.9	7.4	3.2	26.9	11.2	4.8	35.9	15.0	6.5
	1960	8.5	3.3	1.3	17.6	7.1	2.4	26.6	10.9	4.6	35.6	14.7	6.2
	1970	4.6	1.1	0.0	13.1	3.1	0.2	22.4	6.9	1.9	31.4	10.7	3.5
	1973							21.3	8.2(72)	1.5(30)	31.3	12.5	3.1
	1977							19.8	8.9(78)	1.6(32)	31.9	13.2(67)	3.3(50)
Catch available		×			×								
Harem condition								△					
Pattern check													
RY	♀							0 – 500			0 – 700		
	♂							900 – 1,400			2,000 – 2,700		

× : rejected by negative age composition or pattern check
△ : harem condition is less than 1.5 × 1.3
‘Available (exploitable)’ were affected widely due to change of legal size limit.

Table 5

Estimated replacement yield in next 10 years for each situation for the Eastern Division

Situation	Sex	Present available number at the end of 1977	Rate of exploitation %	Replacement yield
5	F			
	M			
10	F			
	M			
15	F	105,388	0-0.5	0- 500
	M	91,204	1.0-1.5	900-1,400
20	F	142,052	0-0.5	0- 700
	M	133,988	1.5-2.0	2,000-2,700
	F			
	M			
	F			
	M			

Table 6

Comparison of actual catch with calculated available number in 1977 for the Eastern Division

Age interval	Catch	Situation 5		Situation 10		Situation 15		Situation 20	
		Available (exploitable)	Adjusted catch	Available (exploitable)	Adjusted catch	Available (exploitable)	Adjusted catch	Available (exploitable)	Adjusted catch
15-19	82					26,862	82	36,150	82
20-24	37					17,467	53	24,299	55
25-29	22					7,650	23	12,562	28
30-34	20					2,559	8	6,090	14
35-39									
40-44									

Annex F

NORTH PACIFIC SPERM WHALES (ALLEN KIRKWOOD MODEL)

(thousands) from Japanese CPUE data

Female MSY level Age at recruitment	Eastern stock				Western stock				
	50%	60%	70%	90%	50%	60%	70%	90%	
	male 11+		female 13+		male 13+		female 13+		
Pelagic data					Data Pooled				
1910 Stock (♂)	86.1	87.6	87.7	87.7	304.8	328.2	324.6	306.0	
1910 Stock (♀)	116.0	118.0	118.1	118.1	359.8	387.4	383.2	361.2	
1979 Stock (♂)	58.9	60.4	60.6	61.5	240.8	267.2	267.7	267.1	
1979 Stock (♀)	110.7	112.8	113.0	114.0	325.5	355.9	355.8	352.5	
% 1979/1910 (♂)	68.4	68.9	69.1	70.1	79.0	81.4	82.5	87.3	
% 1979/1910 (♀)	95.4	95.6	95.7	96.5	90.5	91.9	92.8	97.6	
MSY (♂)	1,392	1,463	1,653	2,126	4,713	5,191	5,825	7,007	
MSY (♀)	220	614	909	1,417	648	2,014	2,951	4,334	
MSY Level (♂)	49.6	47.0	50.5	61.3	183.5	170.1	193.5	221.2	
MSY Level (♀)	96.4	87.5	91.4	108.0	304.6	289.4	297.5	330.4	
% 1979/MSYL (♂)	119	128	120	100	131	157	138	121	
% 1979/MSYL (♀)	115	129	124	106	107	123	120	107	
Catch Limit (♂)	1,253	1,317	1,488	1,913	4,242	4,672	5,242	6,307	
Catch Limit (♀)	198	552	818	1,275	583	1,813	2,656	3,901	
Catch Limit (♂ + ♀)	1,451	1,869	2,306	3,188	4,825	6,485	7,898	10,208	A
Male catch only									
(same for all n)									
MSY (♂)	1,554	1,581	1,582	1,582	5,181	5,579	5,518	5,201	
MSYL (♀)	58.4	59.4	60.0	59.5	206.7	222.5	220.1	207.5	
% 1979/MSYL (♂)	101	102	101	103	117	120	122	129	
Catch Limit (♂)	1,399	1,423	1,424	1,424	4,663	5,021	4,966	4,681	B
Weight MSY (♂ + ♀)	31,494	37,476	44,890	60,148	97,506	122,573	145,003	183,092	C
Weight MSY (♂)	31,992	32,544	32,572	32,572	98,585	106,148	104,997	98,969	D
Weight % B/A	96	76	62	45	97	77	63	46	
Weight % D/C	102	87	73	54	101	87	72	54	

Annex G

SOUTHERN HEMISPHERE SPERM WHALES (ALLEN KIRKWOOD MODEL)

Table 1

Estimates of population sizes and their relation to initial and MSY levels

(a) CPUE data from Japan – Outside Baleen Season, Division 5.

Females (13+ years) 1947 = 27,674
Males (20+ years) 1947 = 12,943
Mature females 1947 = 32,639

Females (13+) 1979				Males (20+) 1979		
n	number	% of 1947	MSYL as % initial	number	% of 1947	MSYL as % initial
0.0	24,002	87	79	1,283	9.9	47
1.4	24,009	87	73	1,283	9.9	45
4.04	24,023	87	77	1,283	9.9	48
33.0	24,159	87	91	1,287	9.9	58

(b) CPUE data from USSR – North of 40° S, Division 5.

Females (13+ years) 1947 = 37,628
Males (20+ years) 1947 = 17,599
Mature females 1947 = 44,378

Females (13+) 1979				Males (20+) 1979		
n	number	% of 1947	MSYL as % initial	number	% of 1947	MSYL as % initial
0.0	35,168	94	79	5,938	34	47
1.4	35,177	94	73	5,938	34	45
4.04	35,194	94	77	5,939	34	48
33.0	35,372	94	91	5,942	34	58

(c) Albany Sightings data – Total Area, Division 5.

Females (13+ years) 1947 = 31,830
Males (20+ years) 1947 = 14,887
Mature females 1947 = 37,540

Females (13+) 1979				Males (20+) 1979		
n	number	% of 1947	MSYL as % initial	number	% of 1947	MSYL as % initial
0.0	29,210	92	79	3,236	22	47
1.4	29,218	92	73	3,236	22	45
4.04	29,234	92	77	3,236	22	48
33.0	29,401	92	91	3,240	22	58

(d) Albany Sightings data within Area, Division 5.

Females (13+ years) 1947 = 33,403
Males (20+ years) 1947 = 15,623
Mature females 1947 = 39,395

Females (13+) 1979				Males (20+) 1979		
n	number	% of 1947	MSYL as % initial	number	% of 1947	MSYL as % initial
0.0	30,893	92	79	3,971	25	47
1.4	30,901	93	73	3,972	25	45
4.04	30,918	93	77	3,972	25	48
33.0	31,090	93	91	3,975	25	48

(e) CPUE data from USSR – North of 40° S, Division 7.

Females (13+ years) 1947 = 57,400
Males (20+ years) 1947 = 26,847
Mature females 1947 = 67,697

Females (13+) 1979				Males (20+) 1979		
n	number	% of 1947	MSYL as % initial	number	% of 1947	MSYL as % initial
0.0	51,685	90	79	17,769	66	47
1.4	51,701	90	73	17,769	66	45
4.04	51,730	90	77	17,769	66	48
33.0	51,981	91	91	17,769	66	58

(f) CPUE data from Japan – North of 40° S, Division 7.

Females (13+ years) 1947 = 25,708
Males (20+ years) 1947 = 12,024
Mature females 1947 = 30,319

Females (13+) 1979				Males (20+) 1979		
n	number	% of 1947	MSYL as % initial	number	% of 1947	MSYL as % initial
0.0	19,993	78	79	2,946	25	47
1.4	20,008	78	73	2,946	25	45
4.04	20,035	79	77	2,946	25	48
33.0	20,213	79	91	2,946	25	58

(g) CPUE data from Japan – Outside Baleen Season, Division 7.

Females (13+ years) 1947 = 34,785
Males (20+ years) 1947 = 16,269
Mature females 1947 = 41,025

Females (13+) 1979				Males (20+) 1979		
n	number	% of 1947	MSYL as % initial	number	% of 1947	MSYL as % initial
0.0	29,071	84	79	7,192	44	47
1.4	29,086	84	73	7,192	44	45
4.04	29,114	84	77	7,192	44	48
33.0	29,323	84	91	7,192	44	58

(h) CPUE data from Peru*, Division 9.

Females (13+)				Males (15+)			
		1978 MSYL as % of				1978 MSYL as % of	
		1936	1978			1936	1978
n =							
0.0	84,969	62,684	74	90	55,280	33,319	60
n =							
1.39	75,690	53,876	71	77	49,243	28,145	57
m =							
4.04	81,045	62,173	77	79	52,727	33,235	63
m =							
33.0	93,609	84,228	90	92	60,901	47,440	78

* Pregnancy rate range 0.25–0.30.

Annex H

SUBCOMMITTEE ON SPERM WHALE RESEARCH NEEDS

Members: Best, Mitchell (Convenor), and Tillman.

We believe that in view of the complex behaviour, social structure and distribution of the sperm whale, CPUE data currently used may not be reliable measures of abundance. The stated policy of the Scientific Committee, to carry out the 'best estimate' of abundance, based upon the 'available data', has resulted in 'best estimates' being attempted even when insufficient data were tabled at meetings to carry out scientifically defensible assessments. Rather than labour to estimate ranges for parameters needed for complex and unverified models, parameters for which there are sometimes absolutely no hard data 'available', committee effort should be directed particularly towards development of assessment methods independent of CPUE analysis. The following data needs are identified, with emphasis on the analysis of existing data, and the collection of some new, but specified data.

1. Analysis of existing tag-recapture data, especially all putative stock areas of the North Pacific. More than 2,000 sperm whales have been marked in the North Pacific with tens of returns, but the only recent analysis (SC/SPC/Doc 3) has pooled the data. The data are published in essentially raw form. Analysis should be directed towards:

- (a) identity of stock areas,
- (b) percent interchange between specified area (stock areas, 10° squares, and other statistical regions), and
- (c) estimates of population abundance in these regions.

2. Analysis of existing sightings data, especially from the raw data with detailed information on relative proportion of all species of whales sighted per mile steamed with known sighting strip width. Data on sightings are collected but are not generally 'available' to the Committee in raw form, only as indices of abundance. Emphasis should be on estimation of absolute population size in stock areas and statistical regions through time.

Both 1 and 2, above, represent a useful minimum control against which population estimates derived from CPUE models could be compared.

3. Aging studies. All existing collections of sperm whale teeth should be processed in order to generate new age-length keys, especially for different stock areas and to examine possible changes in growth rates.
4. Modelling growth. Studies are needed to parameterise growth curves, as non-parameterised age/length keys do not lend themselves well to deductive modelling.
5. Schooling behaviour:
 - (a) Incidence of schools of differing composition by age and sex by season. This study could be based upon substantial, direct observations from scouting vessels and aircraft.
 - (b) Composition of schools. This must be accomplished by the taking of whole schools, preceded by observation of the school and the role of various animals in it before the kill; it should be preceded by analysis of all existing relevant data.

- (c) Observations of schooling behaviour during the breeding season, including monitoring movements of individuals by means of radio-tagging, and possible examination of the effect of removing school-master males.

6. Feeding studies for the analysis of trophic differences between sexes and age classes.
7. Log book studies, to examine the catching tactics of early whalers especially in regard to selection of large males on the breeding grounds, to identify different putative stock areas, and to test whether these areas were fished at different rates and became depleted at different times, and to devise methods of estimating initial abundance in the stock identified.
8. Compile detailed catch and other statistics by stock and statistical region, from existing data in national research files, BIWS records, and elsewhere.
9. Undertake case studies of stocks for which there are substantial data of reasonable quality, e.g. Southern Hemisphere Divisions 3 and 9 (in which equal numbers of both sexes were taken), and the North Pacific 'Coastal Japan' stock.
10. Distribution of the pelagic fleet in time and space, as a theoretical problem, and with specific goals of recommending particular fleet deployment, e.g. between Zones L, M, N, P, within a 1–2 year period to determine if previous data from these Zones can be treated as a single time series.

The subcommittee met with Horwood and Ohsumi as an *ad hoc* group on tagging data in order to devise a timetable for analysis of tagging data (1, above), and found that sufficient data were not available at this meeting to carry out preliminary analyses of estimates of abundance by putative stock areas in the North Pacific. Ohsumi indicated that the basic, detailed marking data, as well as data on returns, have been previously published. These data were first handled by a committee set up within the Japan Whaling Association, then responsibility for tagging was transferred to the Whales Research Institute, Tokyo, and finally to the Far Seas Fisheries Research Laboratory, Shimizu. The data thus are available in the following publications:

- (a) (Miscellaneous publications), Japan Whaling Association, Tokyo, 1950–54.
- (b) Scientific Reports of the Whales Research Institute, Tokyo, 1955–66.
- (c) (Annual Reports), Far Seas Fisheries Research Laboratory, Shimizu, 1967–73.
- (d) Japan, Progress Report on Whale Research, Report of the International Whaling Commission, 1974–present.

Ohsumi will xerox extracts of these data from the above publications and other archival files as necessary to make available to subcommittee members a complete set of the Japanese marking data for the North Pacific, 1949–present. These data include, for each whale marked: Date, species, location, results of marking, estimate of length of whale, name of tagging vessel, and remarks. These may be available before the next meeting of the Scientific Committee. Tillman agreed to chair the subsequent meeting of the tagging group, and direct an analysis of the raw data to test for items (a)–(c) in 1 (above).

Annex I

FINANCIAL PROVISION FOR COMPUTER SERVICES

At the June 1978 meeting the Scientific Committee 'noted that its operations were becoming more dependent upon efficient computer facilities' and 'agreed on the need for the establishment of a permanent data bank' and the Commission should 'appoint a suitably qualified person to its permanent staff' for this purpose. The present meeting has underlined the urgency of these requirements.

The Committee's work has now become totally dependent on the availability of efficient computer services both to handle and make available the data base, which is rapidly increasing in size and complexity, and to carry out the highly sophisticated calculations which are required for the stock assessments. This tendency will undoubtedly continue, probably at an increasing rate. Unless an efficient, continuing system can be set up to provide these services to the Committee its contribution to the work of the Commission will become increasingly inadequate and it will be totally unable to provide the Commission with advice based on scientific analysis of the quality and thoroughness which it needs. This is particularly true at the present time when its activities are being subjected to much vigorous public scrutiny.

Up to the present, the computer services available to the Committee have been set up afresh for each meeting by the host Government and been operated by members of national delegations. For the last four meetings of the Committee (Canberra, Cronulla, Cambridge and La Jolla) these services have been essentially set up and operated by a single Australian scientist, who has on the last two occasions spent several weeks in advance of the meeting at its venue establishing the facilities. In addition, other scientists on the Committee have also spent a great deal of time during the meeting in operating the computing services and providing analyses to the Committee. At the present meeting, at least three members of the Committee have devoted the greater part of their time to this work.

Between meetings, however, this work virtually ceases and is only picked up again by the individual Committee members as the next meeting approaches. The whole arrangement is therefore on an essentially make-shift basis and dependent upon the availability of very few members of the Committee. It could therefore collapse completely if certain people were no longer available to undertake the work, and could only be re-established with difficulty as other suitably qualified people could be made available by the national delegations.

In addition, the present arrangement, which essentially only operates during meetings, cannot undertake either the active collection of additional data which the Committee requires or the preparation in advance of the meetings of the various tabulations and analyses which the Committee needs. As a result, work in the early stages of the meeting frequently cannot proceed in a way which would make the best use of the available time, since it has to await completion of the necessary analyses.

The Scientific Committee is therefore strongly of the opinion that unless the Commission can take steps immediately to provide an adequate computer based system for the storage, retrieval and analysis of its data there is a serious risk that the Committee will become totally incapable of carrying out the studies which are essential for it to supply the Commission with the informed advice

which is essential to its operations under modern conditions.

These risks can be minimized only by the establishment within the Commission's organization, and preferably in close association with the Secretary's office, of a permanent computer system with well qualified staff.

The tasks involved in setting up this group and in its subsequent activities include:

A. Establishment

This involves the setting up of a modern efficient data handling system and the storage in it of the large amount of data already available in existing computer files used by the Committee or in the B.I.W.S. The system would have to be capable of storing the great quantity and diversity of data which is available now and will be added in the future. It should also provide easily and rapidly any analyses of these data which were required. It would also have to be capable of expanding indefinitely to accept both updating of existing data sets and the establishing of sets of new kinds of data (e.g. time budget data in 1977, school size data in 1978) as the need for them was identified.

Four steps can be distinguished in the establishment phase:

- A1. A preliminary design study to develop a specification for the system itself including the identification of the kinds of data to be handled and outputs required. It should also consider the location of the central facility, and the extent to which access to the facility will be required for meetings at other centres.
- A2. The design of the system itself and its installation in operating condition on the selected computer.
- A3. Incorporation into the system of all the relevant data immediately available.
- A4. Acquisition of the necessary computer hardware and other equipment.

B. Operation

- B1. Continuing work with the Scientific Committee and national groups to identify and obtain additional data, and then to incorporate in the system.
- B2. Preparation in advance of each meeting of the Scientific Committee of a variety of standard analyses and tabulations which it is known would be needed by the Committee in its work.
- B3. Preparation, during the meetings themselves, of special data tabulations which the Committee required.
- B4. Running of stock assessment analyses during the meetings using programmes developed by the scientists on the Committee and possibly by others. This work would be done to the specified direction of the Committee as to the data and parameter values etc. to be used. It is not proposed that the Commission staff should undertake the development of such programmes since these must be initiated by scientists expert in the techniques of population analysis and assessment. Their function would be to ensure that these programmes were incorporated and maintained in the system in a manner which made them fully available for use and updating.

B5. A minor, but not unimportant activity could also be the provision, perhaps at cost, of specified data to scientists outside the Commission. There are probably many scientists carrying out research in population dynamics and related fields who would be very glad to have access to some of the data which the Commission would hold in the system. The provision of a service of this kind could only be beneficial to the public image of the Commission.*

The first two stages of the establishment process would require to be undertaken by experts in the field of computer systems. They should therefore be done by consultants on contract.

The third stage, incorporation of existing data into the system needs to be kept separate from the operation of the system to meet existing needs. Unless this is done incorporation of these data is likely to be very seriously delayed by conflicts with day-to-day demands. It would require staff experienced in the handling of biological or fisheries type data, but not a high level of computer expertise. It could be done either as a separate contract or by temporary IWC staff who had no other responsibilities.

The key figure in the Commission's permanent staff would have to be a biologist with a strong background in computer science. He should work with the consultant in the establishment of the system and would afterwards be responsible for its maintenance and operation. He should have the ability and qualifications to understand both the needs of the Scientific Committee, and to make effective use of the computer system. He would oversee the incorporation phase of the establishment system, but should not be personally involved since his primary responsibility should be operating the system and supplying the necessary information to the Scientific Committee so as to enable it to work effectively. For at least the first year he could be expected to undertake the actual operation of the computer for both the storage and retrieval of data. He

should also be responsible for the scrutiny and editing of incoming data for accuracy and compatibility.

As the system develops it may be anticipated that the key person would require the help of a person at the computer operator level who would do most of the machine operation, and some coding and keypunching of data. It is not clear at this stage when such a person might be required. There might well be a phase in which such support was only needed periodically in association with meetings of the Committee and was unnecessary at other times.

At a still later stage a lower grade assistant to undertake coding and keypunching etc. might be required, but this need is not foreseen in the immediate future.

The principle costs of setting up and operating such a system are seen to be:

Establishment	Consultant to conduct preliminary study and development specifications	£1,000
	Consultant to set up the data system – one time cost – includes travel	£15,000
Operating	Incorporation of existing data in the system	£20,000
	Computer hardware – terminal, keypunch etc.	£5,000
	Computer operation during system establishment	£9,000
	Biologist – computer scientists, annual salary costs including other expenses	£13,000
	Computer operating costs – annual	£8,000

The Committee strongly urges the Commission to make provision to enable at least initial steps towards the establishment of the system to be taken before the June 1978 meeting. It expresses its grave concern that, unless this is done, it could well be unable to provide the Commission with the advice expected of it on even that early occasion. Even so, the new system would not be fully operational by that time. It should however be fully available by June 1980.

*It would be essential for the person doing this work to spend at least several weeks with Dr G. P. Kirkwood, either in England or in Australia, since he is the only person fully familiar with the existing systems and data bases. The work would probably take 3–6 months.

Annex J

REVISED REQUIREMENTS FOR DATA ON CATCHING EFFORT

Title page (one logbook per catcher per season)

CATCHER NAME YEAR BUILT

ATTACHED TO EXPEDITION/LAND STATION

SEASON

OVERALL LENGTH WOODEN/STEEL HULL

GROSS TONNAGE

TYPE OF ENGINE H.P.....

MAXIMUM SPEED AVE. SEARCHING SPEED

ASDIC SET, MAKE AND MODEL NO.

DATE OF INSTALLATION

MAKE AND SIZE OF CANNON

TYPE OF FIRST HARPOON USED (EXPLOSIVE, ELECTRIC, NON-EXPLOSIVE)

TYPE OF KILLER HARPOON USED

LENGTH AND TYPE OF FORERUNNER

TYPE OF WHALELINE

HEIGHT OF BARREL ABOVE SEA LEVEL

SPEEDBOAT USED, YES/NO

NAME OF CAPTAIN

NUMBER OF YEARS EXPERIENCE

NAME OF GUNNER

NUMBER OF YEARS EXPERIENCE

NUMBER OF CREW

Daily record sheet

DATE.....

CATCHER NAME.....

SHEET NO.

SEARCHING: TIME STARTED (OR RESUMED) SEARCHING

TIME WHALES SEEN

WHALE SPECIES

NUMBER SEEN and NO. OF GROUPS

POSITION FOUND

NAME OF CATCHER THAT FOUND WHALES

CHASING: TIME STARTED CHASING (OR CONFIRMED WHALES)

TIME WHALE SHOT or CHASING DISCONTINUED

ASDIC USED (YES/NO)

HANDLING: TIME WHALE FLAGGED or ALONGSIDE FOR TOWING

SERIAL NO. OF CATCH

TOWING: TIME STARTED PICKING UP

TIME FINISHED PICKING UP or STARTING TOWING

DATE AND TIME DELIVERED TO FACTORY

RESTING: TIME STOPPED (FOR DRIFTING OR RESTING)

TIME FINISHED DRIFTING/RESTING

TIME CEASED OPERATIONS

TOTAL SEARCHING TIME.....

TOTAL CHASING TIME.....

TOTAL HANDLING TIME

TOTAL TOWING TIME.....

TOTAL RESTING TIME.....

OTHER TIME

(e.g. bunkering, in port).....

WEATHER CONDITIONS

TIME	SEA STATE	WIND FORCE & DIRECTION	VISIBILITY

WHALES SEEN (No. and No. of schools)

BLUE.....

FIN

HUMPBACK.....

RIGHT.....

SEI.....

BRYDE.....

MINKE.....

SPERM.....

OTHERS.....

(specify)

SIGNED.....

Annex K

SOVIET TIME BUDGET DATA FOR SPERM WHALE OPERATIONS

Summary by M. F. Tillman

Table 1
North Pacific

	Season	Scouting (searching)	Taking ¹ (chasing)	Processing (handling)	Towing	Resting & Other ² (resting)	Total catch	No. of ³ Catchers
A. Season	1972	1,979	303	64	137	2,059	144	3
Total	1973	3,267	770	131	389	3,749	440	3
(hour)	1974	3,673	1,022	158	324	4,166	562	5
	1975	3,090	1,022	196	249	4,245	584	3
	1976	3,493	775	107	269	3,418	379	3
	1977	3,963	665	90	188	3,934	291	3
B. Per Whale	1972	13.74	2.10	0.44	0.95	14.30		
(hour)	1973	7.43	1.75	0.30	0.88	8.52		
	1974	6.54	1.82	0.28	0.58	7.41		
	1975	5.29	1.75	0.34	0.43	7.27		
	1976	9.22	2.04	0.28	0.71	9.02		
	1977	13.62	2.29	0.31	0.65	13.52		
	Ave.	9.31	1.96	0.33	0.70	10.01		

¹ Soviet "taking" data did not include time spent chasing lost whales.
² "Other" included time refueling, repairing, etc. which usually is included in "resting." May also include time spent chasing lost whales.
³ None equipped with ASDIC. Composition different each season.

Table 2
Southern Hemisphere

	Season	Scouting (Searching)	Taking ¹ (Chasing)	Processing (Handling)	Towing	Resting & Other ² (Resting)	Total (Catch)	No. of ³ (Catches)
A. Season	1972/73	1,951	531	97	491	3,427	483	3
Totals	1973/74	2,685	644	107	322	4,522	508	3
(Hour)	1974/75	3,257	558	127	403	4,290	496	3
	1975/76	4,481	596	142	455	4,572	447	3
	1976/77	2,864	385	94	387	4,432	409	6
B. Per Whale	1972/73	4.04	1.10	0.20	1.02	7.10		
(hour)	1973/74	5.29	1.27	0.21	0.63	8.90		
	1974/75	6.57	1.13	0.26	0.81	8.65		
	1975/76	10.02	1.33	0.32	1.62	10.23		
	1976/77	7.00	0.94	0.23	0.95	10.84		
	Ave.	6.58	1.15	0.24	0.89	9.14		

¹ Soviet "Taking" data did not include time spent chasing lost whales.
² "Other" included time refueling, repairing, etc. which usually is included in "Resting". May also include time spent chasing lost whales.
³ None equipped with ASDIC. Composition variable each season.

Annex L

COMMENTS ON SPERM WHALE PREGNANCY RATE, BRITISH COLUMBIA, 1954–1967,
FROM DATA COLLECTED BY G. C. PIKE*

Edward Mitchell

Arctic Biological Station, Box 400, Ste. Anne de Bellevue, Province of Quebec, Canada

Gordon C. Pike made extensive biological collections from whales taken off British Columbia, at the Coal Harbour whaling station, in the 1950s–1960s. On his death in 1968 (Rice, 1970), he had completed a few manuscripts on this material, but had decided not to publish them, for various reasons.

One illustration apparently prepared for an uncompleted paper by Pike, is a plot of lengths of 149 sperm whale foetuses by month for the period April – August, 1954–1967 (Fig. 1). Also available are tables for years 1951–1967 giving reproductive information by month (Pike, 1967 Ms; summarized in my Table 1), and the sex ratio in the monthly catch for the period 1949–1967 (Pike, 1964 Ms; summarized in my Table 2).

extends over more than one year. In order to compensate for this, the true pregnancy rate must be calculated from one or the other of the foetal length classes in the sample. During the catching period, both early foetuses, under 100 cm, and late foetuses, over 100 cm, were found (Fig. 1). (In the sexual maturity data in Table 1, pregnancy for a few whales may have been judged on the presence of a corpus luteum only, but the total is close to the number of foetuses measured and I have assumed Pike carefully examined the whales for small foetuses.) In this sample of 149 measured foetuses, only five were early, thus, for this sample, 96.6% were late foetuses (i.e. 149–5 for 144/149 late foetuses).

Applying this percentage to the total sample available

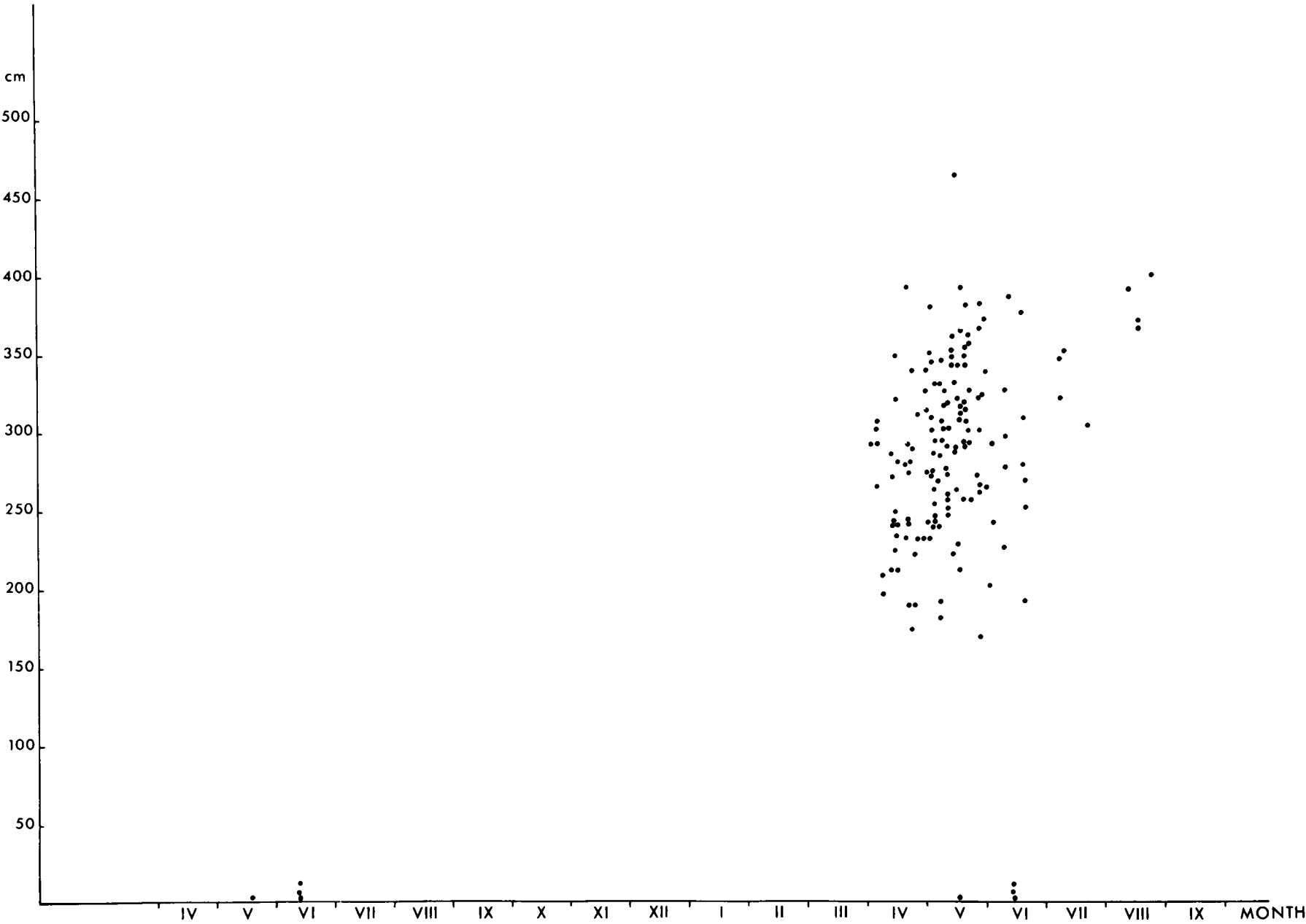


Fig. 1. Lengths of 149 sperm whale foetuses taken off British Columbia, April–August 1954–67.

Ohsumi (1965), Best (1968) and Gambell (1972) have presented increasingly detailed information for a four year breeding cycle in female sperm whales. The gestation period

(Table 1, last column) results in an estimate of true pregnancy rate of 33%.

This appears to be very high compared with true pregnancy rates of 22.7% from Best's (1968) data, and rates of 18.5% for the Azores and 18.8% for Durban as analyzed by Gambell (1972). For the North Pacific, Ohsumi (1965) estimated the Japanese coastal true pregnancy rate as 26–29%, which Gambell (1972, p. 320) believed to be an

*IWC SC/SP 78/22, revised. Curation and search of Pike files partially supported by Center for Environmental Education, Washington, D. C.; carried out by M. McLaughlin. I thank V. M. Kozicki, J. M. Breiwick and D. W. Rice for critical comments on the first draft.

overestimate. Rice (1963) reported 39% pregnant in a sample of 26 adult females taken off coastal California. Rice and Wolman (1970 Ms) recalculated this rate from a larger sample of 198 mature females, and, on the basis of a three year cycle, concluded that the rate was 0.33. Considering only the 99 September–December females in their sample, 0.33 were in early pregnancy. (See also the section on Pregnancy Rates (p. 67) in the main report and papers cited therein.)

Since the sperm whale has a complex social organization, the female component may segregate by reproductive state, but Best (1979) found no clear cut evidence for this. Nevertheless, the reported high rate for California and British Columbia might have been due to migration of pregnant females into the catching area.

Another reason might have been selection in the Coal Harbour fishery for larger whales, resulting in the capture

of more pregnant females. The data do not bear this out, however. There is no clear cut trend in the estimate of corrected, true pregnancy rate through time (Table 1), as would be expected with increasing selection for fatter whales. Also, the minimum size of 35 ft for shore stations was not lowered until after the period involved here, so this cannot be a factor.

The percentage of females in the catch increased steadily through time (Table 2), possibly reflecting local depletion of males, selection for females, or changes in the hunting grounds or the nature of the migrating schools. Writing in 1962, Pike stated that ‘periods of operation, catching efficiency, number or catchers, size limits and incentive bonuses all affect the catch’ for the entire operation, and that specifically for sperm whales, ‘although harem schools appear almost every year off this coast, mostly in April and May, and again in August, few are taken because of the

Table 1

Results of examination of reproductive tract by G. C. Pike and I. B. MacAskie of some female sperm whales landed at Coal Harbour, British Columbia, 1951–67; data as reported by Pike, 1967 Ms. (in Sheets 1–8 of form Sp. 3).

Year (April– August)	Immature		Sexually Mature				Total (Immature + Mature)	Uncorrected P + (P + L) M	Corrected P + (P + L) M
	Ovulating	Pregnant	Lactating	Lactating and Pregnant	Resting	Total Mature			
1951–58	0	1	28	21	0	22	72	.3889	.3757
1962	3	1	18	9	1	16	45	.4222	.4079
1963	2	0	21	7	3	11	42	.5714	.5520
1964	0	1	13	19	0	4	37	.3514	.3394
1965	1	0	20	31	4	13	68	.3529	.3409
1966	0	0	18	29	2	33	82	.2439	.2356
1967	1	1	35	71	1	26	135	.2687	.2595
Totals	7	4	153	187	11	125	480	.3416	.3301

Table 2

Ratio of sexes in catch by month, of Sperm whales landed at Coal Harbour, British Columbia, 1949–67. Data from Pike, 1964 Ms (Form NP 1), 1967 Ms (in Sheets 1–3 of form Sp. 4), and *International Whaling Statistics*, Oslo.

Year	Month	Number ♂ : Number ♀						Totals ♂:♀	% ♀
	April	May	June	July	August	September			
1949		0:0	9:0	7:0	28:0	16:0	9:0	69:0	0
1950		0:0	15:0	19:0	6:0	0:0	0:0	40:0	0
1951		15:1	28:10	20:6	30:0	30:0	14:0	137:17	11.0
1952		0:0	38:3	21:0	17:0	19:1	27:0	122:4	3.2
1953		13:1	28:5	41:0	77:0	72:0	37:0	268:6	2:2
1954		34:4 ^a	38:7	43:0	37:0	39:0	24:0	215:11	4.9
1955		23:6	41:5	40:5	58:0	69:0	73:0	304:16	5.0
1956		0:0	25:20	24:0	26:0	14:0	18:0	107:20	15.8
1957		21:8	26:18	32:18	20:0	30:1	18:0	147:45	23.4
1958		6:6	14:30	4:0	6:0	32:0	14:0	76:36	32.1
1959		18:1	45:38	28:4	41:0	50:2	32:0	214:45	17.4
1960 ^b		—	—	—	—	—	—	—	—
1961 ^b		—	—	—	—	—	—	—	—
1962		6:4	20:50	21:3	7:0	18:0	39:4	111:61	35.5
1963		0:0	18:34	28:11	5:7	24:0	20:0	95:52	35.4
1964		16:11	13:21	5:13	12:0	9:0	5:0	60:45	42.9
1965		21:27	21:35	1:10	3:4	20:2	7:0	72:78 ^c	52.0
1966		35:34	53:55	4:8	7:0	6:0	28:0	132:97 ^d	42.4
1967		51:79	38:53	24:19	17:0	13:10	0:0	143:161 ^e	53.0
Totals		259:182	470:384	362:97	397:11	461:16	365:4	[2312] ^{c,d} :694	23.0

^a Also may include March catches.
^b No whaling from British Columbia, 1960–61, *fide International Whaling Statistics*.
^c ‘In addition, one sperm-whale, sex and length not stated’, *fide IWS*, vol. 57, p. 60n, but which Pike listed as a male in breakdown by month, as above, so total is 73:78.
^d Pike’s breakdown by month totals 133:97, but IWS reported 132:97.
^e Pike’s data, but IWS reported 140:164.

35-foot size limit and the abundance of very small whales in the schools' (Pike, 1962 Ms, p. 2; and see Pike and MacAskie, 1969, p. 14).

British Columbia began operating land stations in 1905 (Pike, 1953). Sperm whale catches listed for the period 1919–1948 (Pike, 1953, table 1) were taken mainly near Rose Harbour and Naden Harbour, and show a peak of a few hundred a year in the mid 1930s; interest in the species has been constant. The 1949–1967 catches (Table 2) likewise indicate constant interest throughout the period and over the six month season of operation. The preponderance of females caught in April–June, with a peak in May, presumably reflects their availability inshore on the northward, spring migration (cf. Pike and MacAskie, 1969, p. 14).

In conclusion, the data on true pregnancy rate, in a sample of over 600 females, based on late pregnancies, indicates a value of 33%. The high value may be the result of northward, and/or inshore segregation of pregnant females in the local, northeast Pacific population.

REFERENCES

Best, P. B. 1968. The sperm whale (*Physeter catodon*) off the west coast of South Africa. 2. Reproduction in the female. *Investl. Rep. Div. Sea Fish. S. Afr.* 66: 1–32.

Best, P. B. 1979. Social organization in sperm whales, *Physeter catodon*. Chapter 7, pp. 227–89 In: H. E. Winn, and B. L. Olla [Eds.], *Behavior Of Marine Animals*, Vol. 3, Plenum Publishing Corporation.

Gambell, R. 1972. Sperm whales off Durban. *Discovery Rep.* 35: 199–358.

Ohsumi, S. 1971. Some investigations on the school structure of sperm whale. *Sci. Rep. Whales Res. Inst., Tokyo* 23: 1–25.

Pike, G. C. 1953. Whaling on the British Columbia coast. pp. 370–3 In: *Proceedings of the Seventh Pacific Science Congress*, Vol. 4, Auckland, Whitcombe and Tombs.

Pike, G. C. 1962 Ms. Canadian whaling off British Columbia, and progress of research, 1948 to 1959. Fisheries Research Board of Canada, Biological Station, Nanaimo, B.C. 15 June 1962, p. [i–iii] + 1–40 typescript (mimeographed).

Pike, G. C. 1964 Ms. Whaling data tables. Coal Harbour, British Columbia, 1948–1964. Fisheries Research Board of Canada, Biological Station, Nanaimo, B.C., 15 March 1964, 82 pp.

Pike, G. C. 1967 Ms. Basic data tables on sperm whales from British Columbia. IWC Sperm Whale Sub-Committee; Submitted to the IWC/FAO Sperm Whale Assessment Group, December 1967, 41 pp. (in Sheets 1 *et seq.* for forms Sp. 1–Sp. 6).

Pike, G. C. and I. B. MacAskie. 1969. Marine Mammals of British Columbia. *Fish. Res. Board Canada, Bull.* 171, Queen's Printer for Canada, Ottawa, pp. i–x + 1–55.

Rice, D. W. 1963. Progress report on biological studies of the larger Cetacea in the waters off California. *Norsk Hvalfangsttid.* 52(7): 181–7.

Rice, D. W. and A. A. Wolman. 1970 Ms. Sperm whales in the eastern North Pacific: Progress Report on research, 1959–1969. IWC Sci. Comm., Sperm Whale Biology and Stock Assessments meeting, March 1970, Honolulu, (unpubl. doc.) SP/3, 18 pp.

Rice, D. W. 1970. Gordon C. Pike, 1922–1968. *J. Mammal.* 51(2): 434–5.

Annex M
(SC/SP78/34)

COMPARISON OF PREGNANCY AND RECENTLY OVULATED RATE
AT PAITA 1959–64 vs. 1976–78

D. G. Chapman

Proportions of pregnant and recently ovulated females by year (February to July where data is available – number in sample in parentheses).

1959	0.300	(20)
1960	0.312	(154)
1961	0.266	(169)
1963	0.368	(95)
1964	0.360	(25)

Weighted average: 0.309 (463)		
1976	0.341	(44)
1977	0.192	(52)
1978	0.583	(12)
Weighted average: 0.296 (108)		

χ^2 test comparing early and late years yields a value of 0.064 (1d.f.). This is not significant. Overall weighted average: 0.306.

Annex N
(SC/SP 78/35)

PREGNANCY RATES IN SOUTHERN HEMISPHERE SPERM WHALES

Observed pregnancy rates in Japanese pelagic catches. Data expressed by calendar year, not season. Division between early and late pregnant animals made at 110 cm. Pregnant animals with lost foetuses not included as pregnant. Values in parenthesis include ovulating whales.

(a) Division 2

March 1976, n = 13, early = 0.08 (0.15), late = 0.

(b) Division 3

	1966	1969	1977
November			
n	8	88	—
early	0	0.01 (0.19)	—
late	0	0.22	—
December			
n	4	—	—
early	0	—	—
late	0	—	—
March			
n	—	—	28
early	—	—	0.07 (0.18)
late	—	—	0.11

(c) Division 4

	1966	1969	1970	1974	1976
November					
n	0	41	257	219	—
early	0	0 (0.05)	0 (0.28)	0.04 (0.12)	—
late	0.25	0.20	0.14	0.17	—
December					
n	—	—	—	—	—
early	—	—	—	—	—
late	—	—	—	—	—
February					
n	—	—	—	—	39
early	—	—	—	—	0.08 (0.21)
late	—	—	—	—	0.21

(d) Division 5

	1970	1971	1974	1975	1976
November					
n	—	7	—	—	—
early	—	0	—	—	—
late	—	0.29	—	—	—
December					
n	57	183	5	—	—
early	0 (0.28)	0.01 (0.26)	0.(0.40)	—	—
late	0.28	0.19	0	—	—
January					
n	—	—	—	33	—
early	—	—	—	0.30	—
late	—	—	—	0.12	—
February					
n	—	—	—	—	46
early	—	—	—	—	0.02 (0.15)
late	—	—	—	—	0.13

(e) Division 6

	1970	1971	1972	1974	1975	1976
November						
n	41	135	205	23	6	3
early	0.05 (0.24)	0.06 (0.31)	0.10 (0.25)	0.22 (0.43)	0 (0.50)	0
late	0.24	0.19	0.22	0.13	0	0.33
December						
n	—	—	21	22	—	
early	—	—	0.19 (0.38)	0.14 (0.32)	—	
late	—	—	0.05	0.14	—	

(f) Division 7

	1970	1971	1972	1973	1974	1975
November						
n	241	184	133	88	42	49
early	0.02 (0.17)	0.04 (0.28)	0.05 (0.18)	0.05 (0.17)	0.10 (0.24)	0.02 (0.22)
late	0.17	0.20	0.25	0.22	0.19	0.31
December						
n	—	—	—	133	133	0
early	—	—	—	0.12 (0.26)	0.06 (0.25)	0 (1.00)
late	—	—	—	0.19	0.20	0
January						
n	—	—	—	—	9	—
early	—	—	—	—	0	—
late	—	—	—	—	0.22	—

(g) Division 8

	1975	1977
January		
n	8	—
early	0.13 (0.25)	—
late	0	—
March		
n	—	21
early	—	0 (0.19)
late	—	0.10
November		
n	47	—
early	0 (0.32)	—
late	0.19	—

Annex O
(SC/SP78/37)

PELAGIC WHALING OFF THE 'COAST OF PERU' 1936–1954. STATISTICAL MATERIAL COMPILED BY T. GARRETT

In considering sperm whales in Division 9, it should be realized that intermittently heavy pelagic exploitation of sperm whales occurred off Peru from 1935 through 1954. Failure to consider this exploitation might result in (a) underestimation of initial population size, and (b) underestimation of effects of prior exploitation on pregnancy rates recorded from 1959 onward.

Length and sex data from pelagic operations are available from 1941–1951. The most useful data are those

compiled by the Norwegian vessel *Thorshammer* which operated off Peru from 27 October to 11 January 1941, from 29 May to 31 August 1942 and from 31 July to 11 November 1943. Catch data from the *Olympic Challenger* for 1954 are not considered reliable.

I have assembled the following tables to summarize information presently available on the pelagic killing of sperm whales 1935–54.

Table 1

Reported total kill by expedition 1935–54			
Year	Expeditions	No. catchers	Total reported kill
1936	<i>Salvestria</i>	16	2,021
	<i>Sourabaya</i>		
1937	<i>Salvestria</i>	22	3,776
	<i>Sourabaya</i>		
	<i>Anglo Norse</i>		
1938	1 Unidentified (German Flag)	8	602
10/27/41		8	1,913
1/11/42	<i>Thorshammer</i>		
5/29/42			
8/31/42	<i>Thorshammer</i>	8	3,342
6/31/43			
11/10/43	<i>Thorshammer</i>	8	3,299
6/19/47			
9/12/47	<i>Anglo Norse</i>	20	2,887
	1 Unidentified		
7/16/48			
12/19/48	<i>Anglo Norse</i>	13	2,497
4/14/51			
12/2/51	<i>Olympic Challenger</i>		6,317
1954	<i>Olympic Challenger</i>		4,068*
Total kill 1936–54			30,722

* Figure taken from *Norsk Hvalfangst-Tidende*. This figure is much larger than that initially reported by *Olympic Challenger*. The higher figure is accepted here because of strong evidence that only a portion of the whales taken were reported. It is also felt that the higher figure would help produce a more realistic total for mortality during the period because of unreported struck and lost whales, which was a particular problem during the war because of defective forerunners. An alternative estimate consistent with reports submitted by the *Olympic Challenger* is 2,563 whales.

Table 2

Total reported pelagic kill of male and female sperm whales 1941–51			
Year	Total males	Total females	Total
1941	1,078	835	1,913
1942	1,627	1,715	3,342
1943	1,738	1,516	3,254
1947	2,589	298	2,887
1948	2,207	290	2,497
1951	5,573	944	6,517
Total	14,812	5,598	20,410

Table 3

Sex and length of whales taken by <i>Thorshammer</i> 1941–43. Coast of Peru'							
Length	1941		1942		1943		
	Males	Females	Males	Females	Males	Females	
21		1					
22	1				1		
23	2			3			2
24	1	2	3	6			1
25	6	27	21	29	8		10
26	8	14	24	23	17		27
27	14	20	41	64	23		49
28	11	23	29	89	27		57
29	17	50	47	106	31		90
30	27	79	79	225	53		176
31	25	98	100	232	50		164
32	29	104	81	265	72		228
33	30	91	84	193	73		222
34	45	113	100	213	89		211
35	60	101	134	130	127		167
36	54	49	94	77	105		86
37	61	33	78	35	110		38
38	58	17	87	12	89		18
39	57	12	64	5	75		5
40	84	1	79	6	94		
41	73		41	1	75		
42	68		33		55		
43	48		38		57		
44	56		43		48		
45	50		37		44		
46	34		28		47		
47	31		31		48		
48	25		28		43		
49	17		29		24		
50	29		40		54		
51	18		22		40		
52	13		38		38		
53	12		23		47		
54	13		25		29		
55	0		19		19		
56	1		5		9		
57			1		3		
58			1		1		
59					1		
60					2		
Total	1,078	835	1,627	1,715	1,738		1,516
Average length of whales taken (in feet)							
	39.77	32.33	37.82	31.76	39.66		32.23

Total males 1941–43 = 4,433; total females 4,066.
Average length males 1941–43 = 38.98 ft; average length females 1941–43 = 32.2 ft.

Table 4

Breakdown of size composition of sperm whales taken by <i>Thorshammer</i> 1941–43						
Length (ft)	1941		1942		1943	
	Male	Female	Male	Female	Male	Female
Under 30	60 5.6%	137 16.4%	165 10.1%	320 18.7%	107 6.1%	236 15.1%
30–35	156 14.5%	485	444 27.3%	1,128 65.7%	337 19.4%	1,001 64.1%
Over 35	862 79.9%	213	1,018 62.6%	267 15.6%	1,294 74.5%	324 20.8%

Table 5
Summary of pregnancy data from *Thorshammer*

(a) Percentage of females found to be pregnant: 1941 1942 1943				(d) Pregnant females by month killed and average length of foetus by month			

Timing of Oestrus Within Sperm Whale Schools

Peter B. Best and Douglas S. Butterworth
Sea Fisheries Branch, Cape Town, South Africa.

ABSTRACT

Conception dates of sperm whale fetuses at Durban were estimated from the average foetal growth rate. The variance of such conception dates within schools was less than in the population as a whole, particularly in schools where 3 or more pregnant females were examined. Possible causal factors for the tendency for synchronisation of oestrus and its significance in the species' social organisation are discussed.

INTRODUCTION

Available evidence indicates that the sperm whale has a polygynous social organisation, and that most breeding is performed by large males (schoolmasters) that join female schools during the spring (Best, 1979). It is not known, however, how long these males remain in association with the female schools during the breeding season. Recent discussions in the IWC's Scientific Committee have indicated that the length of the schoolmaster's tenure may be an important component in modelling expected changes in the pregnancy rate when the ratio of mature males to females in the population is reduced (IWC, 1979).

Berzin (1971) and Tormosov (1975a) have commented that female sperm whales from one school may be in very similar stages of pregnancy. As schools of adult females appear to be stable, year-round units (Best, 1979), these observations indicate that there may be synchronisation of oestrus within a school. If this is so, there would seem to be little reproductive advantage in a schoolmaster prolonging its tenure with a particular female school once all the available females had ovulated.

This paper investigates the size distribution of fetuses from sperm whales landed at Durban to determine if synchronisation of oestrus occurs.

MATERIAL AND METHODS

Fetuses found on the flensing platform at Durban were examined either by a biologist, an inspector or the platform foreman, and the total length (tip of snout to notch in flukes) and sex were recorded in the official statistics. The accuracy of these measurements therefore varies with the personnel concerned, and there is no guarantee that all fetuses were actually found or measured (Best, 1980). For the purposes of this paper, however, it is only necessary to assume that there was no systematic bias towards or against any particular size-group of fetus. It is possible that the smallest fetuses would be missed by platform foremen or inspectors, hence data for February (where the highest proportion of such fetuses was found during the Durban whaling season) have been omitted. Furthermore, females in late pregnancy (Best, 1980) have been omitted from this analysis because the beginning of the Durban whaling season coincided with the end of the calving season, and the size composition of the largest fetuses was correspondingly skewed.

Data for the seasons 1973 to 1975 only has been

analysed, because during these seasons systematic collections were made of ovaries from all females landed, and this probably resulted in a high proportion of the pregnant females being reported. Measurements of 404 fetuses from females in early pregnancy were available.

During the 1973 to 1975 seasons the catcher crews were also asked to complete special forms for each day's catch which included the time and geographical position of each whale killed. In the absence of any direct information on which whales came from the same school, the assumption has been made that sperm whales killed by the same catcher on the same day and in the same position were from the same school. As a check on this, the killing intervals (i.e. times between successive kills) for such whales were examined to see whether the times were compatible with animals being killed in the same vicinity. Individual whales from a day's catch could be recognised on the flensing platform from a system of notches cut in the tail that identified the catcher and the serial number of the whale.

A total of 98 groups from which two or more females in early pregnancy were killed by the same catcher was available from the period 1973 to 1975.

RESULTS

There appears to be a linear relationship between the length of the sperm whale fetus in early pregnancy and time (Fig. 1). A regression fitted to the data by the method of least squares produced the estimating equation

$$y = -0.535 + 0.028x \quad \dots (1)$$

where x = time in days from 1 January (chosen as day 1) and y = foetal length (feet). The growth in length per day of 0.028 ± 0.0014 ft (s.e.) has a metric equivalent of 0.85 ± 0.04 cm. This is very similar to foetal growth rates calculated for Durban (0.88 ± 0.01 cm/day) and the North Pacific (0.85 ± 0.02 , 0.86 ± 0.02 cm/day) from official statistics (Gambell, 1972).

If the assumption is made that there is no variation in foetal growth rate, then the scatter of foetal lengths about the regression line should only represent variation in the date of conception. Under this assumption, the distribution of 'conception dates' in the population can be compared with that in individual groups, and if some synchrony of oestrus should occur then the variance of the former will be greater than that of the latter.

Individual 'conception dates' (d_i) have been calculated using the growth rate of 0.028 ft per day, where x_i = foetal

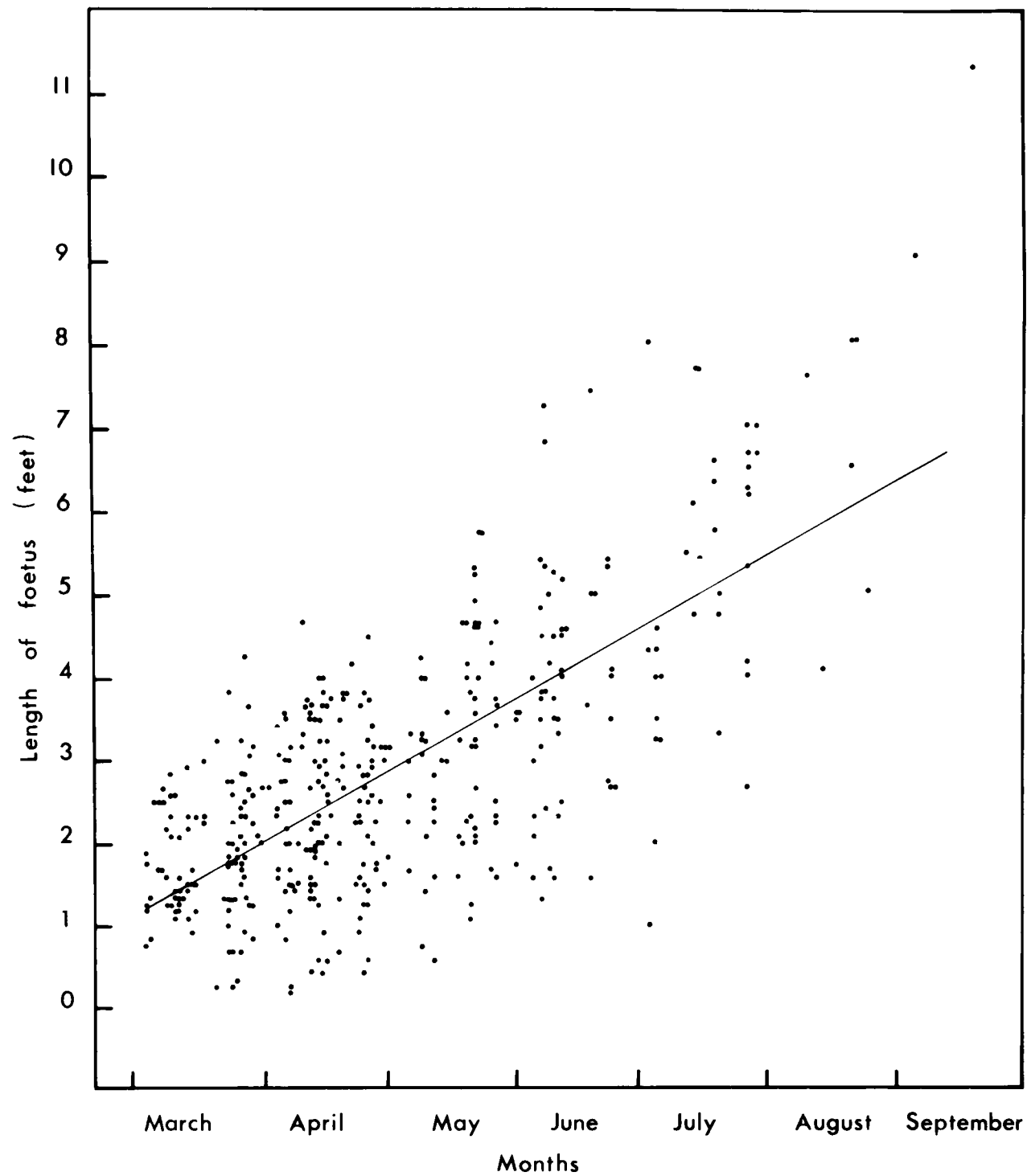


Fig. 1: Sperm whale foetal growth in early pregnancy, Durban 1973–75.

length (ft) and y_i = date of capture (with 1 January as day 1).

$$d_i = y_i - \frac{x_i}{0.028} \quad \dots (2)^1$$

It should be pointed out that these are not true conception dates, as the initial rate of mammalian embryonic growth is thought to be much slower than that occurring throughout the remainder of pregnancy (Huggett and Widdas, 1951). The conception dates calculated here will therefore be somewhat later than the true dates. However in the same spirit as the assumption of no variation in foetal growth rate, we may assume a constant difference between the d_i and the true conception date, so that variation of true conception dates is equivalently represented by variation of the d_i .

¹ Strictly since variance in the d_i is to be considered, the x_i should be regressed against the y_i rather than vice versa. However such analysis would be biased by the absence of catches prior to 1 March, so that the procedure adopted is reasonable in the circumstances.

A more rigorous analysis should also allow for the fact that there is a greater uncertainty in d_i calculated in this manner for larger foetuses than for smaller foetuses. However this aspect affects both group and total population variances (to be calculated), and is unlikely to affect consideration of their ratio markedly.

The mean conception date for the population ($\bar{d}$) and its variance (V) were then calculated, where M = number of foetuses examined.

$$\bar{d} = \frac{1}{M} \sum_{i=1}^M d_i \quad \dots (3)$$

$$V = \frac{1}{M-1} \sum_{i=1}^M (d_i - \bar{d})^2 \quad \dots (4)$$

For the 404 foetuses measured from 1973 to 1975 the mean conception date was 18.61 with a variance of 1674.45. This is equivalent to a mean conception date of 18–19 January (with a standard deviation of 41 days). The true mean conception date of sperm whale foetuses at Durban has been determined as 23 December (Gambell, 1972), and as expected this is earlier than the date calculated here.

For each group (j) the mean conception date ($\bar{d}_j$) and its variance (V_j) were calculated exactly as for the total population (Table 1). The combined group variance (V_c) was then derived as shown below, where N = total number of groups examined and n_j = size of each group.

$$V_c = \frac{\sum_{j=1}^N (n_j - 1) V_j}{\sum_{j=1}^N (n_j - 1)} \quad \dots (5)$$

Table 1

Mean 'conception date' ($\bar{d}_j$) and its standard deviation ($s_j = \sqrt{V_j}$) for foetuses in early pregnancy from sperm whale schools, grouped according to sample size (n_j). Entries are in order of increasing variance: the lines drawn across the columns indicate where group variance exceeds that for the total population ($\sqrt{V} = 40.9$: $\sqrt{V_y} = 40.4$).¹

No.	$\bar{d}_j$	s_j	No.	$\bar{d}_j$	s_j	No.	$\bar{d}_j$	s_j
$n_j = 2$			36	+27	27.6	8	+45	20.5
1	+23	0	37	+37	29.7	9	+35	23.5
2	-25	0	38	+41	29.7	10	+41	25.0
3	+44	0	39	+12	31.8	11	+ 4	25.4
4	+ 6	0	40	- 1	35.4	12	+10	27.1
5	+24	2.1	41	+75	36.1	13	+48	28.0
6	+90	2.1	42	-39	37.5	14	-34	31.2
7	+17	3.5	43	+41	37.5	15	+28	31.3
8	-26	4.2	44	- 4	38.2	16	+50	33.0
9	- 5	4.2				17	+ 4	34.6
10	+30	6.4	45	+44	41.7	18	-41	36.4
11	+28	6.4	46	+58	46.0	19	-10	37.0
12	+13	8.5	47	+63	48.8			
13	-33	8.5	48	- 2	50.2	20	+38	43.4
14	+18	10.6	49	+48	52.3	21	+35	43.8
15	-29	12.0	50	-51	60.8	22	+69	46.0
16	-20	12.7	51	+17	60.8	23	+21	47.1
17	+12	12.7	52	0	61.5	24	+ 9	68.5
18	+47	12.7	53	+57	62.9	25	-37	95.3
19	-21	14.1	54	+21	62.9			
20	+22	14.9	55	+30	65.1	$n_j = 4$		
21	+ 1	14.9	56	+53	73.5	1	+25	5.7
22	+84	16.3	57	+17	75.7	2	- 1	14.2
23	+72	16.3	58	+36	77.8	3	+13	15.4
24	+14	17.0	59	- 6	83.4	4	- 1	16.0
25	+27	17.0	60	+89	83.4	5	+23	19.1
26	+ 8	18.4	61	+40	87.7	6	- 8	29.8
27	+21	19.1	62	+50	89.8	7	+71	30.4
28	+25	19.1				8	+ 2	37.0
29	+37	19.1	$n_j = 3$					
30	+45	19.1	1	-24	9.0	$n_j = 5$		
31	+47	19.1	2	+24	9.3	1	-25	25.2
32	+31	19.1	3	+62	13.1			
33	+65	21.2	4	-14	14.8	2	+21	58.2
34	-10	22.6	5	-21	14.8	$n_j = 6$		
35	+ 5	23.3	6	- 7	16.7	1	+33	16.9
			7	+13	17.6			

¹ Negative $\bar{d}_j$ values indicate number of days prior to 31 December of preceding year.

The combined group variance for all 98 groups examined was 1322.61. We now wish to determine whether this group variance is significantly less than that for the total population.

However before comparison is made one must abstract from the variance for the total population (V , equation (4)) the effect of differing mean 'conception dates' for the different years over which measurements were taken. Thus:

$$\bar{d}_y = \frac{1}{M_y} \sum_{k=1}^{M_y} \bar{d}_k \quad \dots (6)$$

$$V_y = \frac{1}{M_y - 1} \sum_{k=1}^{M_y} (d_k - \bar{d}_y)^2 \quad \dots (7)$$

where M_y = number of foetuses examined in year y , and summations extend only over measurements taken in that year. Calculations yield:

y	M_y	$\bar{d}_y$	V_y
1973	157	19.82	1377.89
1974	124	13.94	2014.21
1975	123	22.07	1561.04

Combining these yearly variances as per equation (5) yields

$$\bar{V}_y = \frac{(156 \times 1377.89) + (123 \times 2014.21) + (122 \times 1561.04)}{(156 + 123 + 122)} = 1628.79$$

We thus wish to test whether the group variance V_c is significantly less than this variance $\bar{V}_y$, for which purpose we consider the ratio

$$F = \frac{\bar{V}_y}{V_c} = 1.2315$$

The associated degrees of freedom are $M - 3$ for the numerator (n_1), and $\sum_{j=1}^N (n_j - 1)$ for the denominator (n_2). With $n_1 = 401$ and $n_2 = 149$, the value of F obtained was significant at the 10% level ($p = .068$).

For comparison, a similar computation was carried out for groups containing 3 or more females in early pregnancy (i.e. excluding groups of only 2). For these groups (of which there were 36):

$$V_c = 1129.08$$

$$\text{so that } F = 1.4426$$

With $n_1 = 401$ and $n_2 = 87$, this value for F was significant at the 2.5% level ($p = .019$).

Hence the variance in conception dates for sperm whales off Durban is (at the significance levels indicated) greater for the population as a whole than for individual groups of females.

We therefore conclude there seems to be some synchronisation of oestrus within schools. The relevant significance levels are however such as suggest this is not an all-dominant effect. It must be borne in mind that our selection procedure does not absolutely exclude the possibility of grouping whales in fact not from the same school, which would bias against a positive result.

DISCUSSION

The presence of a degree of synchronisation of oestrus within sperm whale schools implies that it is unnecessary for a schoolmaster to remain with a female school for the duration of an entire breeding season to achieve maximum breeding success. As there appears to be no other advantage for a schoolmaster in remaining with a female school (and there may in fact be some nutritional disadvantage - Best, 1979), mature males may circulate between different female schools in one breeding season. If this is so it clearly has implications for what might be considered an adequate ratio of mature males to females in the population.

The mechanism behind this tendency for synchrony of oestrus is unknown.

Tormosov (1975b) discussed the possibility of induced ovulation in sperm whales, but concluded from the relatively slow maturation of follicles and the relatively high incidence of corpora albicantia not representing pregnancies that ovulation was more likely to be spontaneous. This conclusion is accepted, for if ovulation was induced the variance of foetal length (and thus age) within schools would presumably be very much less than is actually found.

The suggestion (Tormosov, 1975a) that sperm whales might form temporary concentrations according to their physiological state and individual biological rhythm (thus accounting for the association of females at similar stages of

pregnancy) is not accepted. Evidence from mark returns, and the reproductive composition of and colour variation within female schools, is to the contrary, and indicates that mature females tend to form stable social groupings (Best, 1979a).

Because of this permanency of association, relative synchrony of ovulation may arise through exposure of the school to common environmental conditions. The level of nutrition, for instance, may vary from school to school due to local accumulation or dispersion of squids. In cattle it has been shown that under-feeding in late pregnancy can increase the calving-to-oestrus interval, the increase being very marked (2 or 3 months) with fairly low levels of feeding. This effect cannot be corrected entirely by a high level of feeding after calving (Tassell, 1967). As food appears to be an important limiting factor in sperm whale populations (Best, 1979), an environmental mechanism such as the one postulated above may be the most likely reason for the degree of synchrony of oestrus observed in sperm whale schools.

ACKNOWLEDGEMENTS

We are indebted to the following people for looking for and measuring foetuses on the flensing platform — A. Hermansen, C. van der Watt (Union Whaling Company), K. Botes, J. F. Groenewald, H. S. Huysamen, P. C. B. Jurgens,

I. Muir, W. E. van Zyl (Sea Fisheries Inspectors), with the assistance of B. Mbonambi and P. Mthembu. P. van der Byl was responsible for collating the platform records. We also thank Dr L. Underhill of the Department of Mathematical Statistics, University of Cape Town, for useful discussions.

REFERENCES

- Berzin, A. A. 1971. *The Sperm Whale* (A. V. Yablokov, Ed.) Pishchevaya Promyshlennost, Moscow; translation by Israel program for Scientific Translations, 1972, 394 pp.
- Best, P. B. 1979. Social organization in sperm whales, *Physeter macrocephalus*. pp. 227–89. In: H. E. Winn and B. L. Olla (eds), *Behavior of Marine Animals. 3. Natural History of Cetaceans*, Plenum Press, New York.
- Best, P. B. 1980. Pregnancy rates in sperm whales at Durban. Paper SC/30/Doc 33 (published in this volume).
- Gambell, R. 1972. Sperm whales off Durban. *Discovery Rep.* 35: 199–358.
- Huggett, A. St. G. and Widdas, W. F. 1951. The relationship between mammalian foetal weight and conception age. *J. Physiol.* 114: 306–317.
- International Whaling Commission. 1979. Report of the scientific committee. *Rep. int. Whal. Commn* 29: 38–105.
- Tassell, R. 1967. The effects of diet on reproduction in pigs, sheep and cattle. V: Plane of nutrition in cattle. *Br. vet. J.* 123: 459–463.
- Tormosov, D. D. 1975a. Ecologo-physiological basis of different structures of sperm whale concentrations. *Morskie Mlekopitajushie*, (2) Kiev: 127–129.
- Tormosov, D. D. 1975b. Characteristics of ovulation in sperm whales. *Morskie Mlekopitajushie* (2) Kiev: 129–131.

The Influence of Schooling Behavior on CPUE as an Index of Abundance

K. Radway Allen

CSIRO, Cronulla, Australia

Catch per unit effort, as usually employed in estimating whale populations, is based on the assumption that whales are caught individually. Searching catchers find a whale, chase and capture it — or lose it — and then search for another one. In practice most species of whales are found in schools of various sizes. In this situation, a catcher finds a school, attacks it, either alone or in cooperation with other catchers, catches and handles a whale, and then turns its attention to another whale in the school which will be close by so that only a minimal search is required. After several whales have been taken, hunting on that particular school will stop because, for example, all the large whales in the school have been caught, or the school has become too dispersed to be worth pursuing any longer. The catchers will then resume the search for other whales.

Thus, when schools of whales are being hunted, the number of whales caught per unit searching time depends both on the average amount of searching time required to find a school, and on the number of whales caught at each encounter with a school. The number of schools found per unit searching time can be taken as providing an index of the density of schools. The product of this and the mean number of whales in a school then provides an index of the population density. The relation of population density to CPUE then depends upon the proportion of whales in the school which is caught in an average encounter. If this proportion is constant, the CPUE is implicitly an index of population density; but if it changes, the relation between CPUE and population density will change.

For a given species of whale, school size is not only variable in the sense that it is distributed in some way about a mean value; it may also vary between areas or seasons, between population components, and possibly also over longer time periods with changes in population size. It is the changes over longer periods that are particularly important, since they will cause changes in CPUE to be not proportional to changes in population density, and will therefore lead to biased estimates of both absolute and relative population size.

Changes in the size of the schools of sperm whales hunted have certainly taken place as a result of changes in the areas of operation. In both Northern and Southern Hemispheres the tendency has been for the main effort to shift from large bulls in high latitudes to the breeding herds of females and younger males in low latitudes; there has therefore been a very great increase in the size of the groups principally hunted.

On the other hand, there is the possibility in all exploited species of whales that the reduction in the total sizes of the populations has led to a reduction also in the average size of the schools. Such changes would have the opposite effect to those resulting from changes in the area of operations on sperm whales.

The object of this paper is to examine in more detail

some ways in which school size could influence the use of CPUE as an index of abundance, and to propose a possible means of expressing these effects in quantitative terms.

A POSSIBLE MODEL

If we assume that the number of schools found per unit searching time is proportional to the density of schools in a given area, we can write:

$$N = q'_s \frac{P}{S} t$$

where N = number of schools found,

P = number of whales in the population,

S = average number of whales in a school,

t = searching time.

q'_s is a school-finding coefficient comparable to the catchability coefficient.

If the number of whales caught from a school of size S in a single operation by V catchers before the school is caught out or dispersed is given by the function:

$$C(S, V)$$

then the total catch for the period with searching time t is given by:

$$Y = N C(s, v) = \frac{q'_s P t C(s, v)}{S}$$

Thus the catch per unit searching time is given by:

$$\frac{Y}{t} = \frac{q'_s C(s, v) P}{S}$$

so that $q'_s C(s, v)/S$ is the proportionality factor between CPUE and population size or density.

q'_s is the probability of finding one school of size S with unit searching effort in an area where such schools are distributed with unit density. The chance of finding a school probably increases in some way with the number of whales in the school, and we can write:

$$q'_s = q A(s)$$

where q is the chance of finding an individual whale with unit effort where they occur with unit density. Expressed in this way q is similar to the usual catchability coefficient except that it is the chance of encounter rather than the chance of catching; its value will therefore be somewhat higher since it includes animals which are found but not captured.

The proportionality factor between CPUE and population size has now become:

$$A(s) C(s, v)/S$$

The Catch Function

Consider first a single catcher attacking a school of S whales. Assume that one whale is caught, and of the others

Table 2.
The effect of the chance of success, g, on the total catch for different combinations of the other parameters in the model.

S	V	a	d	g			
				0.25	0.50	0.75	1.00
5	3	0	0.5	2	3	3	4
			0.8	3	4	4	4
		1.0	0.5	1	1	2	3
			0.8	2	3	3	4
	10	0	0.5	3	5	5	5
			0.8	4	5	5	5
		1.0	0.5	2	5	5	5
			0.8	2	5	5	5
15	3	0	0.5	3	5	6	7
			0.8	6	8	9	10
		1.0	1.0	1	3	3	4
			0.8	3	5	6	7
	10	0	0.5	6	10	11	12
			0.8	10	12	13	14
		1.0	0.5	2	5	7	10
			0.8	3	6	8	10
50	3	0	0.5	4	7	10	12
			0.8	9	15	18	22
		1.0	0.5	2	3	4	6
			0.8	4	7	10	12
	10	0	0.5	10	16	21	25
			0.8	20	27	32	36
		1.0	0.5	2	5	7	10
			0.8	5	9	12	14

initial size of the school, and the number of catchers used. These theoretical relationships may be compared with actual data to provide an indication of sets of parameter values which may be appropriately used in further applications of the model.

Table 1 shows the catches given by the model for various school sizes and numbers of catchers with

d set at 0.1, 0.5, 0.8, and 0.9;
a set at 0 and 1.0; and g set at 1.0.

Table 2 shows the effect of changing the value of g for different combinations of the other parameters, and indicates that the reduction in total catch in this model is rather less than the reduction in chance of success in a single attack.

Of particular interest is the ratio of catch to school size because it is this ratio which determines any bias due to schooling in CPUE as an index of abundance. In Fig. 1 this ratio is plotted against school size for 1, 3 and 10 catchers with

d = 0.5 and 0.9;
a = 0 and 1.0; and g set at 1.0.

Under the assumptions of this model the ratio diminishes rapidly as the school size increases above the number of catchers employed for almost all combinations of parameters and, except when V = 10: d = 0.9: and a = 0 (i.e. a very low dispersion rate) it drops to values of 0.5 or less. Thus, if the model behaves at all like the true situation, changes in school size may have a very significant effect on the relation between CPUE and population density. In practice it is unlikely that the number of catchers used will be greater than the initial number of whales in the school.

The direction of the bias is that if school size is decreasing the ratio will increase and therefore, if the population is decreasing, the rate of decrease will be under-estimated. If however the size of schools being hunted increases, then any rate of population decline will be over-estimated and population size under-estimated.

Up to this point the model assumes that all schools in a population contain the same number of whales. In practice this is not true. In sperm whales, in particular, different population components form schools of very different sizes. It is important therefore to determine how the single value used in the model should be related to the school size structure of the population.

Consider a population P in which k different school sizes (S_i) are possible, the proportion of animals in the population forming schools of size S_i being p_i ; then the number of such schools will be:

$$\frac{Pp_i}{S_i}$$

the number of these schools found in searching time t will be:

$$q \, t \, P \, \frac{A_i p_i}{S_i}$$

and the number of whales caught from them will be:

$$q \, t \, P \, \frac{A_i p_i \, C(\hat{s}_i \, v)}{S_i}$$

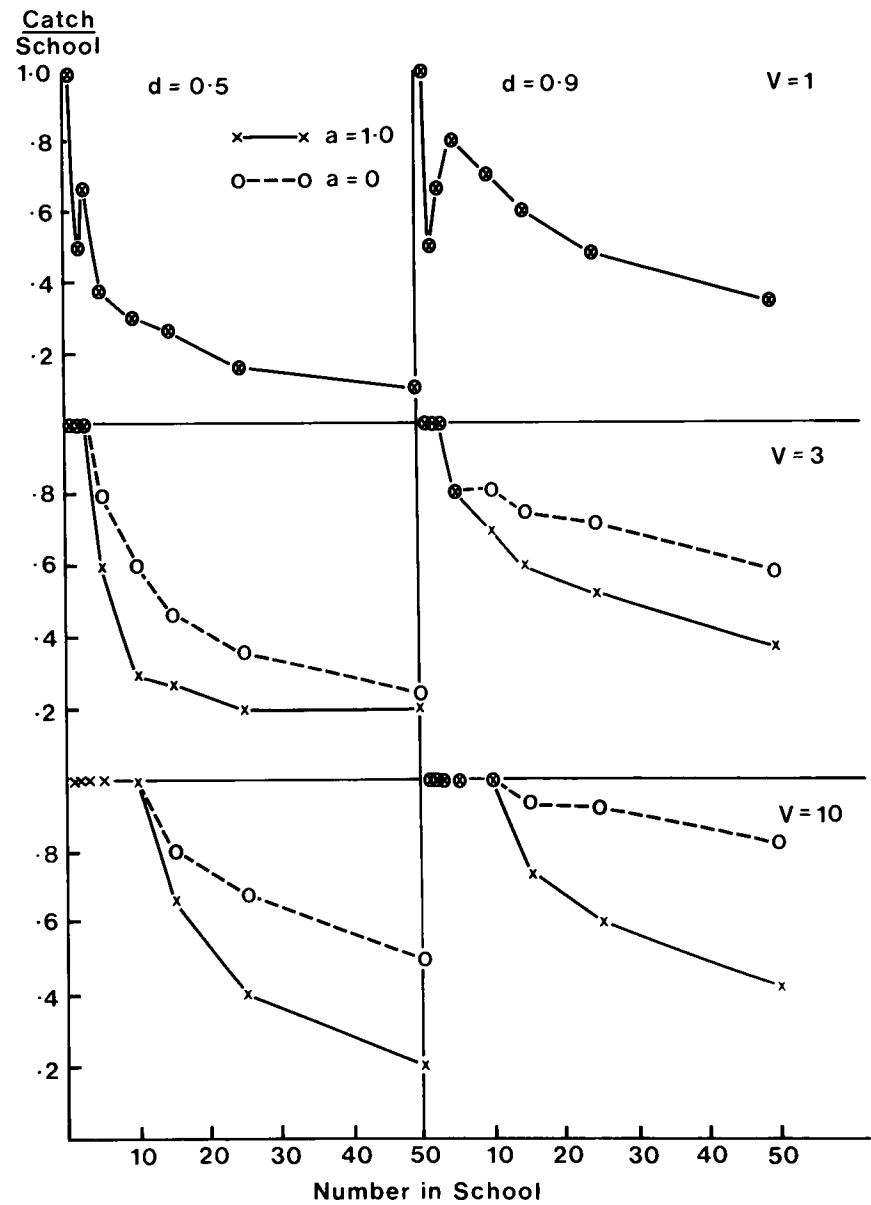


Fig. 1. Ratio of expected catch to school size plotted against school size for 1, 3 and 10 catchers, with a = 0 and 1.0; d = 0.5 and 0.9; and g = 1.0.

and the total catch will be:

q t P \sum_{i=1}^k \frac{A_i p_i C(s_i v)}{S_i}

where \frac{A_i C(s_i v)}{S_i} is the proportionality factor for schools of size S_i and can be written as R_i.

The total catch can also be written - q t P \bar{R}

so that \bar{R} = \sum_{i=1}^k p_i R_i

Thus the appropriate proportionality factor to be used for the population as a whole is the mean of the proportionality factors for the different school sizes, weighted by the proportion of whales in the population forming schools of each size. If different numbers of catchers are used for schools of different sizes the proportionality factors for each school size should be those corresponding to the number of catchers typically used for such schools.

The Sighting Function

It seems reasonable that the larger the school the greater the likelihood of finding it. There seem to be at least two reasons for this. The larger the area covered by the school, the greater the chance that a searching vessel will pass within sighting distance; and the more whales there are in the school the more targets they will offer for sighting. Many other factors also affect the chance of sighting a given school, such as the weather, the size of the whales, and whether the animals are travelling or resting. Ohsumi (pers. comm.) has drawn attention to the fact that large whales are more easily seen than small whales. Size of animal can also be correlated with school size, as in male sperm whales, where the size of the herd apparently diminishes with age or size of the animals, until the largest animals are generally solitary except those within the breeding herds.

If the whales in a school surfaced and blew independently and at random it would be possible to model the effect of increasing numbers of whales on the chances of sighting. Doi (1974) for example has estimated the chances of sighting individual fin, sei, minke and sperm whales as 0.21, 0.20, 0.11 and 0.14 respectively, although the rather elaborate theory he has developed does not take into account the effects of schooling. It is understood that, in practice, whales in a school will tend to surface together, but the effect that this would have on the chance of sighting is difficult to assess.

The area which a school covers, and therefore the distance from the centre of the school to a point at maximum normal sighting distance from the perimeter of the school, will depend both on the number of whales and the spacing between them. This distance is probably proportional to the chance of finding the school when other conditions are equal. In a simple model in which the whales are evenly distributed on a hexagonal pattern, it can be shown that, to a good approximation:

Distance from centre to maximum normal sighting distance from perimeter / Maximum normal sighting distance = 1.0 + 0.5250 (\sqrt{S} - 1) f = B

where S is again the size of the school and -

f = Distance between nearest neighbours in the school / Maximum normal sighting distance.

Table 3 shows calculated values of B for a range of values of S and f. As would be expected, the value of B increases with the number of whales in the school and the average distance between them. For closely spaced schools the effect appears negligible. For a given spacing the effect of the increasing chance of sighting with school size on the combined proportionality factor R will be the reverse of that of the catching function. The overall effect will depend upon the parameter values used in the two functions.

Table 3.

Distance from the centre of the school to the normal maximum sighting distance from the perimeter for various school sizes (S), and spacings between whales (f) as a proportion of the maximum normal sighting distance.

	f	0.02	0.05	0.10	0.20
S	1	1.00	1.00	1.00	1.00
	2	1.00	1.01	1.02	1.04
	5	1.01	1.03	1.06	1.13
	10	1.02	1.06	1.11	1.23
	25	1.04	1.10	1.21	1.42
	50	1.06	1.16	1.32	1.64

PARAMETER VALUES

Statistical estimation of the values of the parameters in these models would require large amounts of data specifying, at the least, the size of the school, the number of catchers employed, and the number of whales caught on each occasion. It would also be necessary to take into account species, area of operation, technical features such as use of ASDIC, weather conditions and so on. No adequate amounts of such data are at present available.

J. L Bannister has kindly allowed me access to some data bearing on these matters which have been extracted from aircraft and catcher logs of the Australian sperm whale fishery in several years. By comparing the numbers of whales recorded in the schools seen from the aircraft with the numbers of whales taken by the catchers it is quite often possible to relate school size and catch. The total number of catchers in the fleet has been three in most years, and individual catches can often be related to the number of vessels employed. As far as possible, schools composed of bulls only have been distinguished in the analysis, and the data presented here refer to bull schools only.

The data are not adequate for compiling detailed tables of school size and catch but some of the salient features are summarised in Table 4. This table compares the mean size of school attacked and mean number of whales taken by 1, 2 or 3 catchers. A limited amount of data are also available for occasions when large schools of 20 or more bulls have been hunted, probably by 2 or 3 catchers, and the number of whales taken can be identified. The summarised data show, as would be expected, that the average size of school attacked and the catch taken from it increases with the number of catchers, and that the proportion of the school taken also increases.

If these results are compared with the model outputs in Table 1, it appears that they fit fairly consistently to the expected values obtained when d = 0.5 and a = 0. If a is set at 1.0, the values of d which give expected catches close to these observations become more variable. For preliminary studies, therefore, at least for male sperm whales, it seems appropriate to use these parameter values and take g = 1.0 in the model. In addition, I have been told by S. Ohsumi that when the model outputs similar to those in Table 1

Table 4.
Comparison of observed school sizes and catches taken by 1, 2 or 3 catchers in the Australian sperm whale fishery.

No. of catchers		1963	1968	1973	1977	Total
1	No. of schools	92	74	22	22	210
	Mean number	6.2	5.4	6.3	7.4	6.1
	Mean catch	2.3	1.6	1.2	1.6	1.9
	Catch/S	0.37	0.30	0.19	0.22	0.31
2	No. of schools	59	41	27	48	175
	Mean number	10.9	10.4	9.8	10.9	10.6
	Mean catch	4.8	3.9	4.8	5.4	4.8
	Catch/S	0.44	0.38	0.49	0.50	0.45
3	No. of schools	—	33	48	18	99
	Mean number	—	11.2	11.4	14.1	11.8
	Mean catch	—	5.6	7.0	7.9	6.7
	Catch/S	—	0.50	0.61	0.56	0.57
Schools of 20 or more	No. of schools	8	5	—	4	17
	Mean number	23.9	21.8	—	29.7	24.6
	Mean catch	6.4	4.4	—	7.0	5.9
	Catch/S	0.27	0.20	—	0.24	0.24

were shown to Japanese whaling staff, some selected the same model as being most like their impressions of the situation.

CHANGES IN SCHOOL SIZE WITH TIME

The Australian sperm whale data referred to earlier have also been examined to obtain the relative numbers of schools of various sizes. Fig. 2 shows the precentage distribution of size of male sperm whale schools observed in 1963, 1968 and 1977. The points show no great differences between years, although there may be a reduction in the proportion of medium-sized schools in the 5 – 8 range in 1977.

From these figures the proportion of animals in schools of different sizes can be calculated and, as discussed earlier, used as a weighting factor in calculating a mean proportionality factor for the relation between CPUE and population density.

Using the parameter values mentioned above, the proportionality factors for the three seasons are:

1963	0.53
1968	0.60
1977	0.49

These limited data do not suggest that there has been a trend over time which would give rise to a bias in population estimates calculated from uncorrected CPUE data. It may be noted that the above proportionality factors correspond to school sizes in about the range 10–14, whereas the average observed sizes in the three years were 6.9, 7.1 and 9.3.

S. Ohsumi has also kindly advised me of some whalers' observations on school sizes of baleen whales in the

Southern Hemisphere. These show quite large changes as whaling proceeded and populations were reduced. These estimated school sizes for fin and sei whales in various years are given in the following table. Using the above model with

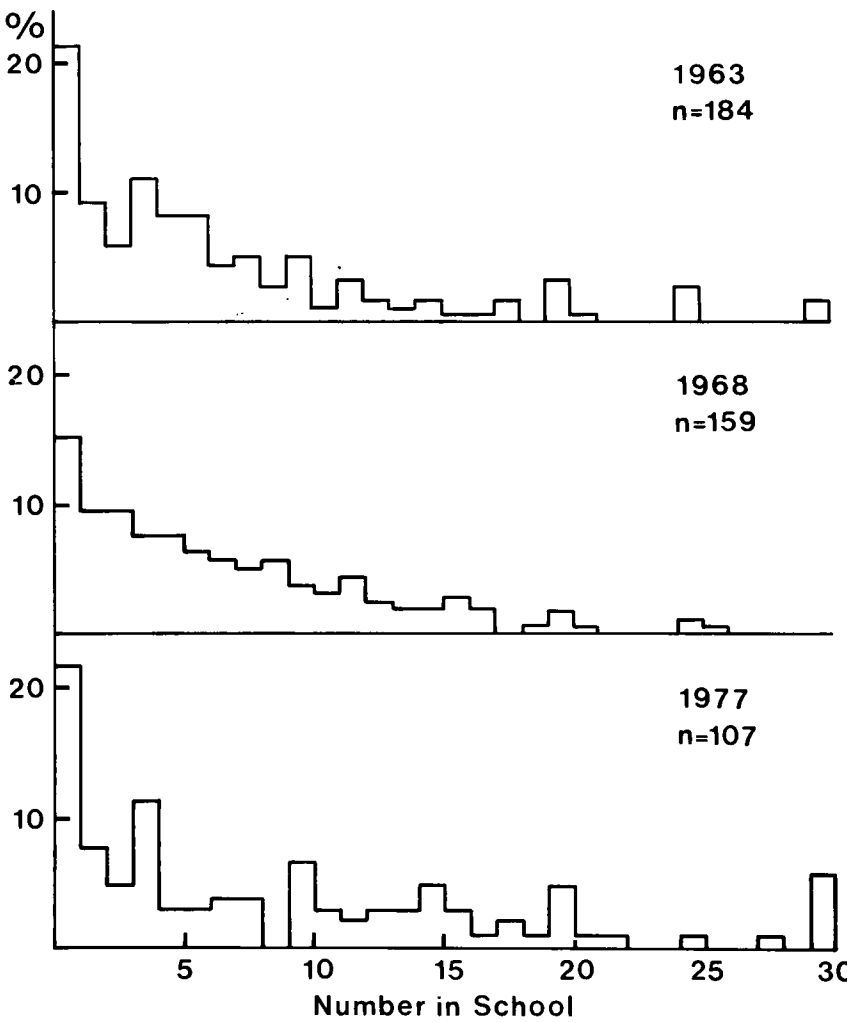


Fig. 2. Percentage distribution of numbers of animals in schools of male sperm whales observed at Albany in 1963, 1968 and 1977.

$d = 0.5$; $a = 0$; and $g = 1.0$: we can also calculate the expected catches. It is assumed that five catchers operate together except when the school size is less than 5, when catchers operate singly. From these expected catches the $C(s, v)/S$ ratios can be calculated, and these are also given in the table.

Species	Years	School Size	Ratio
Fin	–1956	20	0.5
	1958	10	0.7
	1960	5–6	0.8–1.0
	1965–	1–2	1.0
Sei	–1968	20	0.5
	1971	8–10	0.7–0.75
	present	5–8	0.75–1.0

The figures given probably represent mean school sizes observed, and the weighted means used in calculating proportionality factors should be rather higher. This effect will however probably not greatly influence the relative changes in proportionality factors.

If changes of this order in the relationship between CPUE and population density are supported by further analysis it is evident that failure to allow for the effect of changing school size could lead to substantial over-estimates in the population assessments.

REFERENCES

Doi, T. 1974. Further development of whale sighting theory pp. 359–68: *In*: W. E. Schevill (ed.) *The Whale Problem*: a status report, Harvard University Press, Cambridge, Mass., 419pp.

An Assessment of the Sperm Whale Stock Subject to Western Australia Catching

G. P. Kirkwood, K. R. Allen

Division of Fisheries and Oceanography, CSIRO, Cronulla 2230, NSW, Australia

and

J. L. Bannister

Western Australian Museum, Perth, WA, Australia

ABSTRACT

An assessment of sperm whale stocks in Division 5 has been carried out. Qualitative agreement is found between trends in predicted and observed pregnancy rates. It is recommended that both males and females be classified as Protection Stocks.

INTRODUCTION

The stock of sperm whales that has been exploited by Australian catchers falls into Division 5 of the Southern Hemisphere. At its meeting in Cambridge in 1978, the IWC Scientific Committee agreed on an appropriate data base and analytic procedures for the assessment of Southern Hemisphere sperm whale stocks, but time did not permit these assessments to be carried out. In this paper, an assessment of the Division 5 stock has been carried out, along the lines recommended by the Scientific Committee.

ASSESSMENT

Recently detailed data from Australian whaling operations at Albany have been re-examined, and revised series of indices of relative abundance based on aircraft sightings data have been obtained (Kirkwood and Bannister, 1980). Two series were extracted; the first represents the number of exploitable males seen per flying day in a restricted area that has been searched since operations commenced, while the second represents total numbers of exploitable males seen per flying day. In 1967 the original float plane spotter aircraft was replaced by a twin engined aircraft. Recognising the increase in efficiency of this new aircraft, only data from 1968 onwards were used in the assessment. During the 1970s the area searched expanded, inevitably reducing to some extent searching effort in the more restricted original

search area. Thus it is likely that declines in relative abundance seen in the restricted series will overestimate the true decline. On the other hand, an increase in the total area searched will result in more whales being seen, and the decline in relative abundance in the second series is likely to underestimate the true decline. Consequently estimates of initial and current stock sizes based on the restricted area sightings are likely to be underestimates, while those based on the total area sightings are likely to be overestimates, with the best estimates lying between the two. The sightings data are discussed in greater detail in Kirkwood and Bannister (1980).

In addition to the Australian sightings data, catch per unit effort data are available for whaling operations in Division 5 by other nations. In this assessment, two series of catches per searching hour were used, obtained from Japanese operations outside the baleen season (OBS) and Soviet operations north of 40° south (N40S) in Division 5. Shorter series of data for other national operations which were utilised in previous assessments could not be used on this occasion as they required time budget data to convert catcher days worked to searching hours and these data are not presently available.

Using the model structure, parameter values and procedures adopted by the Scientific Committee at Cambridge in 1978, the following estimates of the exploitable female (aged 13 and over) and exploitable male (aged 20 and over) population sizes at the beginning of 1947 and 1979 were obtained.

Estimated population sizes in thousands for each data								
Year	Australian sightings total area		Australian sightings restricted area		Japanese OBS		Soviet N40S	
	Female	Male	Female	Male	Female	Male	Female	Male
1974	27.0	18.4	25.7	17.5	21.5	14.6	32.6	22.2
1979	24.5	4.9	23.2	4.0	18.7	1.2	30.1	8.7

These lead to average 1947 exploited population estimates of 26,700 for females and 18,200 for males. Using these estimates as starting values, the estimated population size each year was obtained by simulation using the actual catches and the sperm whale model. The results are shown in the following table.

Estimated population sizes in thousands		
Year	Exploitable females	Exploitable males
1947	26.7	18.2
1979	24.3	4.7

These analyses show that on the basis of the model now used, the exploitable male and female sperm whales in Division 5 are respectively at 26% and 91% of their 1947 levels. Applying the rules of the 'new management procedure' of the IWC, the male stock would be classified as a Protection Stock with a zero catch limit while the females would be classified as an Initial Management Stock with a catch limit of 131 for the 1978/79 pelagic season and the 1979 coastal season.

DISCUSSION

It seems very likely that pregnancy rates in this stock have declined quite seriously in the last few years. Data on observed percentage of pregnancies amongst mature females, provided by J. L. Bannister, were examined by the Scientific Committee in 1978 and the percentages actually pregnant were estimated from the percentage pregnant and doubtful using the sizes of the corpora lutea. These percentages are presented below:

Estimated percentages of pregnant mature females taken	
Year	% pregnant
1964	37.6
1965	29.3
1973	28.2
1974	22.2
1976	12.5
1977	22.6

Analysis of these data showed a statistically significant decline in percentage pregnant. It should be noted that observed percentages pregnant among captured mature females will almost certainly overestimate the true population pregnancy rates due to protection offered to lactating females. Although the earlier observations were collected by experienced biologists, while later observations were collected by inspectors without scientific training, it is felt that any bias due to the differing observers is small, and that the decline observed in these data should be taken seriously.

Examination of the results of the simulation shows a predicted continuous drop in true pregnancy rate from 0.201 in 1966 to 0.067 in 1977. This drop results from the fact that, in the model, which uses actual catches, the ratio of socially mature males to mature females has dropped below the critical value needed to maintain the normal pregnancy rate for a given level of the female population.

The decline in simulated pregnancy rate is actually greater than that in the observed data. This suggests that, if anything, either the model is somewhat conservative, or the initial population size assumed is too small. Nevertheless the good qualitative agreement between the observed pregnancy data and the model results suggests that some confidence may be placed in results based on the model.

This being so, the exploitable populations of both sexes can be expected to undergo a decline for a time. This will continue until the pregnancy rate has risen as a result of the sex ratio rising again above the critical level and the resulting increased number of recruits has entered the exploitable population. It should be noted that, assuming equal numbers of both sexes are born and equal mortality rates for each sex, one male is recruited to the socially mature stock for about every 2 mature female recruits, whereas only one male is required for about every 7 mature females to maintain the normal pregnancy rate. Normal recruitment will therefore rapidly restore the conditions required to give normal pregnancy rates, in the absence of exploitation.

However the effect of the low pregnancy rate in recent years is to reduce recruitment to the mature and exploitable classes at the present time, and this will continue for some years, whether any further exploitation occurs or not. The simulation run with the model predicts that even without exploitation, the number of exploitable females will decline for some years, and will actually fall into the Protection Stock category in about 1989, and will then take another 35 to 40 years to reach the MSY level again. At its lowest level the exploitable female stock will be 65% of its initial size. In these circumstances, there seems good reason to cease taking females from this stock immediately, in spite of the fact that the simulation suggests that under current IWC rules a quota could be taken for some 10 years as female numbers reduce from their current high level. Immediate cessation would have the effect of minimising the extent of the decline, although some reduction in stock size will inevitably occur.

This situation, in Division 5, seems to parallel quite closely that existing in the western North Pacific. In this case also, the Scientific Committee observed that the data indicated a current decline in pregnancy rate which is in agreement with the effects of changes in sex ratio as shown by the simulations. The Scientific Committee, while pointing out that under the rules a catch was allowable, did 'not wish to recommend catch limits for either sex without drawing attention to the fact that . . . the ratio of socially mature males to sexually mature females fell below that determined by a reserve male ratio of 0.3 . . . the analysis indicated that even if no catch is taken the stock will decline'. (IWC, 1979.)

Thus the present rules of the IWC, which define desirable stock levels and quotas in terms of stable situations, are inadequate in dealing with the dynamic situation which exists when a stock has already been reduced.

When the females have returned to the MSY level, the taking of a sustainable yield would be permitted under the present rules, and this could be taken on a continuing basis without reduction of the stocks. The males however present a different situation. After relatively few years from the present, the number of socially mature males in the population would be expected to be above that required for reproduction, and some harvest could then be taken on a continuing basis. This harvest, if properly determined, could be continued indefinitely. In the dynamic situation which would exist while the female population reduced and

then expanded, the factors affecting the safe male harvest would be complex and would require careful monitoring. They would include not only the size and recruitment rate of the male population, but also the size of the mature female population and the rate at which it was growing. Given the necessary knowledge, the general principles incorporated in the present management procedure would maintain the population of both sexes at or above the MSY level once the mature female population had been brought to it.

It may be noted that other simulations show that if this current procedure had been correctly applied from the

beginning (i.e. with quotas of 464 males and 131 females) the populations would have stabilised well above MSY level. The catches of males which have been taken for a number of years would now appear to have been well above the quota level of 90% of MSY.

REFERENCES

- International Whaling Commission, 1979. Report of the Scientific Committee. *Rep. int. Whal. Commn* 29: 38–105.
- Kirkwood, G. P. and Bannister, J. L. 1980. Abundance indices off Western Australia. Paper SC/30/Doc 22 (published in this volume).

Pregnancy Rates of Sperm Whales in the Southeast Pacific Between 1959 and 1962 and a Comparison With Those From Paita, Peru Between 1975 and 1977

Robert Clarke, Anelio Aguayo L.

Unidad de Ciencias Marinas, Universidad, Autónoma de Baja California, Apartado Postal 453, Ensenada, B.C.N., México.

and Obla Paliza

People's Trust for Endangered Species, Real del Castillo 30, Cerro Chapultepec, Apartado Postal 371, Ensenada, B.C.N., México.

ABSTRACT

The true pregnancy rates are presented from 1039 mature female sperm whales examined at Paita and Pisco in Perú, and at Iquique and Talcahuano in Chile, between 1959 and 1962. Reasons are given for combining the data to give a cumulative true pregnancy rate of 0.30 for the Southeast Pacific in 1959–62. Explanation is offered why this rate is higher than that observed in other parts of the world. Removal of data from simultaneously pregnant and lactating whales from the sample reduces the rate to 0.27. Taking into account that over-exploitation is considered to have just about begun at that time, it is argued that this pregnancy rate is more in accordance with a sexual cycle lasting three years than with one lasting four years.

The data presented by Valdivia (IWC, 1979b p. 73) from Paita during certain months of 1975–1977 are, in effect, rates for all females with a corpus luteum in their ovaries, and, when compared with the corresponding rates from Paita in 1959–61 as 'total ovulation rates' (using all the data from 1959–61, and then only the data from corresponding months), they are seen to have declined since 1959–61. By means of a proportional method, an estimate of what would have been the true pregnancy rate in 1975–77 also shows a decline to 0.23 from the observed rate of 0.28 in 1959–61. Meanwhile there is evidence that the stock exploited from Paita has diminished since 1959–61, and it is shown that the proportion in the catch of males of harem-master status has declined from 35.52% in 1958–61 to about 11% in 1975–75.

It is concluded that the decline in pregnancy rate of whales killed from Paita, between 1959–62 and 1975–77, is due to an insufficiency of mature bulls and that consequently the stock exploited from Paita now stands at risk.

INTRODUCTION

Between 1959 and 1961 the governments of Chile, Ecuador and Perú conducted a cooperative investigation of the whale stocks of the Southeast Pacific, with coordinated research programmes and mutual exchange of national scientists, operating under the aegis of the Permanent Commission of the South Pacific. The research was coordinated by the first author when employed by the Food and Agriculture Organization of the United Nations in the Expanded Technical Assistance Programme of the United Nations.

Much of the work concerned sperm whales. Between 1959 and 1962 biologists examined the carcasses of 2,727¹ sperm whales at the whaling stations of Chile and Perú. The working up of the material proceeded at the National Institute of Oceanography, United Kingdom, and for a time at the Estación de Biología Marina de la Universidad de Chile, Montemar, Chile. After a preliminary report on sexual maturity and breeding (Clarke, Aguayo and Paliza, 1964), publication of the results was planned in some ten parts, under the general title *Sperm whales of the Southeast Pacific*. Three parts have so far been published: Part I, Introduction; Part II, Size range, external characters and teeth (Clarke, Aguayo and Paliza, 1968), and Part III, Morphometry (Clarke and Paliza, 1972). The work was suspended in 1971 when the first author resigned from his institute to undertake a fishing enterprise on the coast of Perú, and thereafter it was not possible to resume again until May 1978 in México, when a grant was provided by

the People's Trust for Endangered Species, 19, Quarry Street, Guildford, England, to which organization grateful acknowledgement is made.

We are currently working on Part IV, Food and fatness, in the sperm whale report, and the breeding and life cycle of the female is planned for a later part. However, Dr Ray Gambell, Secretary of the International Whaling Commission, wrote to the first author on 13 September 1978 requesting sperm whale pregnancy rates for stock assessment purposes from the Commission's sperm whale Division 9, being the Southeast Pacific. We have therefore prepared the present paper as a contribution to the Specir¹ Meeting of the Commission's Scientific Committee at La Jolla, California, 27 November – 8 December 1978.

The first author, in a paper contributed in 1976 to the Sixth Meeting of the Coordinating Commission for Scientific Research of the Permanent Commission of the South Pacific, drew attention to the importance of resuming in Chile and Perú the collection of data on pregnancy rates and other parameters of the female sperm whale stock, which could then be compared with those collected in 1959–61 (Clarke, 1976).

MATERIALS AND METHODS

Saetersdal, Mejía and Ramírez (1963) have shown that in Peru between 1959 and 1961, the samples of sperm whales biologically examined were representative of the catch.

Of the carcasses examined in Chile and Peru, between 1959 and 1962, 1,219 were females and of those 1,039 were sexually mature. For the following reasons we believe that the proportions of the sexual classes in these mature females were very near to being representative of those in the sea at the time of catching. Since its foundation in 1952 the Permanent Commission for the South Pacific has

¹ In 1968 we reported on 2,266 carcasses examined between 1959 and 1961 (Clarke *et al.* 1968), but in subsequent work we have included 461 whales examined at Pisco in Perú in 1962 which for administrative reasons were omitted from the work published in 1968.

prohibited the taking of sperm whales less than 9.1 m (30 ft) long and the taking of any whale accompanied by a calf. At least between 1959 and 1962 these regulations were not observed by the gunners, and those whom we questioned professed ignorance of the regulations. Since Clarke *et al.* (1964), in a preliminary estimate have placed the mean length at sexual maturity in female sperm whales of the Southeast Pacific at about 8.5 m (28 ft), and 23.16% of our sample of females during 1959–61 were between 6.5 m (21.3 ft) and 9.0 m (29.5 ft) long (Clarke *et al.* 1968, Table 6), we believe that the size range of mature females should be fairly represented; whilst the large proportion of lactating animals (38.11%) in the sample of mature whales indicates that nursing whales were killed indiscriminately and therefore are also likely to be fairly represented.

At the time of the investigations, the whales were not slit open after capture to cool the body cavity, so that no foetuses were lost from this practice: nor were there any whales in our sample with a corpus luteum and a greatly enlarged but empty uterus to suggest that they may have aborted from the shock of the harpoon. The uterus was carefully searched in each whale which bore a corpus luteum in its ovaries, and foetuses as small as 10 mm in length were found (Paliza, 1964). In the conditions of the flensing platform we do not expect to find foetuses smaller than 10 mm during routine examinations. The numbers of these very early pregnancies which have been missed will have been significant during August, September and October which, from a re-examination of the data incidental to the preparation of this paper, emerge as the peak of the pairing season when 70% of conceptions take place in the Southeast Pacific.²

Tables 1–3 show the proportions by months and years of pregnant and recently ovulated whales among the sexually mature females examined at Paita (1959–61) and Pisco (1960–62) in Peru, and at Iquique (1960) and Talcahuano (1961) in Chile. Up to the present time the Permanent Commission of the South Pacific has not prescribed any close season for whaling, so that at Paita (Table 1) and Pisco (Table 2) there are data for all months save for those before June 1959 at Paita, and before August 1960 at Pisco, when biological investigations began at those stations. At Iquique biological work began in March 1960, and the station was closed for refitting during July: at Talcahuano in 1961 observations could only be made between March and June, the station in any case being closed during the winter months because of the severe weather (Table 3). The data from Talcahuano are included here but they are too few for separate comment.

So far as we are aware no previous work in other localities has afforded pregnancy data from all months of the year (such as are presented from Perú) because of the close seasons prescribed by the International Whaling Commission, or because the stations concerned were outside tropical waters and sampled only the migrant females of summer, or for both reasons.

The classes of female simultaneously pregnant and lactating, and simultaneously ovulating and lactating, comprised respectively 2.12% and 2.31% of the mature whales, and these classes have been included when calculating the proportions pregnant and recently ovulated in Tables 1–4.

In the tables the proportions in the 'Current pregnant' columns correspond to the true pregnancy rates defined by

Ohsumi (1965), and they have been obtained by inspection of the plots of foetal lengths against months. They identify those whales which have mostly conceived between August and October of the previous year, and whose foetuses are mostly 0.1 – 0.8 m long in January and are near term in December. The pregnancies not counted are those which have been conceived in the actual current pairing season from its very beginning in May through the peak months between August and October as far as December, so that the error arising from failing to encounter very small foetuses, explained above, does not enter into the count for true pregnancy rates.

PREGNANCY RATES 1959–62

From Tables 1–3 the annual true pregnancy rates at Paita, Pisco and Iquique between 1959 and 1962 were,

	1959	1960	1961	1962	1959–61	1960–62
Paita	0.26	0.30	0.24		0.27	
	(Jun-Dec)					
Pisco		0.23	0.38	0.35		0.34
		(Aug-Dec)				
Iquique		0.37				
		(Mar-Jun, Aug-Dec)				

Although in 1960 the rate at Pisco was lower than that at Paita, the higher rate of 0.34 at Pisco during the whole period 1960–62, compared with 0.27 at Paita during 1959–61, could be explained as a response to whaling because the present station at Pisco commenced operations in 1953, and earlier there had been steam whaling, although intermittent and on a small scale, since 1924 at Pisco (Kostrisky, 1963), whereas whaling did not start at Paita until 1957: also the particular distribution of the pelagic fleets whaling off Perú in the 1940s and 50s could have had an effect. (However, there was no whaling from Iquique in Chile until 1957, and here the rate was 0.37 for nine months sampled in 1960). But such an explanation would imply separate stocks, and indeed Rice (1977) has suggested, and Berzin (1978) has claimed, that there is a separate breeding stock of sperm whales in the eastern equatorial Pacific ('Galápagos population'). If such a separate stock exists then probably it is being exploited from Paita. The possibility will be born in mind as elaboration of the Southeast Pacific data proceeds. However, the evidence which has emerged so far, from external characters and teeth (Clarke *et al.*, 1968), from morphometry using the allometry equation (Clarke and Paliza, 1972) and from morphometry using canonical analysis (Machin, 1974), has disclosed no differences in sperm whales taken from the four stations, so that we have been led to believe that there is one continuous stock off Chile and Perú. Again, if the differences were due to migrational effects within a single stock, we should expect these effects to balance out over a year or years. There remains the possibility that the uterus was not always searched with the same rigorous care by biologists at the different stations. The following are the annual rates for 'Current pregnant + recently ovulated' whales from Table 1–3. This group now includes all pregnancies conceived in the 'current' season, because the 'recently ovulated' class comprises all those pregnancies which may have been missed, together with the whales actually ovulating.

² It has become clear that some of our preliminary results on gestation and breeding (Clarke *et al.*, 1964) will need to be revised.

Table 1
Mature female sperm whales. Monthly proportions of pregnant and recently ovulated whales examined at Paita, Perú between 1959 and 1961

Months	1959					1960					1961					1959-61							
	Per cent					Per cent					Per cent					Per cent							
	Number of females	All pregnant	Current pregnant	Recently ovulated	All pregnant + recently ovulated	Number of females	All pregnant	Current pregnant	Recently ovulated	All pregnant + recently ovulated	Number of females	All pregnant	Current pregnant	Recently ovulated	All pregnant + recently ovulated	Number of females	All pregnant	Current pregnant	Recently ovulated	All pregnant + recently ovulated			
																					Current pregnant + recently ovulated	Current pregnant + recently ovulated	Current pregnant + recently ovulated
January	-	-	-	-	-	18	33	22	11	44	33	9	33	22	22	55	44	27	33	22	15	48	37
February	-	-	-	-	-	44	27	27	9	36	36	20	10	10	0	10	10	64	22	22	6	28	28
March	-	-	-	-	-	36	39	39	3	42	42	20	40	35	0	40	35	56	39	38	2	41	39
April	-	-	-	-	-	20	45	45	0	45	45	21	29	29	5	33	33	41	37	37	2	39	39
May	-	-	-	-	-	35	34	34	0	34	34	34	26	26	0	26	26	69	30	30	0	30	30
June	12	33	33	0	33	13	23	23	0	23	23	54	22	20	0	22	20	79	24	23	0	24	23
July	8	25	25	0	25	6	17	17	0	17	17	20	35	35	0	35	35	34	29	29	0	29	29
August	13	8	8	0	8	18	39	33	6	44	39	15	20	20	7	27	27	46	24	22	4	28	26
September	31	39	35	19	58	17	24	24	29	53	53	16	31	31	19	50	50	64	33	31	22	55	53
October	34	38	26	15	53	16	38	38	19	56	56	21	29	19	29	57	48	71	35	27	20	55	46
November	26	27	23	12	38	17	24	6	24	47	29	14	43	21	21	64	43	57	30	18	18	47	35
December	25	44	24	20	64	-	-	-	-	-	-	12	33	25	8	42	33	37	41	24	16	57	41
Year(s)	149	33.6	26.2	12.8	46.3	240	32.5	30.0	8.3	40.8	38.3	256	27.7	24.2	6.6	34.4	30.9	645	30.9	26.8	8.7	39.5	35.5

Table 3
Mature female sperm whales. Monthly proportions of pregnant and recently ovulated whales examined at Iquique (1960) and at Talcahuano (1961), Chile

Months	Iquique 1960						Talcahuano 1961					
	Number of females	Per cent					Number of females	Per cent				
		All pregnant	Current pregnant	Recently ovulated	All pregnant + recently ovulated	Current pregnant + recently ovulated		All pregnant	Current pregnant	Recently ovulated	All pregnant + recently ovulated	Current pregnant + recently ovulated
January	—	—	—	—	—	—	—	—	—	—	—	—
February	—	—	—	—	—	—	—	—	—	—	—	—
March	3	33	33	0	33	33	3	0	0	0	0	0
April	3	100	100	0	100	100	7	14	14	0	14	14
May	10	20	20	0	20	20	0	—	—	—	—	—
June	8	25	25	0	25	25	0	—	—	—	—	—
July	—	—	—	—	—	—	—	—	—	—	—	—
August	7	14	14	0	14	14	—	—	—	—	—	—
September	7	71	71	29	100	100	—	—	—	—	—	—
October	11	45	45	0	45	45	—	—	—	—	—	—
November	11	45	36	9	55	45	—	—	—	—	—	—
December	10	50	30	0	50	30	—	—	—	—	—	—
Year(s)	70	41.4	37.1	4.3	44.3	41.4	10	10	10	0	10	10

	1959	1960	1961	1962	1959–61	1960–62
Païta	0.39	0.38	0.31		0.36	
Pisco	(Jun-Dec)	0.40	0.41	0.37		0.39
Iquique		(Aug-Dec)	0.41			
		(Mar-Jun, Aug-Dec)				

The differences are now seen largely to disappear, except that the rates at Païta and Pisco, which were in fair agreement in 1960, were different from each other in 1961. This difference apart, there appears sufficient conformity to justify the presentation for the time being in Table 4 of the cumulative results for Chile (1960–61), Perú (1959–62) and together for the Southeast Pacific (1959–62).

The true pregnancy rate for the Southeast Pacific between 1959 and 1962 now emerges as 0.30. This appears to be the highest rate so far recorded. Best (1974) summarises a range of 0.19 to 0.29 from other localities and refers to two unpublished reports (which we have not seen) by Bannister (1970) from Western Australia and by Rice and Wolman (1970) from California where the rates were respectively 0.28³ (June to October) and 0.29³ (May to December). He also mentions a rate of ‘<0.35’ from British Columbia (IWC, 1967).

Ohsumi and Fukuda (1972) devised a sperm whale population model where the pregnancy rate is 0.25 in the unexploited female population and increases to 0.33 as the population approaches zero; their revised model put the pregnancy rate at 0.30 when the stock is reduced to 25% of its original size (Ohsumi and Fukuda, 1974). As we understand them, these rates assume a main female sexual cycle

of four years, as proposed by Ohsumi (1965), Best (1968) and Gambell (1972), where the theoretical pregnancy rate is 0.25. Best (1974) considered that the actual pregnancy rate must be less, because of unsuccessful ovulations at the main oestrus which would explain the high proportion of resting whales which all workers have encountered: using these proportions he has calculated that the actual rate should be 0.21 in a lightly exploited stock. He estimated the actual rate to be 0.20 in an unexploited stock, and revised this figure to 0.19 in 1976, proposing that this would increase to 0.25 in a stock reduced to 25% of the unexploited size.

Turning again to the Southeast Pacific data, it will be recalled that these include whales which were simultaneously lactating and pregnant and simultaneously lactating and ovulating. They represent stages in those cycles ancillary to the main sexual cycle which have been comprehensively discussed by Ohsumi (1965) and recognised in more or less complexity by later authors. The range of pregnancy rates from Ohsumi and Fukuda’s model, and Best’s revision of these, must refer only to the main cycle, so it is necessary to remove the simultaneously pregnant and lactating whales from our sample before a comparison can be made. The rate of 0.30 between 1959 and 1962 in the Southeast Pacific is now reduced to 0.27 (actually 27.4%) in the main cycle.

According to Best this rate would place the female stock in 1959–62 at less than 25% of its level before exploitation began. Saetersdal, Mejía and Ramírez (1963) concluded from an analysis of the catch statistics that by 1961 exploitation of the sperm whale stock in the Southeast Pacific was approaching the intensity giving the maximum sustainable yield in numbers and had probably already exceeded that giving the maximum sustainable yield in weight. Over-exploitation then had apparently begun by 1962, but if the female stocks in 1959–62 were in the severely reduced condition required by applying the

³ The Report of the Special Meeting on Sperm Whale Biology and Stock Assessment (*Rep. int. Whal. Comm* 21:43) gave these rates as 0.24+ for Western Australia and 0.33 for California. The latter would have been an apparent pregnancy rate from which Best (1974) calculated a true rate of 0.29 using Ohsumi’s (1965) exchange ratio 2.

Table 4

Mature female sperm whales. Monthly proportions of pregnant and recently ovulated whales examined from the Southeast Pacific in 1959–62

Months	Chile 1960–61						Perú 1959–62						Southeast Pacific 1959–62					
	Per cent						Per cent						Per cent					
	Number of females	All pregnant	Current pregnant	Recently ovulated	All pregnant + recently ovulated	Current pregnant + recently ovulated	Number of females	All pregnant	Current pregnant	Recently ovulated	All pregnant + recently ovulated	Current pregnant + recently ovulated	Number of females	All pregnant	Current pregnant	Recently ovulated	All pregnant + recently ovulated	Current pregnant + recently ovulated
January	–	–	–	–	–	–	46	35	24	9	43	33	46	35	24	9	43	33
February	–	–	–	–	–	–	75	23	23	5	28	28	75	23	23	5	28	28
March	6	17	17	0	17	17	86	35	34	2	37	36	92	34	33	2	36	35
April	10	40	40	0	40	40	64	34	34	2	36	36	74	35	35	1	36	36
May	10	20	20	0	20	20	110	35	35	0	35	35	120	33	33	0	33	33
June	8	25	25	0	25	25	106	31	30	0	31	30	114	31	30	0	31	30
July	–	–	–	–	–	–	62	34	34	0	34	34	62	34	34	0	34	34
August	7	14	14	0	14	14	83	30	29	4	34	33	90	29	28	3	32	31
September	7	71	71	29	100	100	90	33	32	20	53	52	97	36	35	21	57	56
October	11	45	45	0	45	45	90	40	31	17	57	48	101	41	33	15	55	48
November	11	45	36	9	55	45	90	34	19	17	51	36	101	36	21	16	51	37
December	10	50	30	0	50	30	57	39	21	16	54	37	67	40	22	13	54	36
Year(s)	80	37.5	33.8	3.8	41.3	37.5	959	33.5	29.2	7.4	40.9	36.6	1,039	33.8	29.5	7.1	40.9	36.7

observed pregnancy rate of 0.27 to Best’s range of estimates, it does seem surprising that for twelve years after 1962 the catch from Perú was sustained at 1,200 ÷ 3,600 annually, except for those years where part of the whaling effort was diverted to other species (*International Whaling Statistics* 1970, 1976).

It is by no means certain that the female sexual cycle lasts four years, and a more reasonable interpretation of our pregnancy data seems to emerge when a cycle lasting three years is considered. This cycle, where lactation lasts about one year rather than two, has been proposed by Clarke (1956) and Rice and Wolman (1970, reported by Best, 1974) for sperm whales from the Azores and from the coast of California respectively. The theoretical pregnancy rate for the main cycle of three years is 0.33, and Best (1974) calculates that in this case the actual rate should be 0.26 in a lightly exploited stock. Then our observed rate of 0.27 during 1959–62 in the Southeast Pacific might be just about the expected value for a stock considered to be exploited to around the level of maximum sustainable yield at that time.

If then the cycle lasts three years (and even if it does not), the question arises why true pregnancy rates observed in other parts of the world should be less than that for the Southeast Pacific in 1959–62. Two reasons are offered. Firstly, in countries whaling under the regulations of the IWC, where infractions are recorded and penalties applied, the females killed should be mostly the largest and oldest animals whose pregnancy rates are below the average (see Best, 1974). Depression of the rates from this cause would have been particularly effective in the seasons up to 1972, when the IWC reduced the minimum length for taking sperm whales from 38 ft (11.6 m) for pelagic whaling, and 35 ft (10.7 m) for shore whaling, to 30 ft (9.2 m), except in the North Atlantic: the rates for other localities reviewed above were all observed before the 1973 season. On the other hand we have reason to believe (p. 142) that in the Southeast Pacific, at least between 1959 and 1962, the

catch of mature females was representative of those in the sea, including the pregnant class at all ages and fertilities. Secondly, because of the close seasons for whaling prescribed by the IWC, pregnancy data in these localities are not available for certain months, and this will tend to depress the observed pregnancy rates, especially since these months cover parts of the peak pairing seasons north and south.

COMPARISON WITH PREGNANCY RATES FROM PERÚ, 1975–77

The table provided by Valdivia for Perú (Division 9) in IWC, (1979) is presumed to refer to whaling at Paita which we believe to be the only station at present operating in Perú. Certain months only have been sampled between 1975 and 1977. Presumably the numbers of whales recorded were those sexually mature. Because the bellies of the whales are now being slit after capture, some foetuses are lost at sea, so beside the column for the proportions of whales recorded as pregnant there is an additional column for the proportions of whales which had a corpus luteum and no foetus, called ‘recently ovulated’ but including whales which may have been pregnant. A note ‘Apparent pregnancy rates’ means that all pregnancies have been counted in the various months. It should be noted that the sum of the proportions pregnant and the proportions ‘recently ovulated’, given in Valdivia’s table, is not necessarily an approximation to the apparent pregnancy rate in a particular month, because months of the pairing season are included when some whales were actually ovulating. But the sum of these two proportions corresponds to the proportions of ‘All pregnant + recently ovulated’ for any month in our Tables 1–4.

For the purposes of the present paper we call these proportions, which correspond, the ‘Total ovulation rate’. They are the proportions of all whales in any month which bore a corpus luteum in the ovaries. The comparison is

Table 5

Paita, Perú. Total ovulation rates of sperm whales examined in 1959–61 compared with those obtained in 1975–77

Months	1959		1960		1961		1975		1976		1977		1959–61		1975–77	
	Number of females	Rate %	Number of females	Rate %	Number of females	Rate %	Number of females	Rate %	Number of females	Rate %	Number of females	Rate %	Number of females	Rate %	Number of females	Rate %
January	—	—	18	44	9	55	—	—	—	—	5	40.0	27	48	5	40.0
February	—	—	44	36	20	10	—	—	—	—	5	20.0	64	28	5	20.0
March	—	—	36	42	20	40	—	—	—	—	2	0	56	41	2	0
April	—	—	20	45	21	33	—	—	5	0	22	31.8	41	39	27	25.9
May	—	—	35	34	34	26	—	—	14	42.9	23	8.7	69	30	37	21.6
June	12	33	13	23	54	22	—	—	25	36.0	—	—	79	24	25	36.0
July	8	25	6	17	20	35	—	—	—	—	—	—	34	29	0	—
August	13	8	18	44	15	27	—	—	4	25.0	—	—	46	28	4	25.0
September	31	58	17	53	16	50	—	—	12	58.3	—	—	64	55	12	58.3
October	34	53	16	56	21	57	12	41.6	18	33.4	—	—	71	55	30	36.7
November	26	38	17	47	14	64	5	100	—	—	23	21.7	57	47	28	35.7
December	25	64	—	—	12	42	—	—	—	—	27	33.3	37	57	27	33.3
Year(s)	149	46.3	240	40.8	256	34.4							645	39.5		
							17	59	78	37	107	24.3			202	32.2

limited to Paita, and in Table 5 the ‘Total ovulation rates’ have been extracted from Table 1 (1959–61) and from Valdivia’s table (1975–77). Both periods show a decline in the annual rate, from 1959 to 1961 and from 1975 to 1977, and the cumulative rate for 1975–77 is less than that for 1959–61.

1959 : 0.46	1975 : 0.59
1960 : 0.41	1976 : 0.37
1961 : 0.34	1977 : 0.24
1959–61 : 0.40	1975–77 : 0.32

To try and compare the rates more closely, we have re-calculated from Table 1 the annual rates for Paita 1959–61, using data only from those months where data are available for 1975–77, taking 1959 to compare with 1975, 1960 with 1976, and 1961 with 1977. There is little change in these rates for selected months in 1959–61, and the cumulative rate is the same:

1959 : 0.48	1975 : 0.59
1960 : 0.42	1976 : 0.37
1961 : 0.35	1977 : 0.24
1959–61 : 0.40	1975–77 : 0.32

Again, selecting data in this way for Paita between 1959 and 1961, an estimate of what the true pregnancy rate would have been in 1975–77 can be obtained by multiplying the ‘Total ovulation rates’ in each month of 1975–77 by the ratio of the true pregnancy rates to the ‘Total ovulation rates’ in the corresponding months of 1959–61:

All months (Table 1)	Corresponding months	
1959 : 0.26	0.25	1975 : 0.33
1960 : 0.30	0.34	1976 : 0.30
1961 : 0.24	0.25	1977 : 0.16
1959–61 : 0.27	0.28	1975–77 : 0.23

The true pregnancy rates for 1959–61 have scarcely changed by this selection. The estimated true pregnancy rates for 1975–77 follow the same trend of decline as do the ‘Total ovulation rates’ and again the cumulative estimated true pregnancy rate is less than the cumulative rate for 1959–61.

The sperm whale population models for females assume that the pregnancy rate increases with increased exploitation of the stock, which is known to occur in blue and fin whales (Mackintosh, 1942: Laws, 1961) and possibly in certain dolphins (Perrin, Coe and Zweifel, 1976). If this is so, and if the data are sufficient to have significance, then on the evidence of pregnancy rates the stock has at least not declined since 1959–61. But there is evidence from catch-per-unit-effort data that the stock off Paita has indeed declined between 1961 and 1976 (Arriaga, 1976). So there must be some other explanation.

Thus, if the male stock has been so far reduced by whaling that in 1975–77 there were not sufficient mature males recruited into the harem organization to fertilise the females, this would explain the decline in the pregnancy rate. But it would not explain the decline in the ‘total ovulation rate’ if, as most (but not all) workers believe (Tormosov, 1976), ovulation is spontaneous in the sperm whale. Supposing that ovulation were provoked, a deficit of bulls could also account for decline in the ‘total ovulation rate’, whether the provocation were directly by coitus, or whether, in spite of the little understood harem structure, some minimum ambience of mature bulls were necessary to provoke the females to ovulation. This last possibility could explain the likelihood of some unsuccessful ovulations at the main oestrus (Best, 1974) even if ovulation were provoked.

Gambell (1976, 1977) has drawn attention to the decrease in the catch of male sperm whales from Chile and Perú, from an average of 2,313 per season between 1947 and 1964 to 850 per season between 1965 and 1973. But there is also evidence from Paita for a severe reduction in the numbers of mature bulls required by the explanation given above. Males are taken to be socially mature, and capable of becoming harem-masters, when they reach a length of about 45 ft or 13.7 m (IWC, 1971). We give below the proportions of males which were 13.5 m and longer, and also the proportions which were 12.0 m and longer, in the catches from Paita between 1958 and 1961, calculated from Saetersdal *et al.*’s Anexo 1XB (1963). These proportions are compared with those of males 12.0 m and longer, caught from Paita in 1975 and 1976 (January to May),

calculated from Arriaga's data (1976), which do not distinguish a length class longer than 12.0 m for comparison with the data from 1958–61.

	Number of males	13.5 m and longer	12.0 m and longer
1958	777	30.24%	57.66%
1959	1,327	40.02%	57.27%
1960	1,182	37.82%	52.88%
1961	1,119	31.46%	42.00%
1958–61	4,405	35.52%	52.28%
1975	555		18.74%
1976			
(Jan-May)	449		14.48%
1975–76	1,004		16.83%

From the decline in the proportions of males 12.5 m and longer, from 52.28% in 1958–61 to 16.83% in 1975–76, it appears that the proportions of whales of harem-master status, 13.5 m and longer, which contributed 35.52% of the male catch in 1958–61, must have declined (assuming a simple proportion) to about 11% in 1975–76, that is, to less than a third of their proportion in the catch at a time when the stock was already considered to be at or below the level giving maximum sustainable yield. Commenting on the sperm whale population model currently used in the International Whaling Commission, Holt (1980) has noted that if the numbers of socially mature males in a stock are reduced to less than 28.2% (when natural mortality rates are taken to be 0.05 in both males and females), or to less than 37.3% (when the female mortality rate is put at 0.04), of their numbers in the *unexploited* stock, then the pregnancy rate will fall.

CONCLUSION

We conclude then that the decline in the pregnancy rate of whales killed from Paita, between 1959–62 and 1975–77, was due to an insufficiency of mature bulls to serve the females, and that consequently the stock exploited from Paita now stands at risk.

This comparison of pregnancy rates, over an interval without data of some 13 years, provides no evidence that the pregnancy rate rises as a stock of sperm whales diminishes; but there is still the possibility that the rate does increase with diminution of the stock to some critical level (attained and passed during the interval without data in the present case) at which a deficit in the number of mature bulls, in this polygynous species, halts the increase and starts a decline.

REFERENCES

Arriaga, L., 1976. Actividad ballenera en el Pacífico Sur-oriental. Paper ACMRR/MM/SC/119, FAO Scientific Consultation on Marine Mammals, Bergen. 11pp. (mimeo).
Bannister, J. L., 1970. The biology and status of the sperm whale off Western Australia. Paper Sp/12 presented to the IWC Special Meeting on Sperm Whale Biology and Stock Assessments, Hawaii, March, 1970.
Berzin, A. A., 1978. Whale distribution in tropical eastern Pacific waters. *Rep. int. Whal. Commn* 28: 173–7.
Best, P. B., 1968. The sperm whale (*Physeter catodon*) off the west coast of South Africa. 2. Reproduction in the female. *Investl. Rep. Div. Sea Fish. S. Afr.*, 66: 32pp.

Best, P. B., 1974. The biology of the sperm whale as it relates to stock management. pp. 257–93. In: W. E. Schevill (ed.), *The Whale Problem*, Harvard Univ. Press.
Best, P. B., 1976. A review of the world sperm whale stocks. Paper ACMRR/MM/SC/8, Rev. 1, FAO Consultation on Marine Mammals, Bergen. 106+ xvpp. (mimeo).
Clarke, R., 1956. Sperm whales of the Azores. *Discovery Rep.* 28: 237–98.
Clarke, R., 1976. Propuestas para la reasunción de investigaciones sobre ballenas en Chile, Ecuador y Perú. *Comisión Permanente del Pacífico Sur*. VI Reunión de la Comisión Coordinadora de las Investigaciones Científicas, Valparaíso, 22–26 Noviembre de 1976, Doc. Inf., 2, 7 pp. (Mimeographed).
Clarke, R., Aguayo L. A. and Paliza, G. O., 1964 Progress Report on Sperm Whale Research in the Southeast Pacific Ocean. *Norsk Hvalfangsttid.*, 53(11):297–302.
Clarke, R., Aguayo L. A. and Paliza G., O., 1964 Progress Report on Southeast Pacific. Part I: Introduction. Part II: size range, external characters and teeth. *Hvalråd. Skr.*, 51: 80 pp.
Clarke, R. and Paliza, O., 1972. Sperm whales of the Southeast Pacific. Part III: Morphometry. *Hvalråd. Skr.*, 53: 106 pp.
Gambell, R., 1972. Sperm whales off Durban. *Discovery Rep.* 35: 199–358.
Gambell, R., 1976. Male sperm whale density trends in the southern hemisphere. *Rep. int. Whal. Commn* 26 (Sci. Comm.): 317–28.
Gambell, R., 1977. Further analyses of tonnage corrected catch per unit effort data for male sperm whales in the southern hemisphere. *Rep. int. Whal. Commn* 27: 287–94.
Holt, S. J., 1980. Two concerns about the sperm whale model. Paper SC/SP78/17 (published in this volume).
International Whaling Commission, 1967. Sperm Whale Subcommittee Meeting Report, Hawaii, February, 1966. *Rep. int. Whal. Commn* 17: 120–7.
International Whaling Commission, 1971. Report of the Special Meeting on Sperm Whale Biology and Stock Assessments, Hawaii, March, 1970. *Rep. int. Whal. Commn* 21: 40–50.
International Whaling Commission. 1979. Report of the sub-committee on sperm whales. *Rep. int. Whal. Commn* 29:65–74.
International Whaling Statistics, 1970, 1976. LXV, LXXVII, Oslo.
Kostritsky, L., 1963. Los mamíferos marinos de importancia económica. Pp. 23–40 en *Recursos Naturales del Mar*, publicado por Serv. Pesq. Min. Agric. y Fac. Cienc. Univ. S. Marcos, Lima.
Laws, R. M., 1961. Reproduction growth and age of southern fin whales. *Discovery Rep.* 31: 327–486.
Machin, D., 1974. A multivariate study of the external measurements of the sperm whale (*Physeter catodon*). *J. Zool., Lond.*, 172: 267–88.
Mackintosh, N. A., 1942. The southern stocks of whalebone whales. *Discovery Rep.* 22: 197–300.
Ohsumi, S., 1965. Reproduction of the sperm whale in the Northwest Pacific. *Sci. Rep. Whales Res. Inst., Tokyo*, 19: 1–35.
Ohsumi, S. and Fukuda, Y., 1972. A population model and its application to the sperm whale in the North Pacific. *Rep. int. Whal. Commn* 22: 96–110.
Ohsumi, S. and Fukuda, Y., 1974. Revised sperm whale population model and its application to the North Pacific sperm whale. *Rep. int. Whal. Commn* 24: 91–101.
Paliza, G., O., 1964. Desarrollo morfológico del feto de cachalote *Physeter catodon* L., *Bol. Inst. Recurs. Mar., Callao* 1: 137–66.
Perrin, W. F., Coe, J. M. and Zweifel, J. R., 1976. Growth and reproduction of the spotted porpoise, *Stenella attenuata*, in the offshore eastern tropical Pacific. *Fish. Bull.* 74: 229–69.
Rice, D. W., 1977. Sperm whales in the equatorial eastern Pacific: population size and social organization. *Rep. int. Whal. Commn* 27: 333–6.
Rice, D. W. and Wolman, A. A., 1970. Sperm whales in the eastern North Pacific: progress report on research, 1959–1969. (Paper Sp/3 presented to the IWC Special Meeting on Sperm Whale Biology and Stock Assessments, Hawaii, March, 1970).
Saetersdal, G., Mejía, J. and Ramírez, P., 1963. La caza de cachalotes en el Perú. Estadísticas de captura para los años 1947–61 y un intento de analizar las condiciones de la población en el período 1954–61. *Bol. Inst. Invest. Recurs. mar., Callao* 1: 45–84.
Tormosov, D. D., 1976. On ovulation in sperm whale females. *Rep. int. Whal. Commn* 26 (Sci. Comm.): 360–5.

Biases in a Time Budget Model for Modern Whaling

by

Carl Jakob Rørvik

Institute of Marine Research, P.O. Box 1870, 5011 Bergen Norway

ABSTRACT

The time budget model adopted by the Scientific Committee in June 1978 does not account for searching conducted during chasing, handling and towing. Omission of these factors in the model leads to a bias in catch per hour searched which may be of the same magnitude as the bias in the catch per catcher day's work index. A revised model is suggested.

INTRODUCTION

An approach proposed by Beddington (1979) and Holt (1979) for estimating the time used for searching was adopted by the IWC Scientific Committee at the meeting in June 1978. This note explains some reservations about the realism of the model which I made verbally at that meeting.

My main reservation was that the model in its present form does not account for searching conducted during chasing, handling and towing.

This is at least the case in the Icelandic fin whale fishery. Exploring the properties of a similar model to the one of concern here, Rørvik, Jónsson, Mathisen and Jønsgård (1976) pooled the searching, chasing and handling time.

A REVISED TIME BUDGET MODEL

The basic equation used by the sperm whale sub-committee (IWC, 1979) to estimate the time spent searching per day, T_s , was:

$$T_s = (CDW - T_r) - (T_c + T_h + T_t) \times W - T_w \times W_f \quad (1)$$

$CDW = 24 \text{ hr}$

T_r = time resting = 24-day length correction

T_c = chasing time per male sperm whale

T_h = time handling per male sperm whale

T_t = time towing per male sperm whale

T_w = time wasted per female whale caught

W = number of male sperm whales caught per day

W_f = number of female sperm whales caught per day

Corrections to T_s were made for boats not using Asdic, the chasing time was corrected as the mean length of the sperm whales caught changed. A decrease in the searching speed after 1973 because of the increased oil prices was also taken into account. These corrections as well as T_w , which compensates for the time spent in catching and handling female sperm whales are subsequently ignored, as they do not affect the general conclusions below.

An alternative general model, closer to reality I believe, would be,

$$T_s = (CDW - T_r) - [(1 - f_c) \times T_c - (1 - f_h) \times T_h - (1 - f_t) \times T_t] \times W \quad (2)$$

where f_c , f_h and f_t are the fractions of T_c , T_h and T_t respectively which are effectively used for searching.

If $f_c = f_h = f_t = 0$ we get basically the model adopted by the Scientific Committee. If $f_c = f_h = f_t = 1$ we get an effort measure equivalent to catcher day's work.

From my own limited experience onboard two Icelandic catcher-boats in 1973 I would assume that $f_c = 0.5$, $f_h = 0.25$ and $f_t = 0.10$ are reasonable values. However, for pelagic whaling I believe that $f_t = f_c$ is a more reasonable assumption.

Using the values adopted for the Japanese pelagic whaling in the North Pacific we get:

$$T_r = 8 \text{ hr (series N)}$$

$$T_c = 0.57 \text{ hr}$$

$$T_h = 0.33 \text{ hr}$$

$$T_t = 0.22 \text{ hr}$$

Table 1 gives the catch per unit effort for three kinds of effort measurements as the number of whales caught per day decreases from 5 to 1:

CPUE 1 based on T_s and $f_c = f_h = f_t = 0$ (i.e. basically the adopted model).

CPUE 2 based on T_s and $T_c = 0.57 \text{ hr}$, $f_c = 0.50$, $f_h = 0.25$, $f_t = 0.50$.

CPUE 3 is the traditional catch per catcher day's work.

The CPUE's are rescaled so that they all equal 1.00 for $W = 5$.

DISCUSSION

In the following discussion it is assumed that CPUE 2 is based on the correct number of hours effectively searched, and that CPUE 2 is proportional to the stock size.

It appears from Table 1 that the omission in the adopted time budget model of the factors mentioned in my reservation will lead to a systematic overestimation of the relative decline of the stock, when the catch per catcher day's work (CPUE 3) declines.

The bias (overestimated decline of the stock) in CPUE 1 relative to CPUE 2 is for the above values of f_c , f_h , f_t of the same magnitude as the bias (underestimated decline of the stock) in the rejected CPUE 3. Inclusion of time wasted (T_w) and the corresponding f_w in the model would further increase these biases.

No quantitative estimates apart from the above 'guesstimates' of f_c , f_h , f_t are available as far as I know, but they are likely to vary from fishery to fishery. For example I would expect f_t would be lower in a shorebased fishery than in a pelagic fishery. I would expect f_c to be different for catchers chasing baleen whales with Asdic and the 'prøyserjag technique' than for those catchers without Asdic using the 'lusejag-technique', all other factors being equal. Baleen whales are usually scared by Asdic and so area sighted per hour chasing will probably be greater with the

Table 1

CPUE = catch per unit effort for a hypothetical stock. W = number of whales caught per day. CPUE 1 is based on the adopted time budget model. CPUE 2 is based on the revised time budget model. CPUE 3 is the traditional catch per catcher day's work. The CPUE's are rescaled so that they all equal 1.00 for W = 5.

W	CPUE 1	CPUE 2	CPUE 3
5	1.00	1.00	1.00
4	0.722	0.762	0.80
3	0.494	0.545	0.60
2	0.302	0.348	0.40
1	0.140	0.167	0.20

fast and all out chasing 'prøyserjag-technique' than the slow-chasing 'lusejag-technique'. However, searching might be more active during lusejag than prøyserjag, as the aims of lusejag are to anticipate where the whale will surface and to place the quiet and slow moving vessels there at that time.

One way to get a better idea of the magnitude of f_c , f_h and f_t would be to compare the sighting rate during chasing, handling and towing with the sighting rate when only searching is conducted. Information on how these sightings are subsequently utilised is also desired.

The model in its present form assumes a constant chasing time (T_c) independent of the density of whales. If the whales are fastened to the catcherboat and towed during the chase for the next whale, the average chasing speed will increase as the average number of whales caught per trip (or before delivery to the factory ship or towing boat) decreases. This factor will tend to decrease T_c as the stock size decreases. However, in a fishery where the whales are flagged and left adrift before the next chase, this factor is not relevant.

On the other hand, as the density of whales is getting lower, I would expect that the whalers are probably less inclined to give up chasing a 'wild one' because the chance of sighting another more 'quiet' whale during the chase is

getting lower. This might cause T_c to increase as the stock decrease.

If the average chasing time, T_c , decreases as the density decreases, the bias in CPUE 1 relative to the bias in CPUE 3 will decrease. If, however, T_c increases as the density decreases the bias in CPUE 1 will increase relative to the bias in CPUE 3.

The final factor I would mention is the importance of the pod size. If the average pod size decreases as the stock decreases, this would tend to remove some of the non-linearity between catch per day worked and the stock size as also commented on by Rørvik *et al.* (1976).

CONCLUSION

The time budget model adopted at the June 1978 meeting of the Scientific Committee is definitely an improvement in terms of realising some of the factors involved in whaling. However, because of its incompleteness it might not give a better abundance index in terms of biases than the abandoned 'catch per catcher day's work' index.

REFERENCES

Beddington, J. R., 1979. On some problems of estimating population abundance from catch data. *Rep. int. Whal. Commn* 29: 149-54.

Holt, S. J. 1979. A simple model of pelagic whaling. *Rep. int. Whal. Commn* 29: 155-7.

International Whaling Commission, 1979. Report of the Subcommittee on sperm whales June 1978, Annex E (published in this volume) and *Rep. int. Whal. Commn* 29:65-70.

Rørvik, C. J., Jónsson, J., Mathisen, O. A. and Jønsgård, Å. 1976. Fin whales (*Balaenoptera physalus* (L.)), off the West Coast of Iceland. Distribution, segregation by length and exploitation. *Rit. Fisk.* 5(5):1-30.

The Sperm Whale Catch by Japanese Coastal Whaling in the Sanriku Region

Seiji Ohsumi

Far Seas Fisheries Research Laboratory

INTRODUCTION

Although pelagic whaling is active and the vessels can move freely throughout the oceans, coastal whaling is passive and its whaling ground is restricted to within coastal waters (no further than 250 miles from a land station) and hence the whalers must wait for the whales to enter the coastal whaling grounds. This means that the mode of operation of coastal whaling is different to that of pelagic whaling. For example, the relatively long navigation and towing times which are included in the time budgets of coastal operations when compared with pelagic operations, suggest that the efficiency of coastal whaling is lower than that of pelagic whaling.

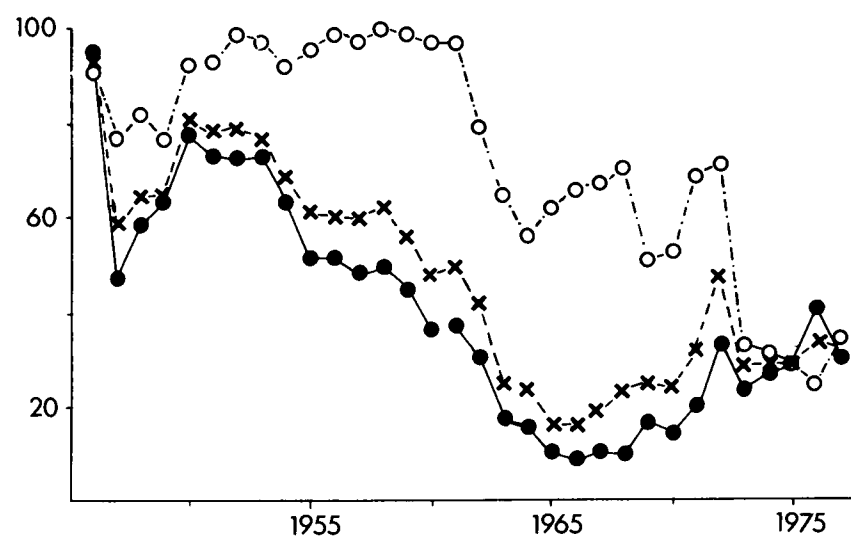


Fig. 1. Yearly change in the ratio of coastal sperm whaling to sperm whaling in the whole North Pacific. ○ - - - ○ females; ● - - - ● males; x - - - x males and females.

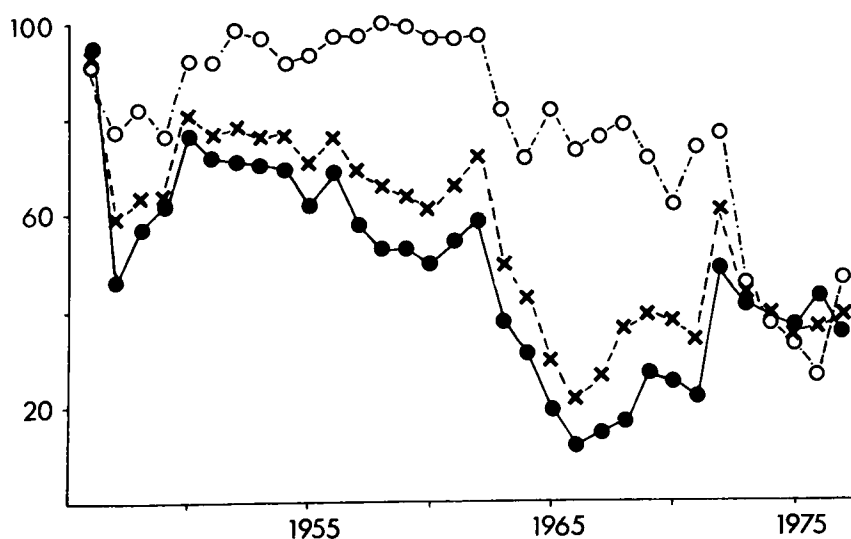


Fig. 2. Yearly change in the ratio of the Asian coastal sperm whale catch to the sperm whale catch in the Western Division. ○ - - - ○ females; ● - - - ● males; x - - - x males and females.

North Pacific sperm whale populations have usually been assessed from pelagic whaling catch and effort data, despite the fact that coastal whaling has played a relatively large part in the sperm whale catch of the North Pacific. Fig. 1 shows the yearly change in the ratio of the catch of sperm whales by coastal whaling to the total catch of sperm whales in the North Pacific. With the development of pelagic whaling in the 1960s, the relative importance of coastal whaling decreased, reaching a minimum of 16% in 1966, but since then it has increased to about 30–35% of the recent total catches.

Japanese coastal whaling has always been the largest coastal whaling operation in the North Pacific, and the Japanese coastal waters have been recognised as one of the best sperm whaling grounds in the world since the traditional mother ship and harpoon boat fishery in the last century. Fig. 2 shows the yearly change in the ratio of the sperm whale catch by Japanese coastal whaling to the pelagic catch in the Western Division of the North Pacific as adopted by the IWC this year (IWC, 1979). It shows a similar trend to that in Fig. 1, declining to a minimum of 21% in 1966, but maintaining a level of 34–39% in recent years.

This brief survey shows that coastal whaling data cannot be neglected in the population assessment of the North Pacific sperm whale, but the complexity of coastal whaling requires further investigation into its operations.

The Sanriku region is the main Japanese coastal whaling ground and I have examined the catch of sperm whales in this region in order to investigate the characteristics of coastal whaling.

MATERIALS

The data which are used in this paper are mainly from the NP 1, NP 2 and NP 3 Forms which have been circulated among the North Pacific Whale Group and which give information on catch, fishing effort and size distribution. The data for the 10° square M 21 (Sanriku) in Japanese coastal whaling are examined for the years 1949–1977/78.

CDW (catcher day's work) is corrected by the horse power of the catcher boats assuming that catch efficiency is proportional to average horse power.

SEASONAL CHANGES IN CPUE IN THE SANRIKU REGION

As Ohsumi (1980) noted, there was no regulation of either the baleen or sperm whaling seasons in Japanese coastal whaling until 1951, when limits of eight successive months for sperm whales and six months for baleen whales were introduced for 1952. The sperm whaling season was set by the Japanese Government to run from April – November

until 1965, changed to May – December for 1966. The sperm whaling season further changed to August – March in 1976. The baleen whaling season was set from May – October from 1952 to 1975, and changed to April – September in 1976.

One of the characteristics of coastal whaling is the large monthly change in CPUE of the sperm whale. Figs 3 and 4 show the monthly change in the CPUE of males and females respectively for each year from 1949 to 1977/78. It can be seen that the patterns of monthly change are not the

same for every year. Fig. 5 shows the yearly change in CPUE of the sperm whale by month and it is clear that the pattern of yearly change in CPUE differs by month. These phenomena suggest that the migration pattern of the sperm whales in the Sanriku region has not remained constant from 1949 to 1977. Fig. 6 shows the peak month of CPUE in each year by sex. The peak was in January in 1949, had moved to September by the middle of 1950s and from the middle of 1960s it again moved to later months reaching January in males and February in females in 1977/78.

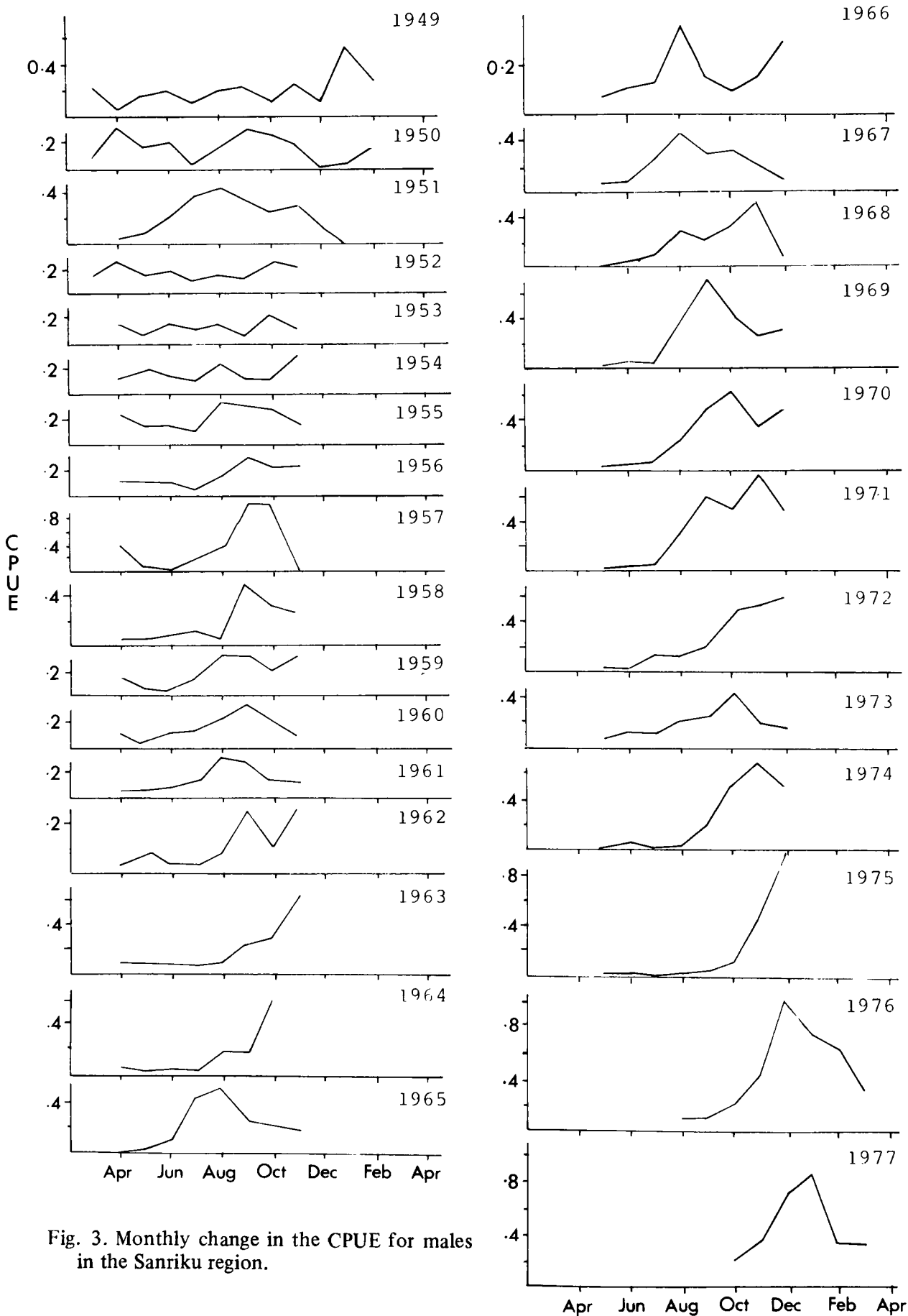
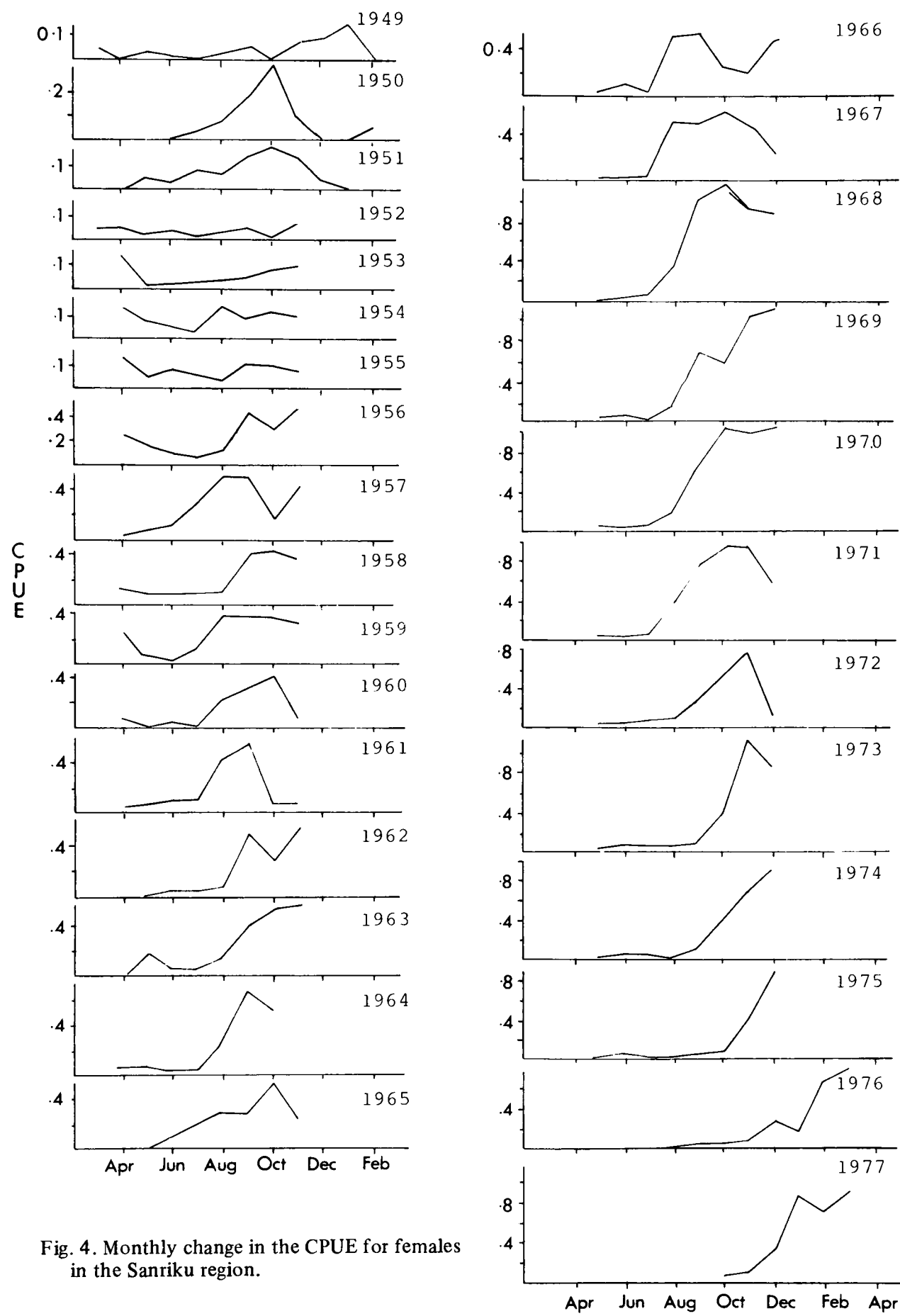


Fig. 3. Monthly change in the CPUE for males in the Sanriku region.



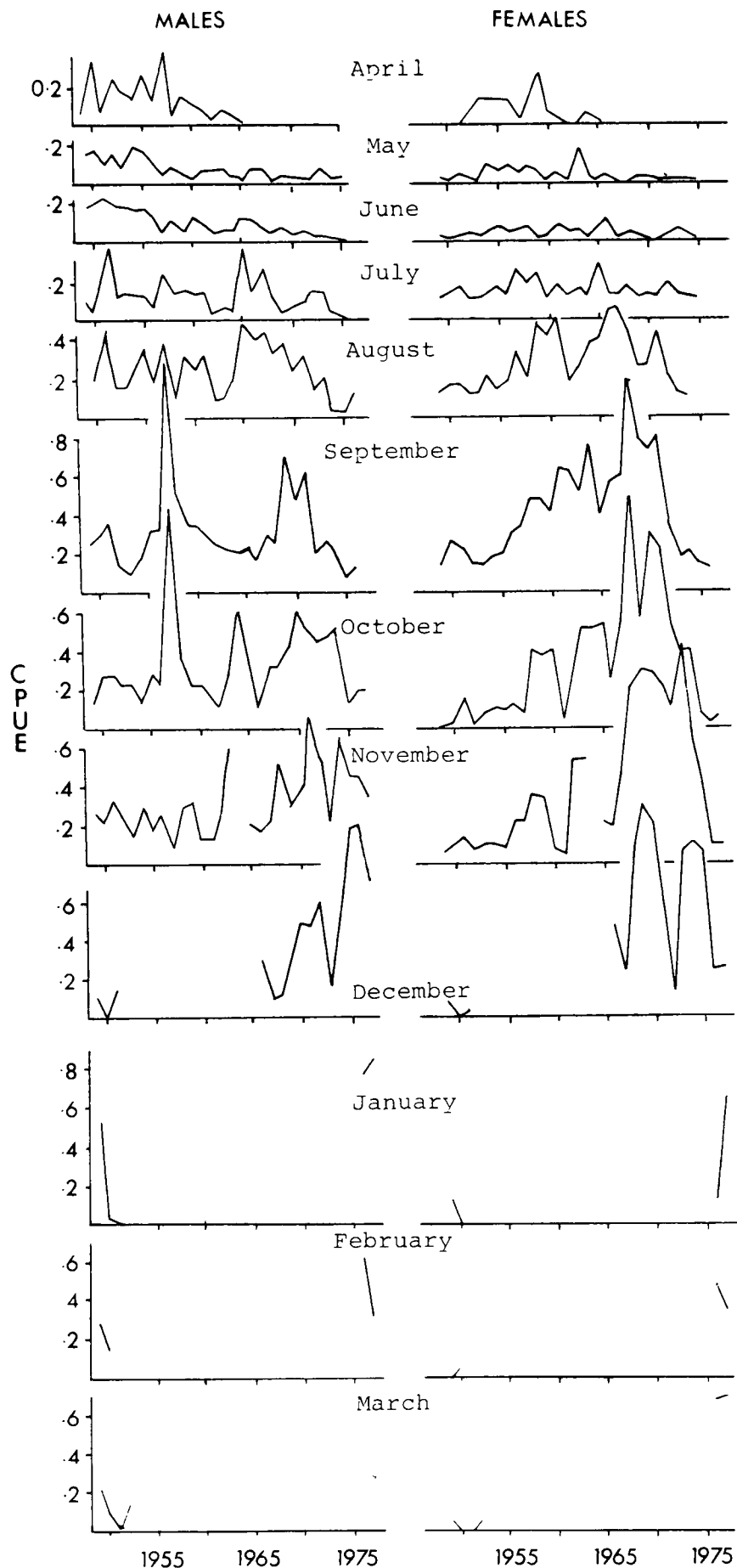


Fig. 5. Yearly change in the CPUE for both sexes in the Sanriku region for each month.

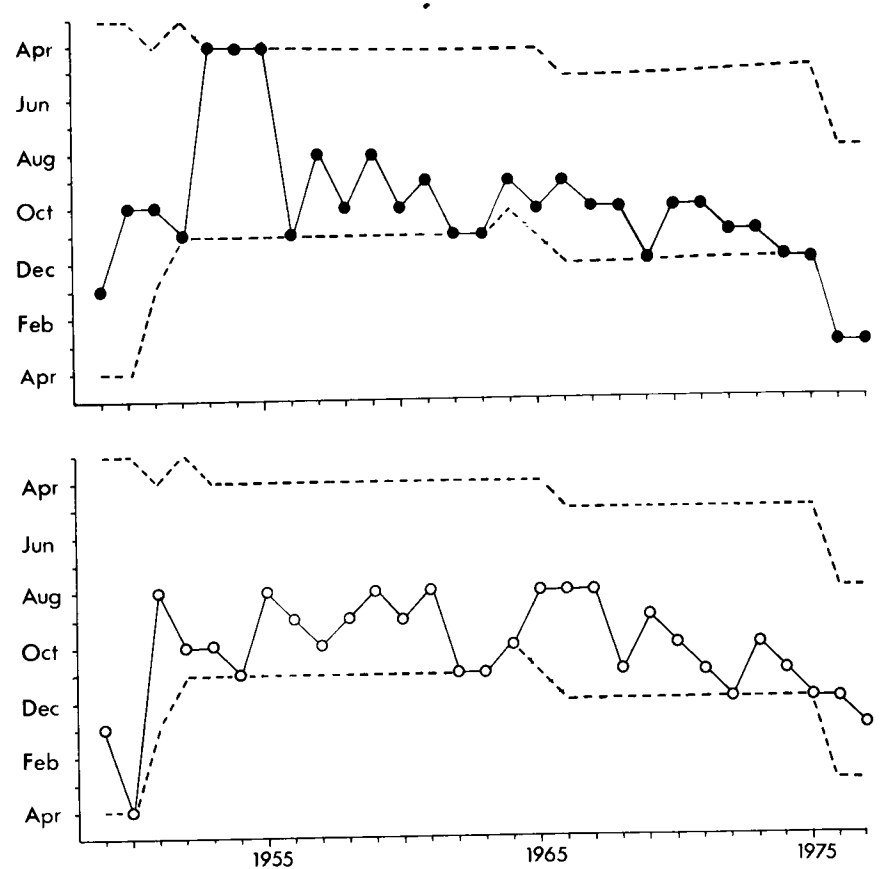


Fig. 6. Yearly change in the month in which the CPUE was highest in the Sanriku region. The dotted lines show the extent of the season. ●—● males; ○—○ females.

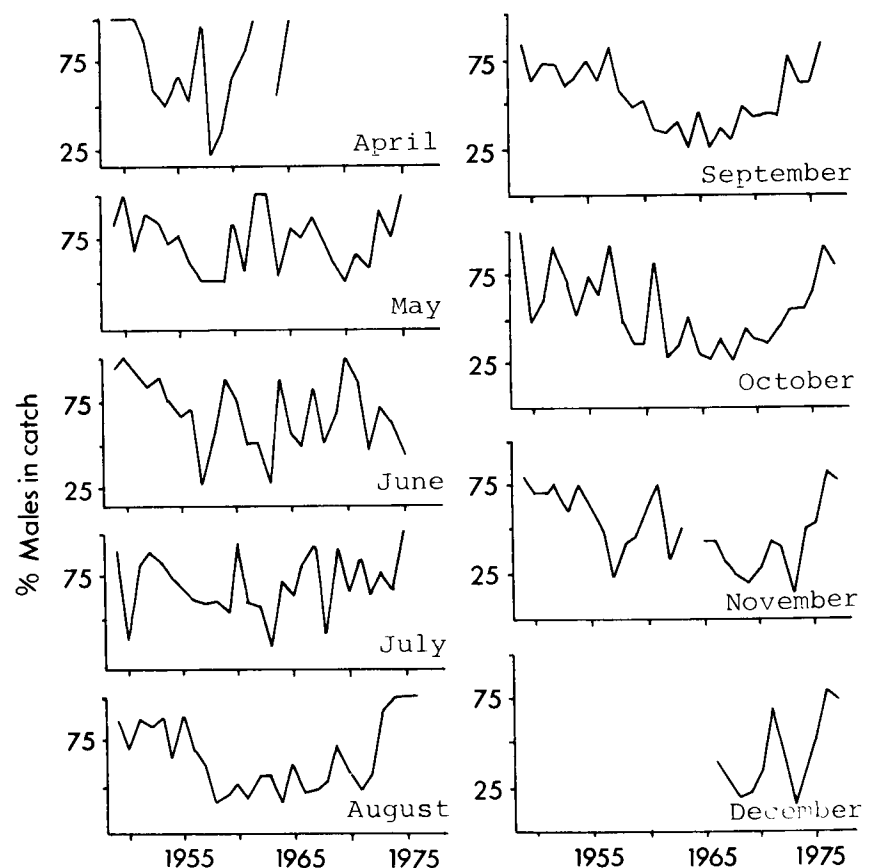


Fig. 7. Yearly change in the sex ratio of whales caught in the Sanriku region for each month.

MONTHLY CHANGES IN THE SEX RATIO OF THE CATCH

Figs 7 and 8 show the monthly change in the ratio of males in the sperm whale catch in the Sanriku region. In general, the male sex ratio is high at the beginning of the Sanriku whaling season, and lowest at the peak time of the season. Both figures show gradual monthly changes each year. The lowest month of the male sex ratio has moved gradually from summer to winter. This trend is very similar to the monthly change in CPUE, and also suggests that the migration of sperm whales has tended to be gradually delayed in recent years.

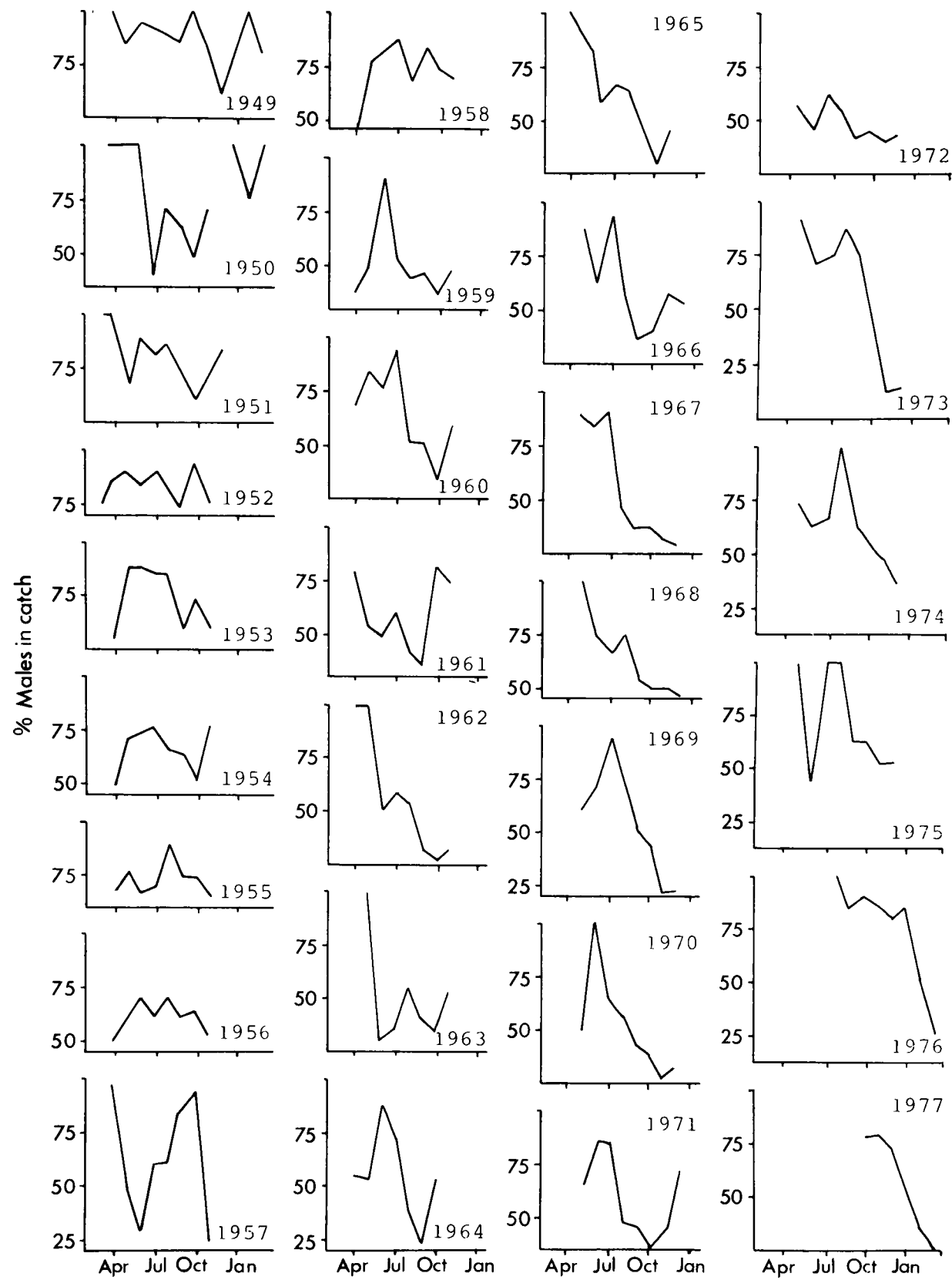


Fig. 8. Monthly change in the sex ratio of whales caught in the Sanriku region.

RELATIONSHIP WITH OCEANOGRAPHIC AND FISHERIES CONDITIONS

The change in the migration pattern of the sperm whale in the Sanriku region can be related to the change in oceanographic conditions in the region. Figs 9 and 10 show the position of the warm and cold water currents in the Sanriku region in August. The northern limit of the warm water current 'Kuroshio' has moved gradually from north to south, while at the same time the centre of the cold water current 'Oyashio' has moved eastwards.

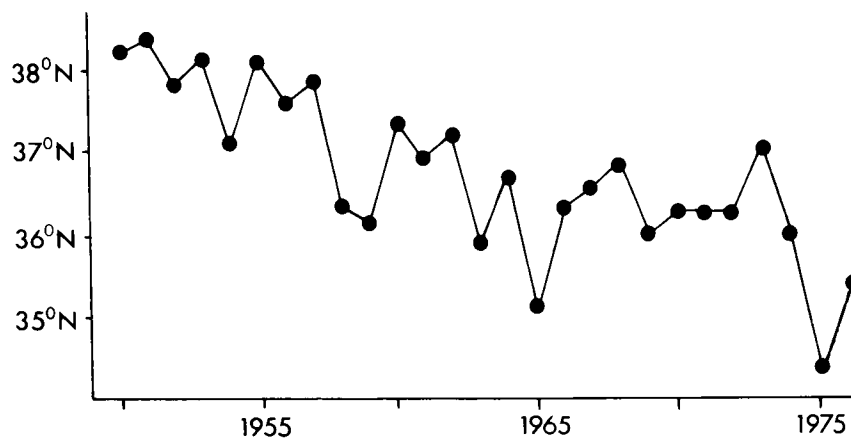


Fig. 9. Yearly change in the northern limit of the Kuroshio Current in the Sanriku region.

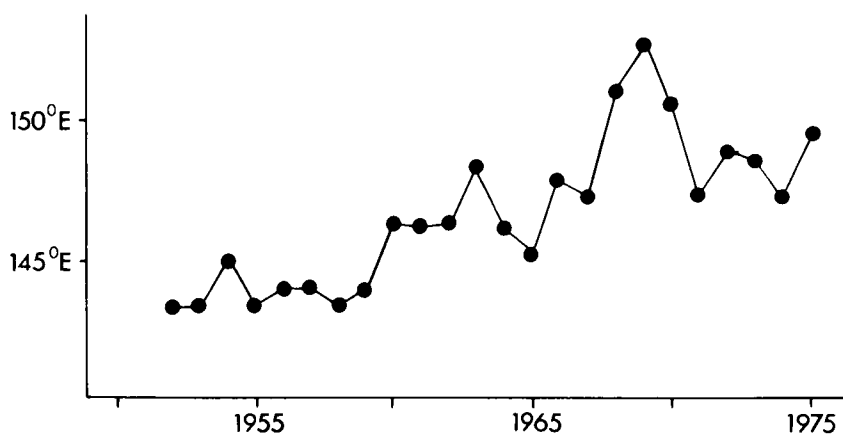


Fig. 10. Yearly change in the position of the centre of the Oyashio Current in the Sanriku region.

This shows that the oceanographic conditions in the Sanriku whaling ground have changed remarkably over the years. Fig. 11 shows the yearly change in the annual yield of the four main fisheries species in the region. The annual yield of sagittated squid gradually increased until 1968, but has been decreasing since then. The yield of saury fish decreased dramatically until the middle of the 1960s and has remained at a low level since then. However, the yield of sardines was very small until 1971, and it has been increasing rapidly since 1972. The yield of mackerel increased until 1970, but since then it has been decreasing. These fisheries results are believed to have been caused by the change in the oceanographic conditions in the regional waters.

The Sanriku whaling ground corresponds to the core of the water boundary between the Oyashio and the northern branch of the Kuroshio, which results in cyclonic rolling eddies in the zone of the Oyashio Front and the Kuroshio Front (Uda, 1954). The change in the migration pattern of the sperm whale in this region is related to the change in these oceanographic conditions.

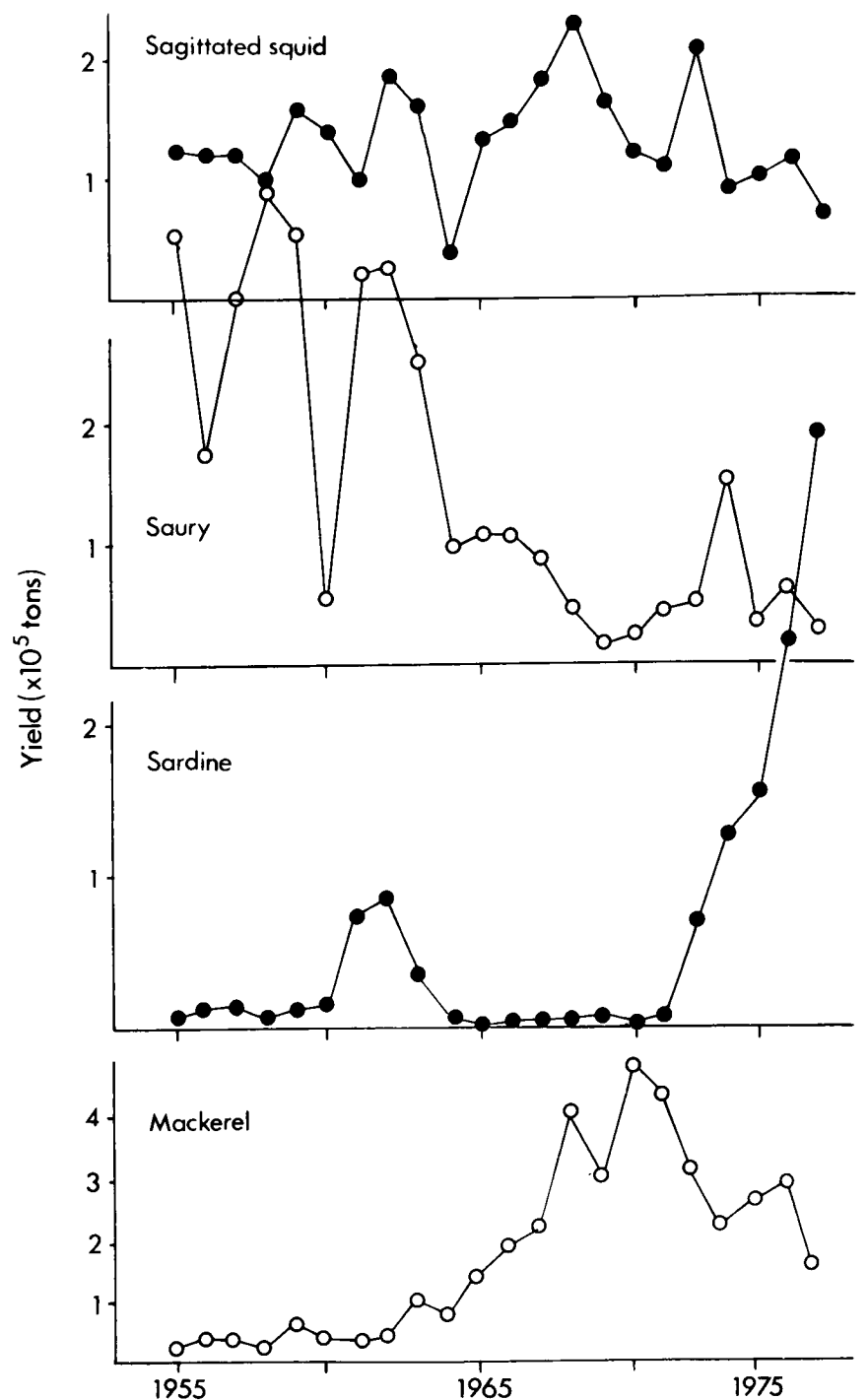


Fig. 11. Yearly change in the yield of four of the main fishery species in the Sanriku region.

YEARLY CHANGE IN CPUE OF THE SPERM WHALE IN THE SANRIKU REGION

We have seen that there is a large seasonal change in the CPUE of the sperm whale in the Sanriku region, and that the migration pattern has been gradually changing. With this knowledge, it does not seem reasonable to use the catch and effort data for sperm whales either in a year as a whole or in the same month, and I believe that the CPUE in the peak month of a year should be used to examine the yearly change in the CPUE of this region.

Fig. 12 shows the yearly change in the CPUE of male and female sperm whales in the Sanriku region using the CPUE in the peak month of a year. Despite yearly fluctuation, a marked trend of increase in the CPUEs of both sexes can be seen. There is a problem as to whether this represents an increase in the availability of the sperm whale in the Sanriku whaling ground or not and in order to answer it some of the following operational factors should be considered:

- (1) Until the 1960s the months with the highest CPUE values were August–October. Baleen whales were caught in these months, and this will cause an underestimate of the apparent CPUE for the sperm whale, as part of the effort was aimed at baleen whales.
- (2) The processing capacity of the land station has gradually increased, while the number of catcher boats which belong to a land station has gradually decreased. These factors allow a catcher boat to tow in more whales per operational cycle in the peak month.
- (3) The whaling ground in the peak month has become more stable in recent years, and catcher boat operations have become easier than in the past.
- (4) Catching ability has been increased due to co-operative chasing, increased experimentation by the whalers, development of navigational instruments, etc.

It is impossible to quantify these factors to correct the apparent CPUE and further work is necessary on the question of increased availability.

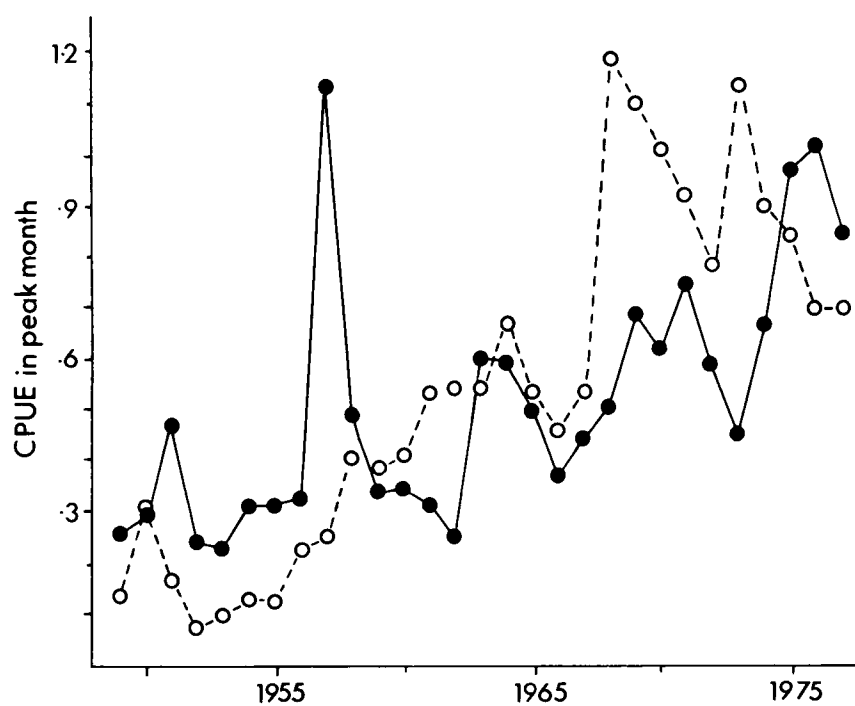


Fig. 12. Yearly change of CPUE in the peak month in the Sanriku region. ●—● males; ○---○ females.

YEARLY CHANGE IN SCHOOL SIZE

Data on the numbers of individual sperm whales and schools found by catcher boats per day were available, except for 1964 and 1968. The whalers' estimates of school size do not include calves and so the apparent school size is less than the true size.

Fig. 13 shows the change in the number of schools seen by a catcher boat by month. It is clear that the peak has moved gradually to later months. Fig. 14 shows the yearly change in the number of schools found by a catcher boat in a month. Similarly to the CPUE, it has changed gradually each year and the number of schools seen by a boat in the peak month has gradually been increasing. Fig. 15 shows the monthly change in the average school size found by catcher boats. It is clear that the school size differs by month and that the pattern is not the same every year. Fig. 16 shows the yearly change in the average school size of sperm whales found in the coastal waters of Japan. The average school size by month is not constant over the years and has been increasing in the peak month.

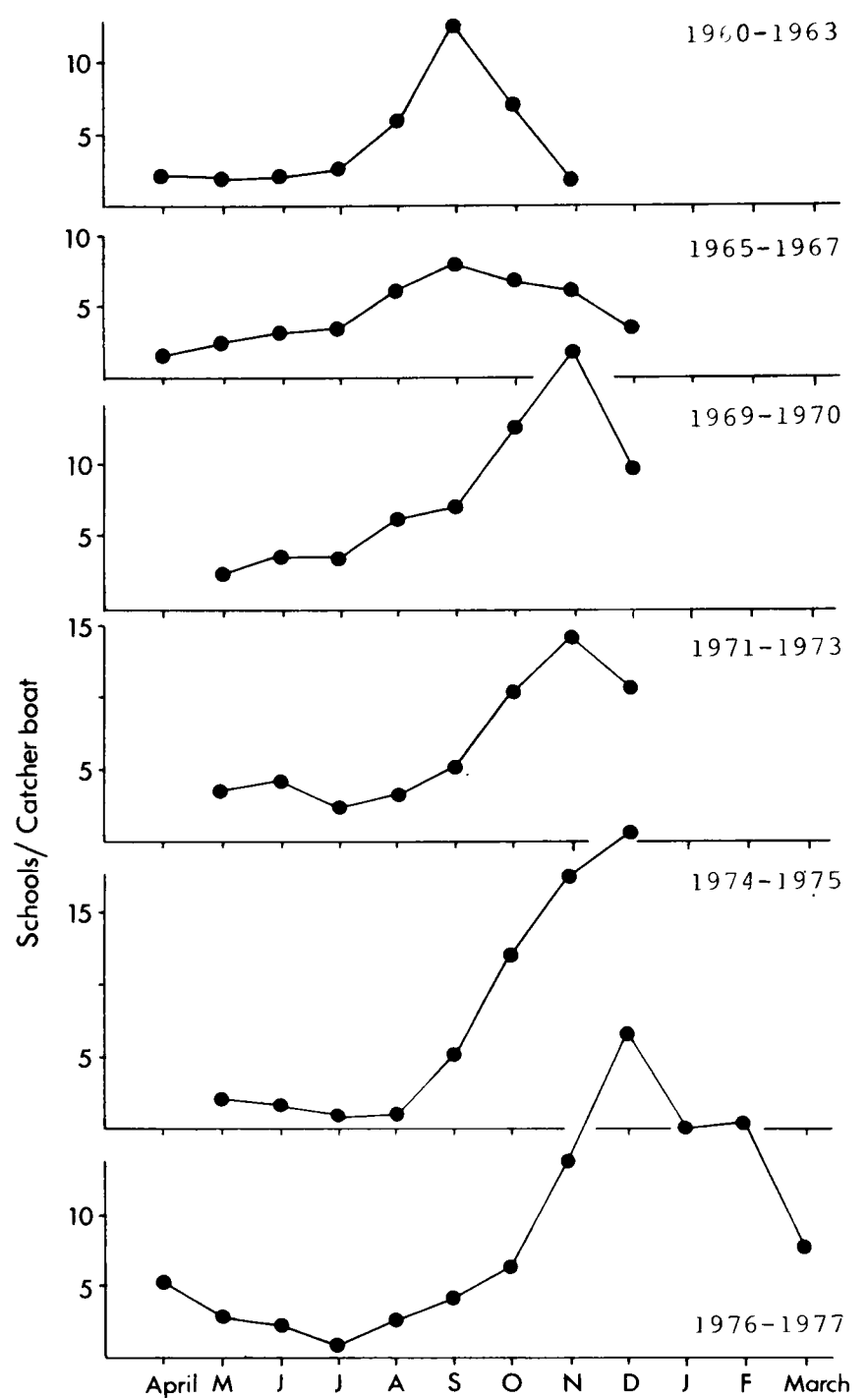


Fig. 13. Monthly change in the number of schools found per catcher boat in Japanese coastal waters.

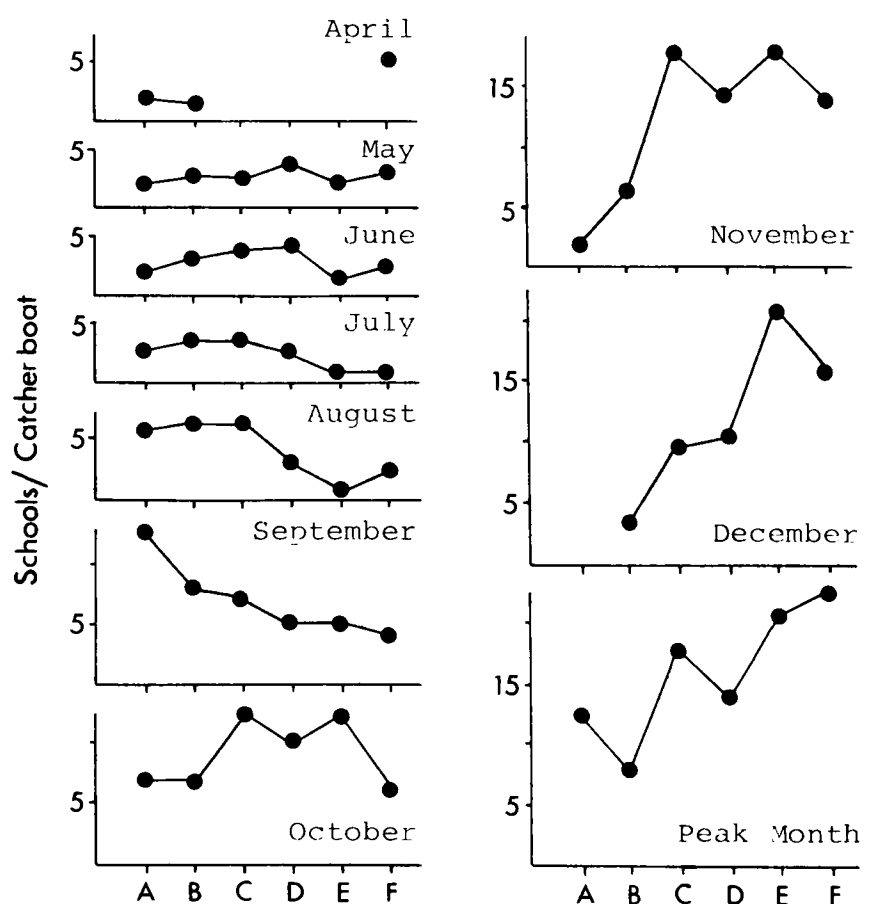


Fig. 14. Yearly change in the number of schools found per catcher boat in Japanese coastal waters for each month. Year groups: A = 1960–63; B = 1965–67; C = 1969–70; D = 1971–73; E = 1974–75; F = 1976–77.

These two features of sperm whale schools, i.e. number of schools found by a catcher boat by month and average school size, suggest that the availability of the sperm whale in coastal waters has been increasing, because these features are not related to operational factors. Therefore, it can be concluded that two independent data sets (CPUE and school-size) confirm that the availability of the sperm whale in the coastal waters has been increasing, although the migration pattern has been changing.

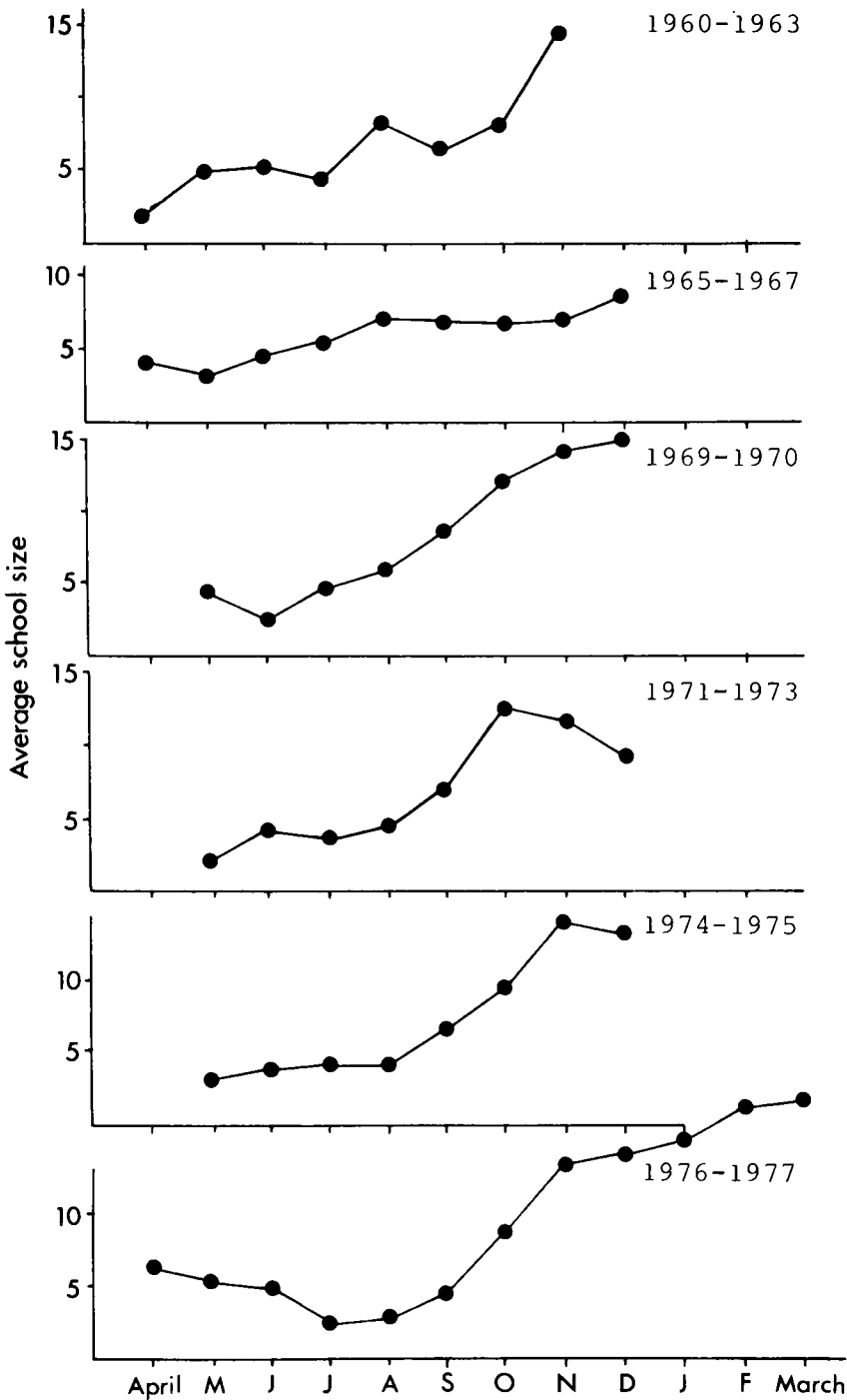


Fig. 15. Monthly change in the average school size found by catcher boats in Japanese coastal waters.

YEARLY CHANGE IN THE AVERAGE BODY LENGTH

The average body length is one of the indicators of the population level. Fig. 17 shows the yearly change in the average body length of male sperm whales caught in the Sanriku region. The legal size limit for coastal whaling for the sperm whale was 30 ft until 1948 when it was changed to 35 ft for 1949 and onwards until it was again changed to 30 ft in 1973. The average body length of the total numbers of whales caught is affected by the legal size limit, but the average body length of whales of 38 ft and over will not be affected by the size limit and so two sets of average

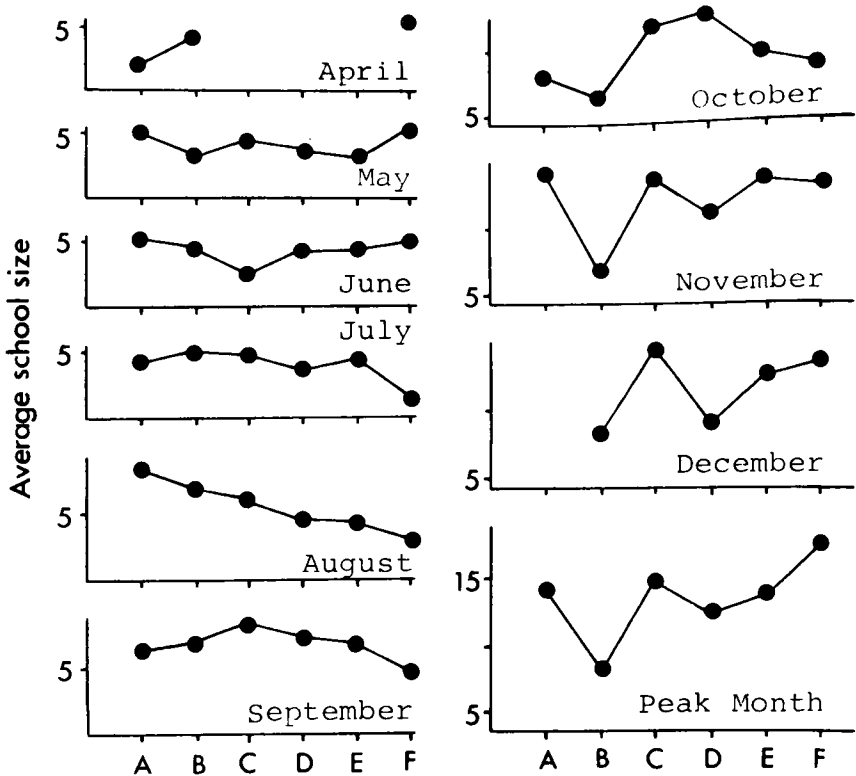


Fig. 16. Yearly change in the average school size found by catcher boats in Japanese coastal waters. Year groups: A = 1960-63; B = 1965-67; C = 1969-70; D = 1971-73; E = 1974-75; F = 1976-77.

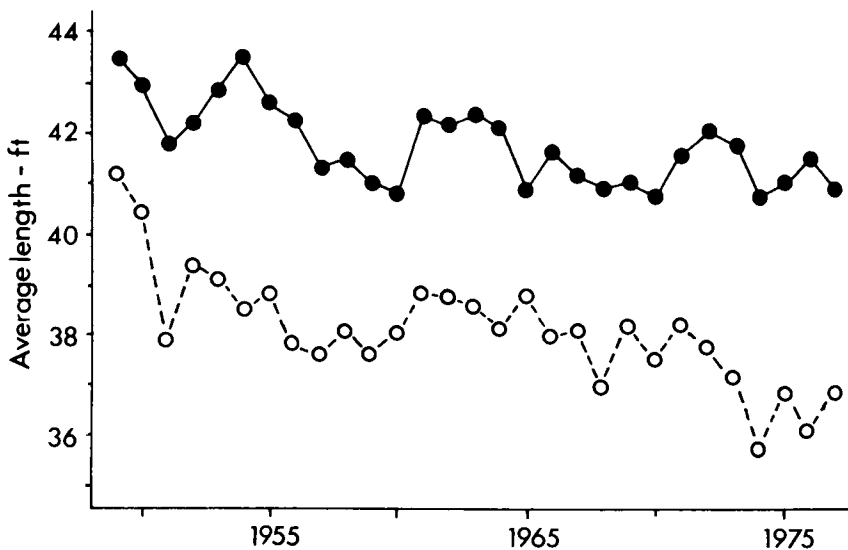


Fig. 17. Yearly change in the average length of males caught by Japanese coastal whaling in the Sanriku region. ○-○ all males caught; ●-● males of 38 feet and over.

body lengths were calculated as shown in Fig. 17. It can be seen that the average body length of whales of 38 ft and over has been almost constant at least since 1957. This suggests that the male sperm whale population level has not decreased over the years.

REFERENCES

Ohsumi, S. 1980. Catches of sperm whales by modern whaling in the North Pacific. Paper SC/SPC/1 (published in this volume).
Uda, M. 1954. Studies of the relation between the whaling grounds and hydrographical conditions (I). *Sci. Rep. Whales Res. Inst., Tokyo*. 9: 179-87.

Examination of the Pregnancy Rate of the Sperm Whale in the North Pacific

Seiji Ohsumi¹

ABSTRACT

Pregnancy rate data for the North Pacific collected by Japanese pelagic whaling fleets from 1966 to 1967 are analysed. Females are classified as sexually mature, ovulating, early pregnant and late pregnant. Zonal differences in pregnancy rate are examined to investigate possible segregation of pregnant whales. The data suggest that late pregnant whales tend to segregate in higher latitudinal water. If this is true then the apparent decline in pregnancy rates with time may be due to the movement of the pelagic whaling ground to lower latitudinal waters. The true pregnancy rate in the Western Division is estimated to be 25–31%. There is insufficient data to obtain an estimate for the true pregnancy rate in the Eastern Division.

INTRODUCTION

The Sperm Whale sub-committee of the IWC Scientific Committee examined the yearly change in the pregnancy rate of the sperm whale at its 30th Annual Meeting and it reported a decline of 38% in the pregnancy rate of sperm whales taken in the Western Division of the North Pacific between 1966–69 and 1974–76 (IWC, 1979).

Ohsumi (1980) has identified the yearly movement of the pelagic sperm whaling ground in the North Pacific. If there is segregation of pregnant whales, it will be dangerous to deal with the data as a whole as the sub-committee in fact did. Masaki (1980) suggested this possibility, and showed two different pregnancy rates for the waters north and south of 40°N. Another problem is that the grouping of years could mask yearly fluctuations in the pregnancy rate.

Pregnancy rates need to be examined as thoroughly as possible, as changes in this biological parameter affect not only the adequacy of the population assessment, but also the management policy for the stocks. Pregnancy rate should be examined by stock and although it is possible that there are more than two stocks of sperm whales in the North Pacific (IWC, 1979) and in particular the Western Division as set by the Committee (IWC, 1979, Annex E, Fig. 1) may be divided into two or more stocks (Bannister and Mitchell, 1980), I have treated the data for the Western Division as one stock to aid comparison with the result reported in Annex E. The data from the Eastern Division are also examined in this paper.

MATERIALS

The biological data used in this paper were collected from Japanese pelagic whaling during the years, 1966–77. Japanese pelagic whaling began to take more than one hundred female sperm whales in the North Pacific in 1966. The ovaries were collected from the whales taken, and then examined and corpus luteum and corpus albicans counts made in my laboratory. National inspectors or their assistants examined the uterus of each whale caught on board the factory ship and when a foetus was found it was measured and its sex determined. The North Pacific sperm whale has a long breeding season with a peak in April and May (Ohsumi, 1965) and Japanese pelagic whaling has operated from May to September. This means that small foetuses or embryos occur frequently in the whaling season, and it is possible that they would be too small to be found. Therefore, any whale with a corpus luteum in the ovaries but apparently no foetus may have been early pregnant. This can be estimated from evidence that the ratio of ovulating whales with a corpus luteum in the ovaries but no foetus found in the uterus, to mature females is large in the month when the early pregnancy ratio is small. Therefore, the ovulating whales are important in any consideration of pregnancy rate. Early pregnant (conceived in the present year) and late pregnant (conceived in the previous year) animals were identified by the size composition of the foetuses in each 10 day period.

Numbers of sexually mature (with at least one corpus luteum or corpus albicans in the ovaries), M, ovulating, V, early pregnant, E, and late pregnant, F, females were tabulated by 10° square, by month and by year. These original tables were then arranged by Division, by Zone, by month and by year (Appendix Tables 1 and 2).

¹ Far Seas Fisheries Research Laboratory

PREGNANCY RATE IN THE WESTERN DIVISION

Seasonal change in observed pregnancy rates

Table 1 and Fig. 1 show the monthly change in the ratios of V, E, F and V + E to M for the total data during the years 1966–1977. The values of F/M decrease remarkably from May to September which means that the sperm whale parturates gradually during these months in the North Pacific. E/M increases from May to July and becomes almost constant from July, whereas V/M decreases from May to July, but also becomes constant from July. V + E/M increases from May to July, and becomes almost constant from July. This suggests that the main ovulating and conception season ceases by July.

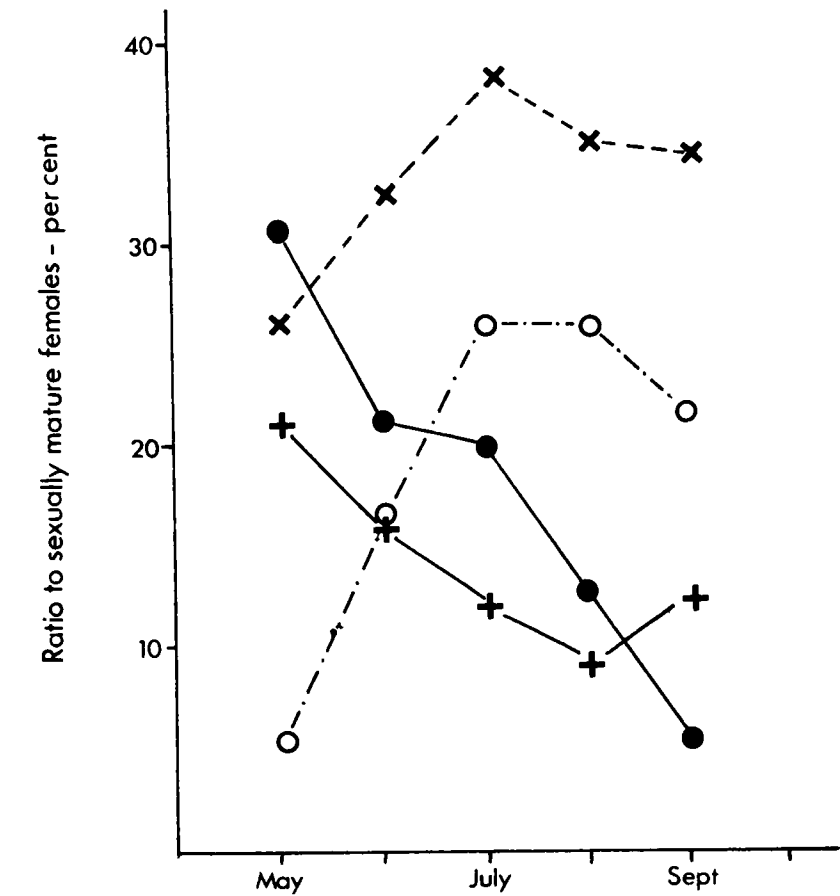


Fig. 1. Monthly change in pregnancy rates in the Western Division of the North Pacific, 1966–77. Late pregnancy; early pregnancy; ovulating; ovulating + early pregnant.

Zonal difference in observed pregnancy rates

Fig. 2 shows the existence of samples by Zone, by month and by year. It is clear that the sampling location has moved from Zone P (50°–60°N) in the 1960s to Zone L (20°–30°N) in the 1970s. It is therefore important to examine whether segregation of pregnant whales occurs or not when considering pregnancy rate.

Table 2 and Fig. 3 show the monthly change in F/M, E/M, V/M and V + E/M in each Zone during the years 1966–77. The value of F/M differs greatly by Zone; that in Zone P is the largest in all months and that in Zone N is lower than that in Zone P but higher than those in the remaining Zones M and L (which are not so very different from each other). However such clear Zonal differences are

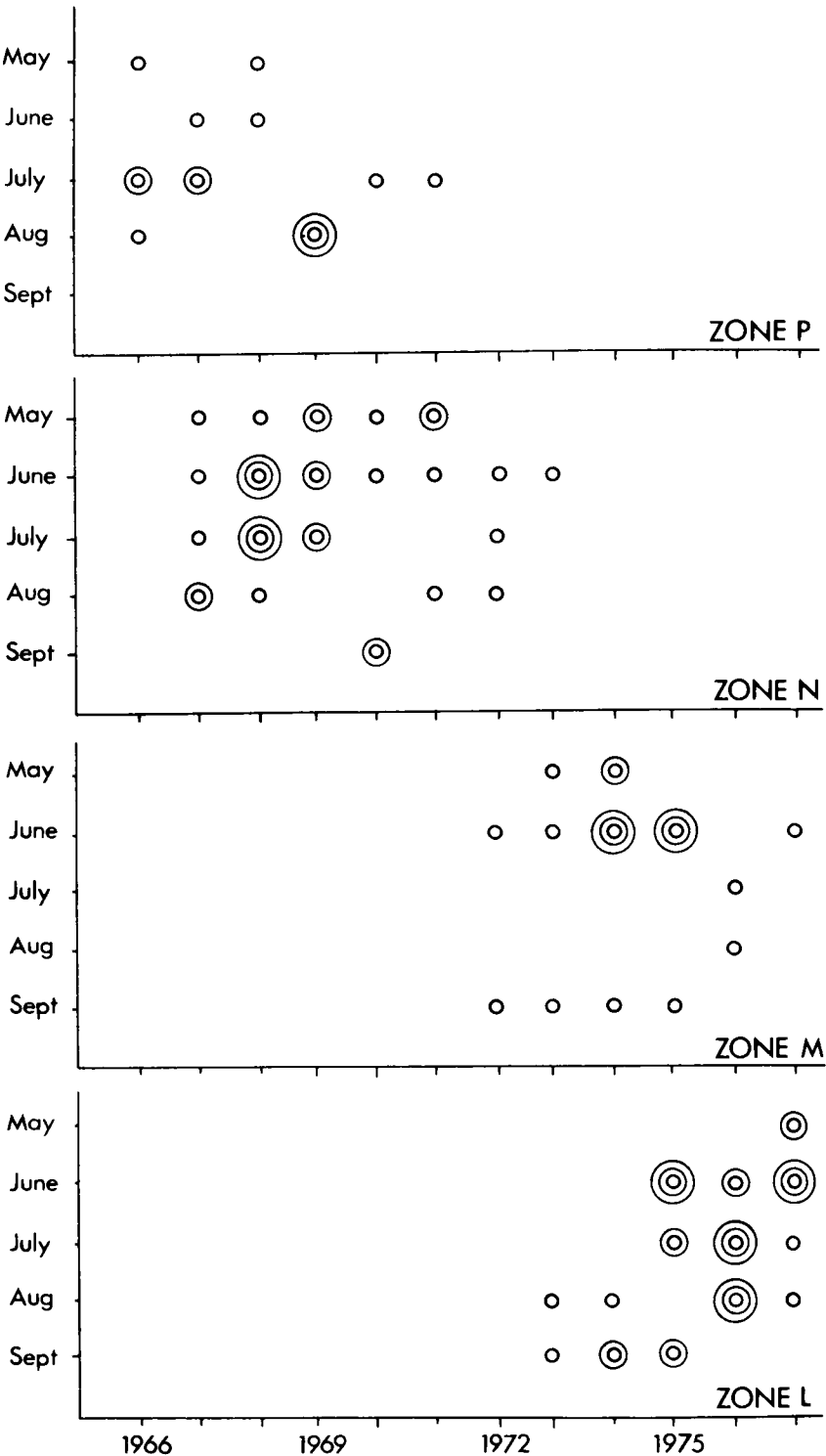


Fig. 2. Samples of mature females in each Zone (Western Division). $\circ$ < 50 whales; $\odot$ < 100 whales; $\odot\odot$ > 100 whales.

not seen in E/M, V/M and V + E/M. The above examination suggests the possibility of the existence of Zonal segregation in late pregnant whales, but to confirm this, data from the same year must be compared, whereas these data are a pooling of the years 1966–77. Unfortunately there has been no year when sufficient data have been obtained from these four Zones (Fig. 2). Comparable data are available for Zones P and N in years, 1967–69. Table 3 and Fig. 4 show the monthly change in F/M and E/M in Zones P and N in 1967–69. The value of F/M in Zone P is clearly larger than that in Zone N. Insufficient data are available for comparison of Zones P or N with those in Zones M or L in that period, but sufficient data are available to compare Zones

Table 1
Monthly change in pregnancy rate in the Western Division of the North Pacific during years, 1966–77

Month	M	V	E	F	V/M	E/M	F/M	V+E/M
May	386	82	20	119	21.2	5.2	30.8	26.2
June	1,047	167	173	223	16.0	16.5	21.3	32.5
July	794	98	206	159	12.3	25.9	20.0	38.3
August	522	48	135	68	9.2	25.9	13.0	35.1
September	303	38	66	16	12.5	21.8	5.3	34.3

Table 2
Comparison of Zonal differences in pregnancy rates in the Western Division of the North Pacific during years, 1966-77

Zone	Month	M	V	E	F	V/M	E/M	F/M	V + E/M
P	May	13	3	—	6	23.0	0.0	46.2	23.0
	June	47	6	5	16	12.8	10.6	34.0	23.4
	July	249	34	68	61	13.7	27.3	24.5	41.0
	August	171	17	55	31	9.9	32.3	18.1	42.1
N	May	216	51	13	77	23.6	6.0	35.6	29.6
	June	363	56	82	84	15.4	22.6	23.1	38.0
	July	190	21	55	38	11.1	28.9	20.0	40.0
	August	99	6	24	16	6.1	24.2	16.1	30.3
	September	55	7	5	6	12.7	9.1	10.9	21.8
M	May	101	20	7	20	19.8	6.9	19.8	26.7
	June	320	42	34	66	13.1	10.6	20.6	23.8
	July	27	1	6	4	3.7	22.2	14.8	25.9
	August	1	—	—	—	0.0	0.0	0.0	0.0
	September	73	2	23	6	2.7	31.5	8.2	34.2
L	May	56	8	—	16	14.3	0.0	28.6	14.3
	June	317	63	52	57	19.9	16.4	18.0	36.3
	July	328	42	77	56	12.8	23.5	17.1	36.3
	August	264	27	65	21	10.2	24.6	8.0	34.8
	September	175	29	38	4	16.6	21.7	2.3	38.3

M and L in 1974-76 (Table 4 and Fig. 4). The values of F/M are almost the same in all months. These results support the previous suggestion regarding the segregation of late pregnant whales, and thus it seems that late pregnant

whales tend to segregate in higher latitudinal waters, or that near-term pregnant whales move earlier from north to south to parturate in the lower latitudinal waters. In order to confirm this, comparison of the size distribution of fetuses

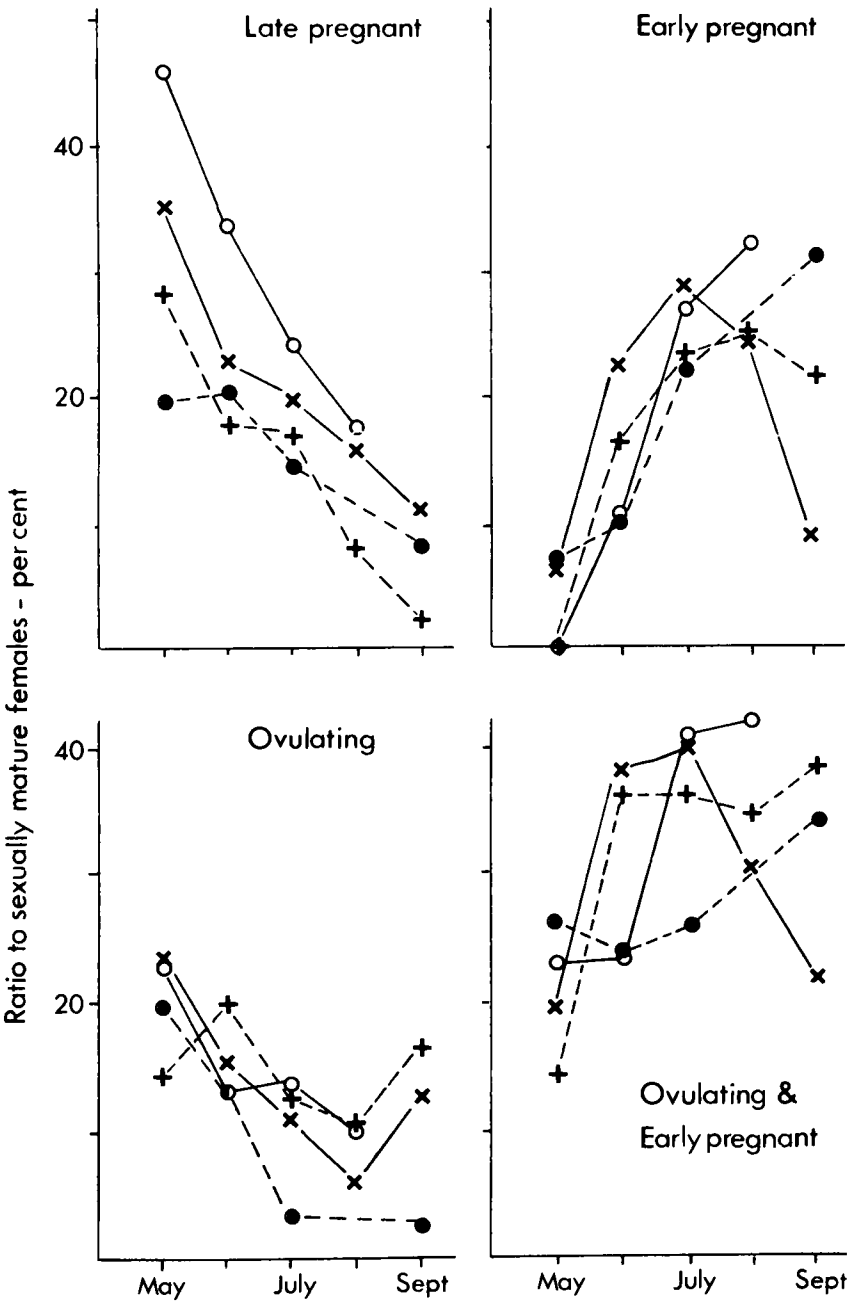


Fig. 3. Comparison of monthly change in pregnancy rates by Zones (Western Division): data from 1966-77. x—x Zone P; ●—● Zone N; +—+ Zone M; ○—○ Zone L.

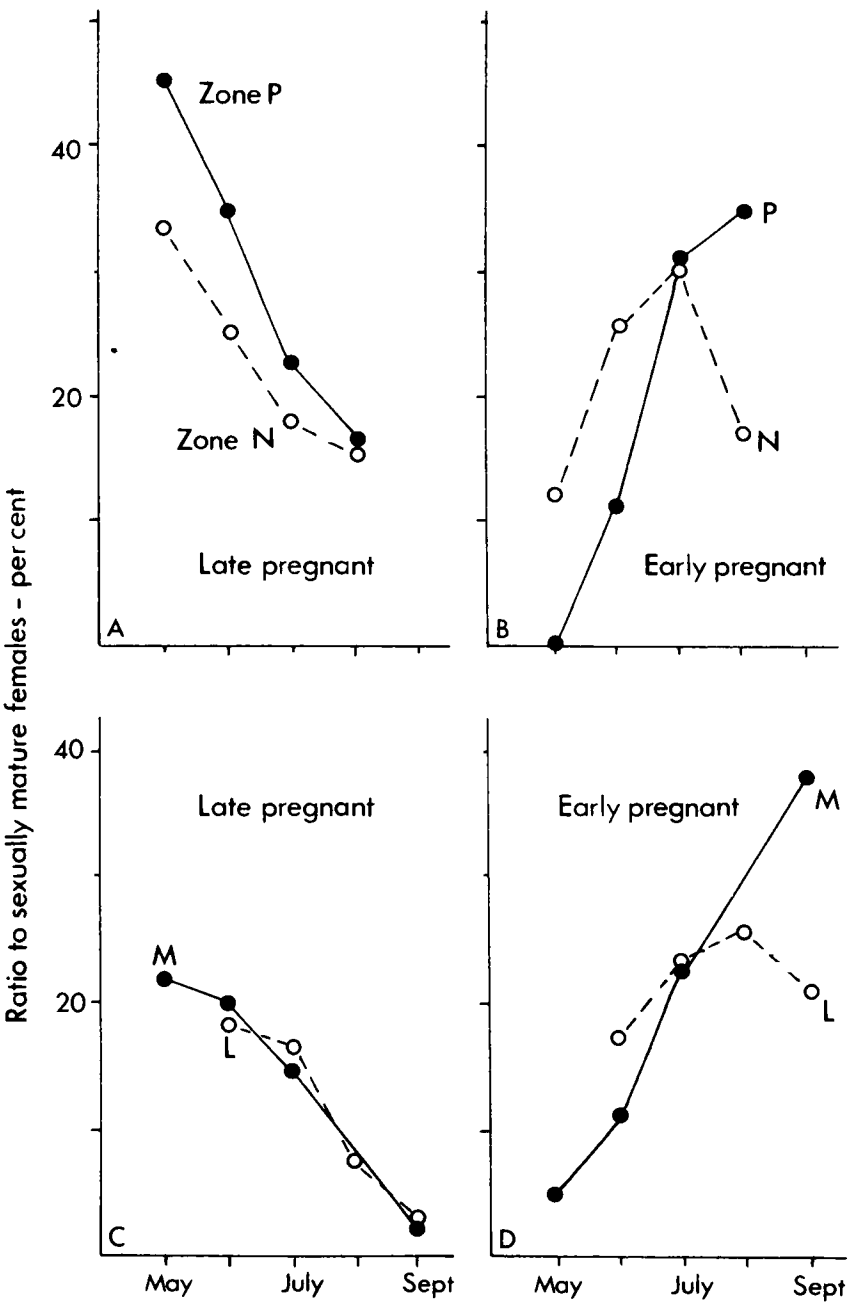


Fig. 4. Comparison of monthly change in pregnancy rates between two Zones of the Western Division. A and B: 1967-1969; C and D: 1974-1976.

Table 3

Comparison of the monthly change in pregnancy rate for Zones P and N in the years 1967–69									
Zone	Month	M	V	E	F	V/M	E/M	F/M	V + E/M
P	May	11	3	—	5	27.3	0.0	45.4	27.3
	June	47	6	5	16	13.0	10.9	34.8	23.9
	July	124	13	38	28	10.5	30.6	22.6	41.1
	August	133	13	46	22	9.8	34.6	16.5	44.4
N	May	110	16	13	37	14.5	11.8	33.6	26.3
	June	305	45	77	76	14.8	25.2	24.9	40.0
	July	172	21	51	31	12.2	29.7	18.0	41.9
	August	68	4	11	11	5.9	16.2	16.2	22.1

Table 4

Comparison of the monthly change in pregnancy rate for Zones M and L in the years 1974–76 (Western Division)									
Zone	Month	M	V	E	F	V/M	E/M	F/M	V + E/M
M	May	78	14	4	17	17.9	5.1	21.8	23.0
	June	269	33	30	54	12.3	11.2	20.1	23.4
	July	27	1	6	4	3.7	22.2	14.8	25.9
	September	45	1	17	1	2.2	37.8	2.2	40.0
L	June	213	42	36	39	19.7	16.9	18.3	36.6
	July	278	37	64	46	13.3	23.0	16.5	36.3
	September	168	29	35	4	17.2	20.8	2.4	38.1

in the same month in the north and south is needed to see if, as this suggests, the late foetuses are smaller in northern waters than in southern waters, but I have no time to examine this in this paper.

I believe the movement of the pelagic whaling ground from north to south is the reason why the total observed pregnancy rate decreased from 1966/69 to 1974/76 as determined at the Annual Meeting of the Scientific Committee in 1978.

Yearly change in early pregnancy rate

We have seen that late pregnant whales should not be used to examine the yearly change in pregnancy rate because there is Zonal segregation of late pregnant whales, and data are not available for the same Zone for sufficient years. However segregation was not observed in E/M and V + E/M, which become almost constant after July and so data for E and V + E from July should be used to examine the yearly change in pregnancy rate.

Table 5 and Fig. 5 show the yearly change in E/M and V + EM in July, August and July + August. Although large yearly fluctuations are seen in these values (E/M in July + August fluctuates between 19.6% and 33.3% and V + E/M also fluctuates between 22.2% and 44.6%), no decreasing trend in the pregnancy rate is observed.

Estimation of the true pregnancy rate

The true pregnancy rate is the ratio of pregnant whales to sexually mature females in a year, and therefore it can be estimated from both F/M and E/M, independently. If there is a high natural mortality during the gestation period, it is more useful to use F/M, because the purpose of determining the pregnancy rate is to estimate the parturition rate of the whale.

However, it is difficult to estimate the true pregnancy rate using F/M from the present data, because the values change markedly from May to September, although it is 30.8% in May. Ohsumi and Satake (1977) reported on the results of a special investigation of sperm whales in the coastal waters of Japan from the middle of January to the

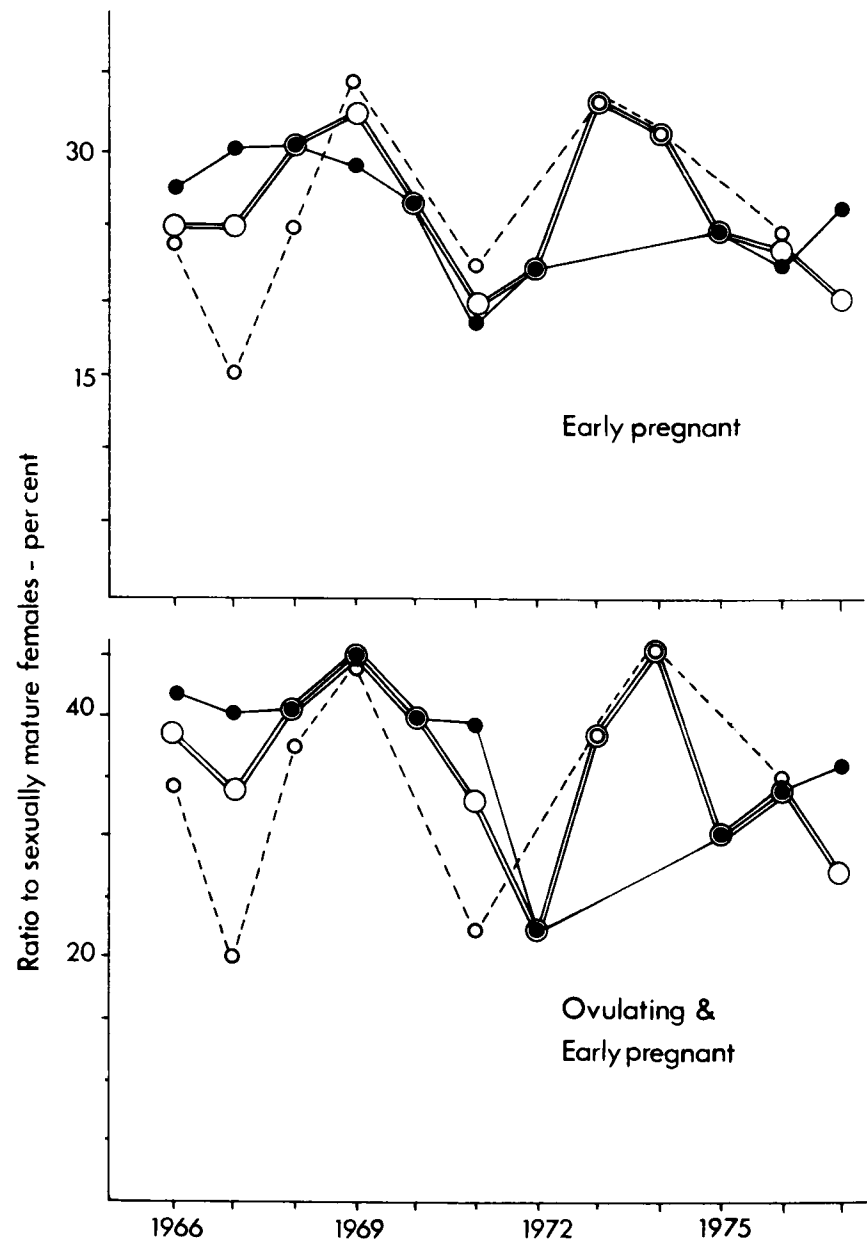


Fig. 5. Yearly fluctuations of pregnancy rate in the Western Division. —●— July; - - - ○ August; —○— July + August (average).

beginning of February, 1976. The foetuses ranged from 128–246 cm in body length, and they were all estimated to be late pregnant whales. The pregnancy rate was calculated to be 25.0%.

Table 5
Yearly change in pregnancy rate of whales caught in the Western Division of the North Pacific

Month	Year	M	V	E	F	V/M	E/M	F/M	V + E/M
July	1966	62	10	16	14	16.1	25.8	22.6	41.9
	1967	126	13	38	30	10.3	30.2	23.8	40.5
	1968	108	11	33	23	10.2	30.6	21.3	40.7
	1969	62	10	18	8	16.1	29.0	12.9	45.2
	1970	30	4	8	7	13.3	26.6	23.3	40.0
	1971	33	7	6	12	21.2	18.2	36.4	39.4
	1972	18	—	4	5	0.0	22.2	27.8	22.2
	1975	69	11	17	21	15.9	24.6	30.4	30.4
	1976	236	27	53	29	11.4	22.4	12.3	33.9
	1977	50	5	13	10	10.0	26.0	20.0	36.0
August	1966	38	4	9	9	10.5	23.7	25.7	34.2
	1967	60	3	9	11	5.0	15.0	18.3	20.0
	1968	8	1	2	—	12.5	25.0	0.0	37.5
	1969	133	13	46	22	9.8	34.6	16.5	44.4
	1971	18	—	4	5	0.0	22.2	27.8	22.2
	1973	18	1	6	2	5.5	33.3	11.1	38.9
	1974	35	5	11	—	14.3	31.4	0.0	45.7
	1976	197	21	48	18	10.7	24.4	9.1	35.0
	1977	15	—	—	1	0.0	0.0	6.7	0.0
July + August	1966	100	14	25	23	14.0	25.0	23.0	39.0
	1967	186	16	47	41	8.6	25.3	22.0	33.9
	1968	116	12	35	23	10.3	30.2	19.8	40.5
	1969	195	23	64	30	11.8	32.8	15.4	44.6
	1970	30	4	8	7	13.3	26.6	23.3	40.0
	1971	51	7	10	17	13.7	19.6	33.3	33.3
	1972	18	—	4	5	0.0	22.2	27.8	22.2
	1973	18	1	6	2	5.5	33.3	11.1	38.9
	1974	35	5	11	—	14.3	31.4	0.0	45.7
	1975	69	11	17	21	15.9	24.6	30.4	30.4
	1976	433	48	101	47	11.1	23.3	10.8	34.4
	1977	65	5	13	11	7.7	20.0	16.9	27.7

There is a problem in the estimation of the true pregnancy rate from early pregnant whales, as very small foetuses may be in the uterus, especially in the main breeding season. Therefore using E/M may result in an underestimate of the true pregnancy rate, but it does give a lower limit. On the other hand, V + E/M will give an upper limit for the true pregnancy rate, and a lower limit for the average ovulation rate. There is no Zonal segregation in E/M and V + E/M and they become almost constant after July. The E/M value in total for July to September in 1966–77 is calculated to be 25.1%, and V + E/M for the same months to be 36.5%.

Considering the results of F/M, the true pregnancy rate in the Western Division of the North Pacific will be 25–31%. The above examinations also suggest that the mortality rate of foetal sperm whales is very low.

PREGNANCY RATE IN THE EASTERN DIVISION

Seasonal change in pregnancy rate

Insufficient data are available to examine seasonal changes in the pregnancy rate, for although data are available for May to August, only two whales were sampled in May. Furthermore the data for May and June only come from Zone P in 1966 and 1967.

Zonal differences in pregnancy rate

As shown in Fig. 6 the data are mainly available for Zones P and N. Table 7 and Fig. 7 show the comparison of values of F/M, E/M, V/M and V + E/M for three Zones. There is no Zonal difference in E/M, V/M or V + E/M, but the values of F/M in Zone M is clearly lower than those in Zones P and N, where the values are very similar.

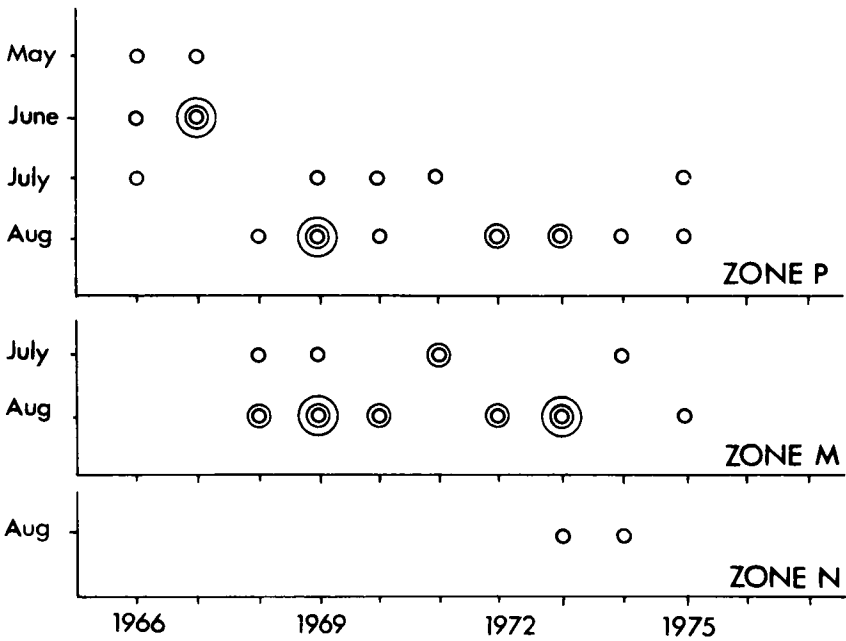


Fig. 6. Samples of mature females from each Zone in the Eastern Division. ○ < 50 whales; ⊙ < 100 whales; ⊗ > 100 whales.

The value of F/M is also examined for data from August in 1972–74, and the Zonal difference was confirmed (Table 8).

Yearly change in pregnancy rate

As shown in Fig. 7, the values of E/M, V/M and V + E are almost identical in July and August and similar to those in the Western Division.

The yearly change in E/M and V + E/M was examined for the data in July + August (Table 9 and Fig. 8). As shown in Fig. 8 there are yearly fluctuations in these values, but no

Table 6
Monthly change in pregnancy rate in the Eastern Division of the North Pacific during the years, 1966–75

Month	M	V	E	F	V/M	E/M	F/M	V + E/M
May	2	1	—	—	50.0	0.0	0.0	50.0
June	163	20	30	45	12.3	18.4	27.6	30.7
July	262	27	40	47	10.3	15.3	17.9	25.6
August	1,233	123	197	207	10.0	16.0	16.8	26.0

Table 7
Zonal differences in pregnancy rate in the Eastern Division of the North Pacific during 1966–75

Zone	Month	M	V	E	F	V/M	E/M	F/M	V + E/M
P	May	2	1	—	—	50.0	0.0	0.0	50.0
	June	163	20	30	45	12.3	18.4	27.6	30.7
	July	137	16	21	24	11.7	15.3	17.5	27.0
	August	330	30	49	55	9.1	14.8	16.7	23.9
N	July	125	11	19	23	8.8	15.2	18.4	24.0
	August	862	88	141	148	10.2	16.4	17.2	26.6
M	August	41	5	7	4	12.2	17.1	9.8	29.3

Table 8
Comparison of Zonal differences in pregnancy rate in the Eastern Division in the years 1972–74, in August

Zone	M	V	E	F	V/M	E/M	F/M	V + E/M
P	146	15	16	23	10.3	11.0	15.7	21.2
N	229	19	47	36	8.3	20.5	15.7	28.8
M	41	5	7	4	12.2	17.1	9.8	29.3

Table 9
Yearly change in pregnancy rate of whales caught in the Eastern Division of the North Pacific in July and August

Year	M	V	E	F	V/M	E/M	F/M	V + E/M
1966	18	2	—	5	11.1	0.0	27.8	11.1
1968	143	13	28	30	9.1	19.6	21.0	28.7
1969	566	57	95	99	10.1	16.8	17.5	26.9
1970	119	12	10	19	10.1	8.4	16.0	18.5
1971	139	15	22	18	10.8	15.8	12.9	26.6
1972	142	—	20	21	0.0	14.1	14.8	14.1
1973	206	32	40	31	15.5	19.4	15.0	35.0
1974	70	7	5	16	10.0	7.1	22.9	17.1
1975	56	7	10	11	12.5	17.9	19.6	30.4

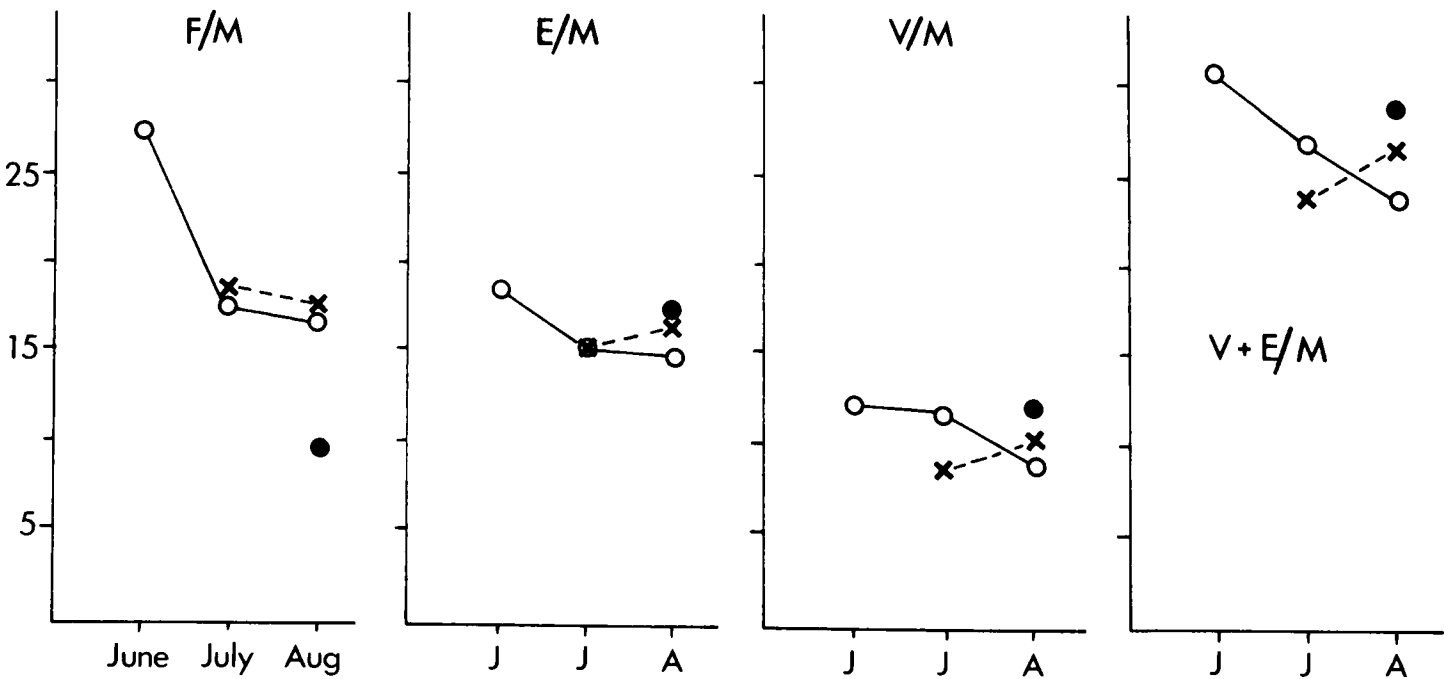


Fig. 7. Comparison of the monthly change in pregnancy rate by Zone. x—x Zone P; ●—● Zone N; + ---+ Zone M; ○—○ Zone L.

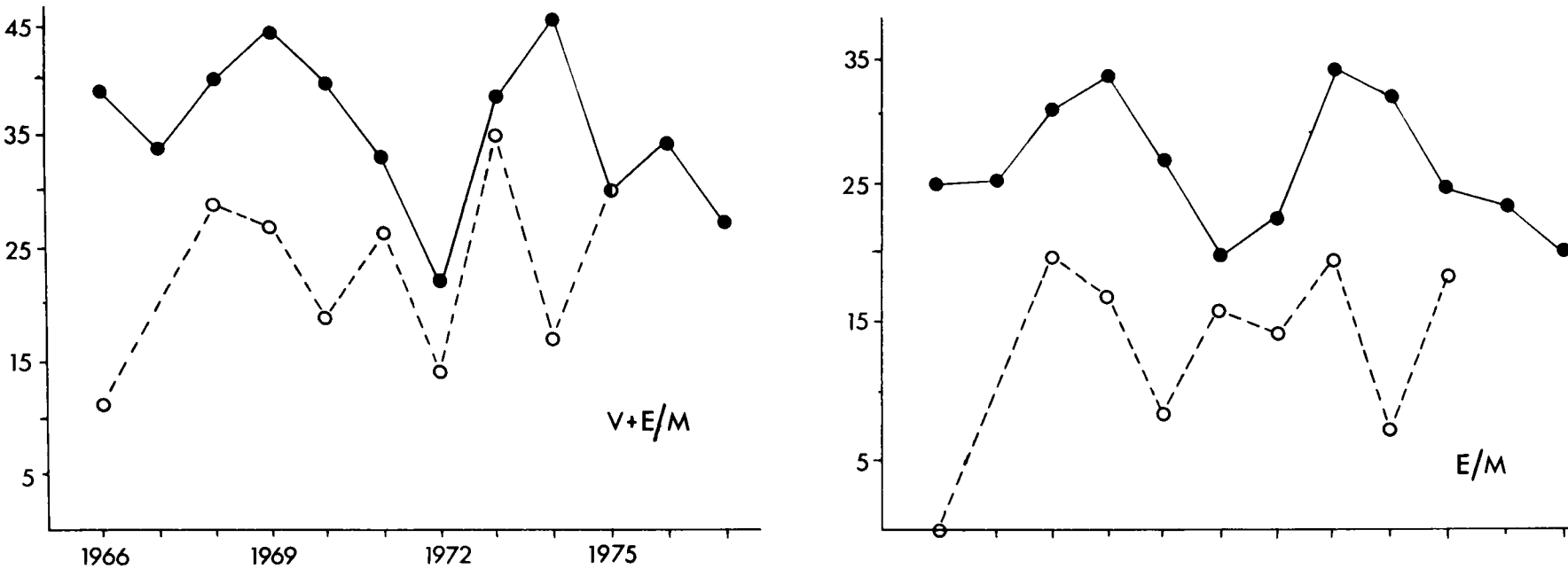


Fig. 8. Yearly change in E/M and V+E/M in the Western and Eastern Divisions. ●—● Western Division; ○ - - - ○ Eastern Division.

overall trend of decrease can be seen. Fig. 8 also suggests that the pregnancy rate in the Eastern Division is lower than that in the Western Division.

Estimation of true pregnancy rate

It is impossible to estimate the true pregnancy rate from F/M, as sufficient data are only available from June to August. The values of E/M and V + E/M in July and August in 1966–75 are 15.9% and 25.9% respectively – lower than in the Western Division. However, there is a value of 27.6%

for F/M in Zone P in June. This is larger than V + E/M. This may suggest the segregation of late pregnant whales in higher latitudinal waters.

REFERENCES

Masaki, Y. 1980. On the pregnancy rate of the North Pacific sperm whales. Paper SC/SPC/4 (published in this volume).
Ohsumi, S. 1975. Reproduction of the sperm whale in the North-west pacific. *Sci. Rep. Whales Res. Inst., Tokyo*. 19: 1–35.
Ohsumi, S. 1980. Catch of sperm whales by modern whaling in the North Pacific. Paper SC/SPC/1 (published in this volume).
Ohsumi, S. and Satake, Y. 1977. Provisional report on investigation of sperm whales off the coast of Japan under a special permit. *Rep. int. Whal. Commn* 27: 324–332.

Appendix Table 1

Pregnancy data for sperm whales in the Western Division of the North Pacific

Zone	Month	Year	M	V	E	F	Zone	Month	Year	M	V	E	F
P	May	1966	2	—	—	1	M	May	1973	23	6	3	3
„	„	1968	11	3	—	5	„	„	1974	78	14	4	17
„	June	1967	1	—	—	—	„	June	1972	11	—	2	3
„	„	1968	46	6	5	16	„	„	1973	14	1	1	3
„	July	1966	62	10	16	14	„	„	1974	102	17	8	19
„	„	1967	124	13	38	28	„	„	1975	167	16	22	35
„	„	1970	30	4	8	7	„	„	1977	26	8	1	6
„	„	1971	33	7	6	12	„	July	1976	27	1	6	4
„	August	1966	38	4	9	9	„	August	1976	1	—	—	—
„	„	1969	133	13	46	22	„	September	1972	21	—	3	4
N	May	1967	2	1	—	1	„	„	1973	7	1	3	1
„	„	1968	46	8	8	12	„	„	1974	19	1	6	—
„	„	1969	62	7	5	24	„	„	1975	26	—	11	1
„	„	1970	46	15	—	17	L	May	1977	56	8	—	16
„	„	1971	60	20	—	23	„	June	1975	143	32	25	25
„	June	1967	4	1	1	2	„	„	1976	70	10	11	14
„	„	1968	206	37	46	47	„	„	1977	104	21	16	18
„	„	1969	95	7	30	27	„	July	1975	69	11	17	21
„	„	1970	18	6	1	—	„	„	1976	209	26	47	25
„	„	1971	20	3	3	4	„	„	1977	50	5	13	10
„	„	1972	2	—	1	—	„	August	1973	18	1	6	2
„	„	1973	18	2	—	4	„	„	1974	35	5	11	—
„	July	1967	2	—	—	2	„	„	1976	196	21	48	18
„	„	1968	108	11	33	23	„	„	1977	15	—	—	1
„	„	1969	62	10	18	8	„	September	1973	7	—	3	—
„	„	1972	18	—	4	5	„	„	1974	92	10	17	—
„	August	1967	60	3	9	11	„	„	1975	76	19	18	4
„	„	1968	8	1	2	—							
„	„	1971	18	2	9	3							
„	„	1972	13	—	4	2							
„	September	1970	55	7	5	6							

Appendix Table 2

Pregnancy data for sperm whales in the Eastern Division of the North Pacific

Zone	Month	Year	M	V	E	F	Zone	Month	Year	M	V	E	F
P	May	1966	1	—	—	—	N	July	1968	24	1	7	6
”	”	1967	1	1	—	—	”	”	1969	2	—	1	—
”	June	1966	45	3	9	16	”	”	1971	61	5	9	8
”	”	1967	118	17	21	29	”	”	1974	38	5	2	9
”	July	1966	18	2	—	5	”	August	1968	83	10	17	15
”	”	1969	8	—	1	3	”	”	1969	430	47	65	78
”	”	1970	8	—	—	3	”	”	1970	98	10	9	14
”	”	1971	78	10	13	10	”	”	1972	88	—	16	13
”	”	1975	25	4	7	3	”	”	1973	141	19	31	23
”	August	1968	36	2	4	9	”	”	1975	22	2	3	5
”	”	1969	126	10	28	18	M	August	1973	31	4	5	1
”	”	1970	13	2	1	2	”	”	1974	10	1	2	3
”	”	1972	54	—	4	8							
”	”	1973	60	13	9	8							
”	”	1974	32	2	3	7							
”	”	1975	9	1	—	3							

Time Budgets of Sperm Whaling Operations by Japanese Whaling

Seiji Ohsumi

Far Seas Fisheries Research Laboratory

INTRODUCTION

The time budgets of whaling operations were discussed for the assessment of catching efficiency and actual fishing effort at the IWC Special Meeting in Cronulla and the 30th Annual Meeting in Cambridge (IWC, 1979). During the discussions it was felt that actual time budget data were needed.

I have been trying to collect this type of data from as far back as possible. It should be possible to get such data from the daily report on whaling operations by each catcher boat, as detailed time records were kept, but unfortunately most of them have been lost. However the following daily reports are available:

Japanese coastal whaling	
Nitto Whaling Company	1962–77
Nippon Whaling Company	1960–69
Antarctic pelagic whaling	
Kyokuyo Whaling Company	1956/57–1962/63

It is very laborious to obtain information on each item in the time budget from the daily reports and in this paper I use data for the Nitto Whaling Company in 1962 and 1977, for the Nippon Whaling Company in 1960 and 1969 and for the Kyokuyo Whaling Company in 1956/57 and 1962/63.

The Japanese coastal whaling season lasts for eight months, and the availability of sperm whales varies remarkably during these months (Ohsumi, 1980a) and so the time budget must be separated by month in order to examine any seasonal changes in the time budgets. The sperm whaling season in the Antarctic pelagic whaling is short and ends by the beginning of the baleen whaling season, so there is no need to separate the time budgets by month.

The mode of operations of coastal whaling differs from that in pelagic whaling (Ohsumi, 1980b) and in particular the operational cycle of coastal whaling lasts more than one day, whereas for pelagic whaling it is one day or less. The time budgets for coastal whaling were separated into the following categories:

Navigating time: the time taken from leaving the land station to beginning searching.

Searching time: the time taken from the start of searching to the finding of a desired school.

Chasing time: the time taken from the finding of the school to the complete capture of a whale. In this paper, the *handling time* is included in this time.

Gathering time: the time taken from the end of catching operations to the time when the gathering in of 'buoyed' whales is completed.

Towing time: the time taken from the start of towing to arrival at the land station.

Drifting time: the time spent drifting at night or in bad weather.

Resting time: the time taken from the return to the land station to leaving it again.

The time budgets for Japanese coastal whaling are shown in Tables 1 and 2, and Figs 1–6.

The time budgets for Antarctic pelagic whaling are separated into the following categories:

Searching time: the time taken from the start of operations to the finding of a desired school.

Chasing time: the time taken from the finding of the school to the harpooning of a whale.

Handling time: the time taken from hitting the whale to its complete capture.

Towing time: the time taken after the complete capture of the whale to tow it to the factory ship.

Resting time: the time spent resting, obtaining supplies or carrying out repairs, drifting in bad weather or cessation of operations by order of the Captain as a means of regulating the catch.

Time budget data for Antarctic pelagic whaling are shown in Table 3.

Time budget data for North Pacific pelagic whaling in 1978 are available from the systematic time budget report of each catcher boat. In this time budget classification, a new category has been added – the *confirming time*, which is the time taken from finding a whale school to selecting which whale to catch. It was previously included in the searching time. The data are given in Table 4.

JAPANESE COASTAL WHALING

Each item on the time budget has been classified with respect to its relationship with the operation cycle, operational day, number of whales caught or availability of whales. Tables 1 and 2 and Figs 1–6 show the seasonal change in each time budget item by operational cycle, by day and by whales caught. If there is no seasonal change in an item with regard to one of the three cases, then it is related to that case, and if not, it is related to availability.

Navigating time

This item is related to the operation cycle. It shows large fluctuations, ranging from one to ten hours, depending on the time of departure from the land station and the sun rise.

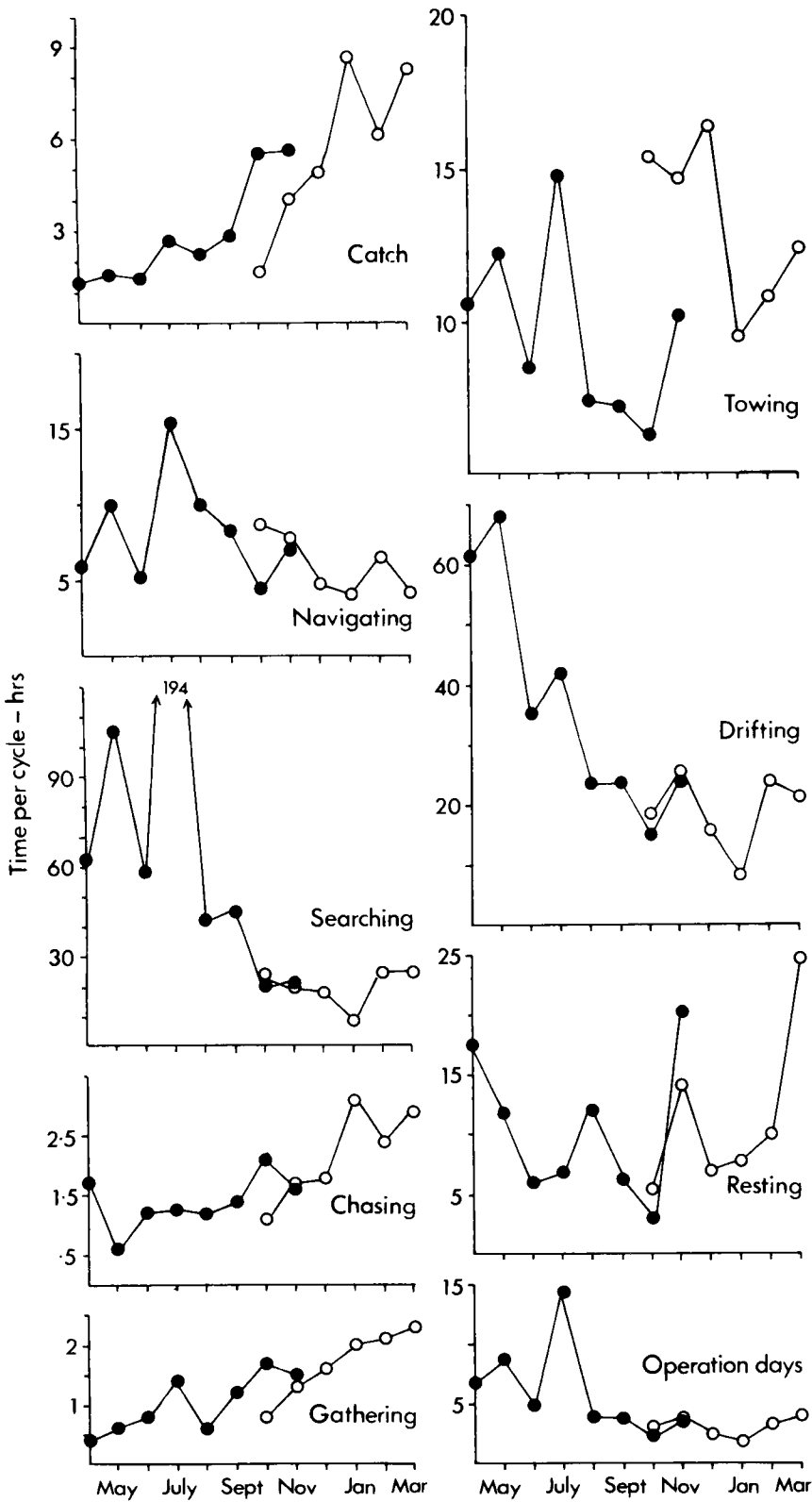


Fig. 1. Time budget data (per cycle) for coastal Japanese sperm whaling: the Nitto Whaling Company. ●—● 1962; ○—○ 1977/78.

Searching time

This is related to the availability of whales.

Chasing time

This would be expected to be related to the number of whales caught, but as shown in Figs 3 and 6, the chasing time per whale is longer earlier in the season than later in the season. This is because large bulls migrate early in the season and small females arrive in the whaling ground later in the season.

Gathering time

It can be seen that this item is related to the number of whales caught, and is 0.3 hrs per whale.

Towing time

This should be related to the operation cycle, but its value varies widely, depending on the distance of the whaling ground from the land station.

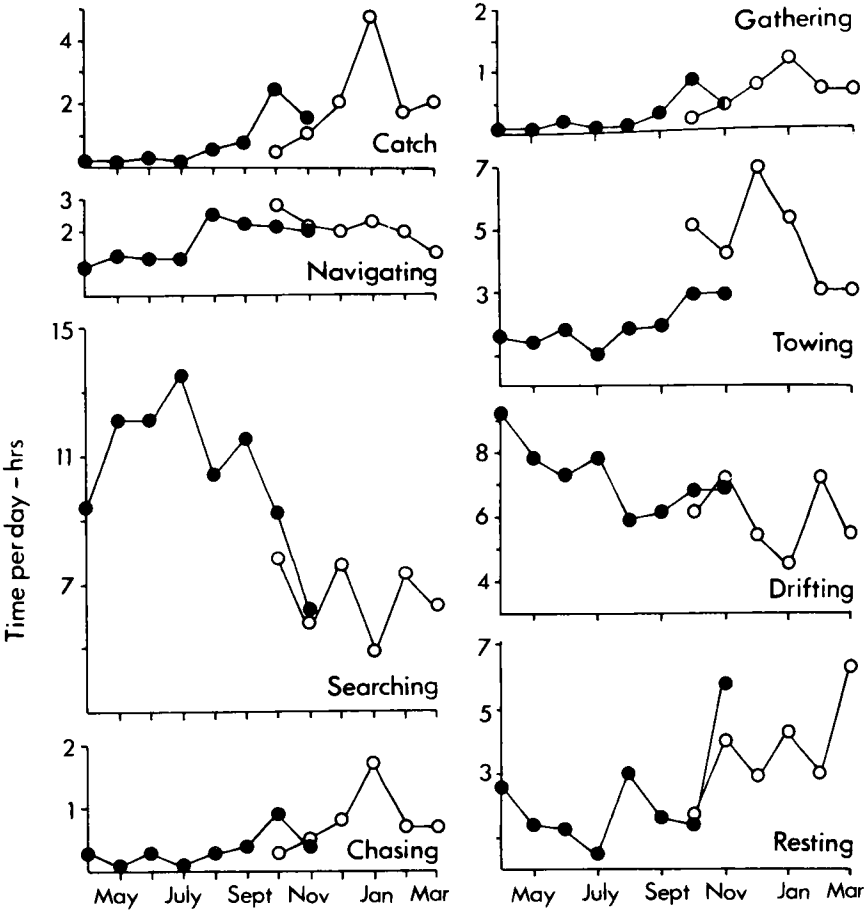


Fig. 2. Time budget data (per day) for coastal Japanese sperm whaling: the Nitto Whaling Company. ●—● 1962; ○—○ 1977/78.

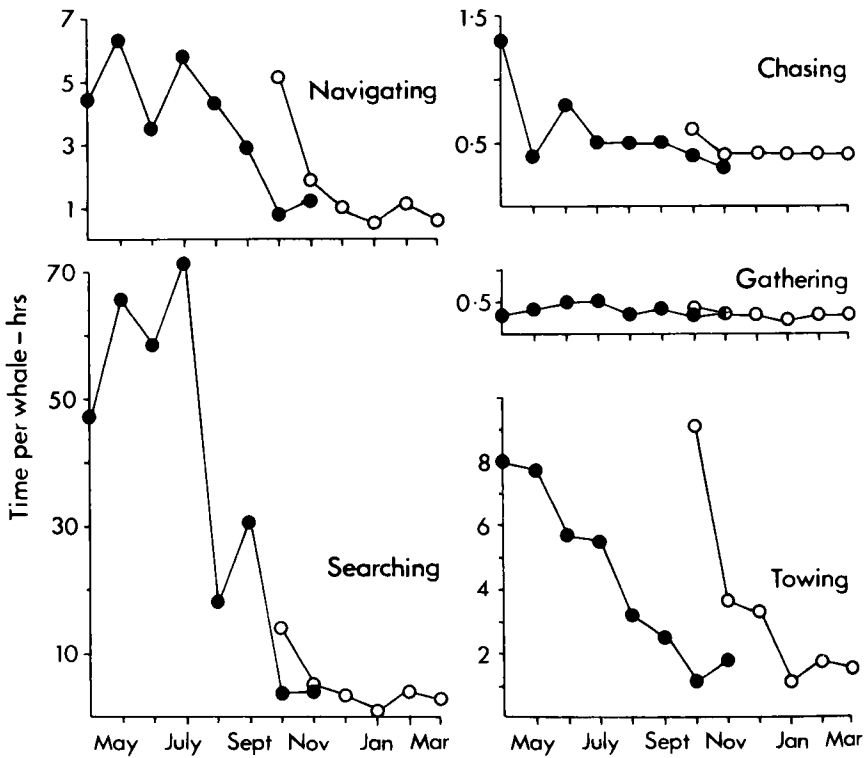


Fig. 3. Time budget data (per whale) for coastal Japanese sperm whaling: the Nitto Whaling Company. ●—● 1962; ○—○ 1977/78.

Drifting time

This is related to the number of operation days, but is also related to the number of operation days per cycle, and becomes shorter as the number of operation days per cycle decreases.

Resting time

This should be related to the operation cycle, but it tends to increase in the peak season.

Table 1
Time budgets of Japanese coastal whaling in 1962 and 1977/78 for the Nitto Whaling Company

1977/78																
	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Total	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Operation day	20.0	43.4	48.3	43.3	48.2	50.4	59.4	59.0	371.9	71	90	84	82	84	43	454
Cycles	3	5	10	3	12	13	27	17	90	23	25	35	45	25	11	164
Whales/Schools	7/3	16/4	20/11	8/3	40/12	60/13	248/28	191/19	590/93	210/31	464/36	835/60	1,037/76	736/45	286/18	3,550/266
Catch	4	8	15	8	28	38	151	97	349	39	102	176	391	155	91	954
Operation/Cycle	6.7	8.7	4.8	14.4	4.0	3.9	2.2	3.5	4.1	3.1	3.6	2.4	1.8	3.4	3.9	2.8
Total (hrs)																
Navigation	17.7	50.2	52.3	46.3	120.1	111.5	122.7	120.0	640.8	199.0	192.0	169.8	191.0	164.0	57.8	973.6
Searching	187.8	526.5	584.8	582.7	501.5	580.8	543.8	364.4	3,872.3	554.2	524.1	641.1	399.3	614.5	270.3	2,823.5
Chasing	5.0	3.1	12.3	4.0	14.2	18.3	56.4	26.5	139.8	24.5	41.7	64.1	137.5	60.4	32.2	360.4
Gathering	1.3	3.2	8.2	4.2	7.0	15.2	45.4	26.3	110.8	17.5	33.7	56.2	88.8	52.4	25.3	273.9
Towing	31.8	61.7	84.9	44.3	88.2	93.6	169.5	171.3	745.3	354.8	368.2	573.8	429.4	269.5	136.9	2,132.6
Drifting	184.5	337.8	354.5	337.4	283.4	307.5	405.5	405.5	2,574.0	430.5	644.2	450.0	371.3	604.5	236.8	2,737.3
Resting	52.4	59.0	61.5	20.7	142.7	81.7	81.7	343.3	843.0	123.8	356.5	242.5	352.5	251.5	273.0	1,599.8
Per cycle (hrs)																
Catch	1.3	1.6	1.5	2.7	2.3	2.9	5.6	5.7	1.4	1.7	4.1	5.0	8.7	6.2	8.3	5.8
Navigation	5.9	10.0	5.2	15.4	10.0	8.6	4.5	7.1	7.1	8.7	7.7	4.9	4.2	6.6	5.3	5.9
Searching	62.6	105.3	58.5	194.2	41.8	44.7	20.1	21.4	43.0	24.1	21.0	18.3	8.9	24.6	24.6	17.2
Chasing	1.7	0.6	1.2	1.3	1.2	1.4	2.1	1.6	1.6	1.1	1.7	1.8	3.1	2.4	2.9	2.2
Gathering	0.4	0.6	0.8	1.4	0.6	1.2	1.7	1.5	1.2	0.8	1.3	1.6	2.0	2.1	2.3	1.7
Towing	10.6	12.3	8.5	14.8	7.4	7.2	6.3	10.1	8.3	15.4	14.7	16.4	9.5	10.8	12.4	13.0
Drifting	61.5	67.6	35.5	42.1	23.6	23.7	15.0	23.9	28.6	18.7	25.8	12.9	8.3	24.0	21.5	16.7
Resting	17.5	11.8	6.2	6.9	11.9	6.3	3.0	20.2	9.4	5.4	14.3	6.9	7.8	10.1	24.8	9.8
Per day (hrs)																
Catch	0.2	0.2	0.3	0.2	0.6	0.8	2.5	1.6	0.9	0.5	1.1	2.1	4.8	1.8	2.1	2.10
Navigation	0.9	1.2	1.1	1.1	2.5	2.2	2.1	2.0	1.7	2.8	2.1	2.0	2.3	2.0	1.3	2.14
Searching	9.4	12.1	12.1	13.5	10.4	11.5	9.2	6.2	10.4	7.8	5.8	7.6	4.9	7.3	6.3	6.22
Chasing	0.3	0.1	0.3	0.1	0.3	0.4	0.9	0.4	0.4	0.3	0.5	0.8	1.7	0.7	0.7	0.79
Gathering	0.1	0.1	0.2	0.1	0.1	0.3	0.8	0.4	0.3	0.2	0.4	0.7	1.1	0.6	0.6	0.60
Towing	1.6	1.4	1.8	1.0	1.8	1.9	2.9	2.9	2.0	5.0	4.1	6.8	5.2	3.2	3.2	4.70
Drifting	9.2	7.8	7.3	7.8	5.9	6.1	6.8	6.9	6.9	6.1	7.2	5.4	4.5	7.2	5.5	6.03
Resting	2.6	1.4	1.3	0.5	3.0	1.6	1.4	5.8	2.3	1.7	4.0	2.9	4.3	3.0	6.3	3.52
Per whale																
Navigation	4.4	6.3	3.5	5.8	4.3	2.9	0.8	1.2	1.8	5.1	1.9	1.0	0.5	1.1	0.6	1.02
Searching	47.0	65.8	58.5	72.8	17.9	15.3	3.6	3.8	11.1	14.2	5.1	3.6	1.0	4.0	3.0	2.96
Chasing	1.3	0.4	0.8	0.5	0.5	0.5	0.4	0.3	0.4	0.6	0.4	0.4	0.4	0.4	0.4	0.38
Gathering	0.3	0.4	0.5	0.5	0.3	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.2	0.3	0.3	0.29
Towing	8.0	7.7	5.7	5.5	3.2	2.5	1.1	1.8	2.1	9.1	3.6	3.3	1.1	1.7	1.5	2.24

Table 2
Time budgets of Japanese coastal whaling in 1962 and 1969 for the Nippon Whaling Company

	1962								1969								
	May	June	July	Aug.	Sept.	Oct.	Nov.	Total	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Operation days	11.3	13.3	35.0	44.2	58.1	41.0	13.1	216.0	63.8	56.1	66.2	58.8	56.0	72.6	89.6	62.5	525.6
Cycles	1	2	4	6	23	10	4	50	5	9	3	15	26	28	45	26	157
Whales/Schools	4/1	7/5	8/4	45/6	175/23	67/10	76/4	382/53	14/5	34/9	4/3	122/16	242/26	291/28	607/46	380/29	1,694/162
Catch	1	2	5	29	108	30	27	202	10	19	4	61	174	167	287	215	937
Operation/Cycle	11.3	6.7	8.7	7.4	2.5	4.1	3.3	4.3	12.7	6.2	22.1	3.9	2.2	2.6	2.0	2.4	3.34
Total (hrs)																	
Navigating	14.6	8.0	10.0	21.4	47.7	51.2	15.1	168.0	20.0	10.0	4.0	14.0	18.0	22.0	48.0	33.8	169.8
Searching	118.3	154.8	573.5	511.7	491.3	303.9	73.7	2,227.2	850.8	773.2	897.5	524.9	451.0	573.1	514.4	264.7	4,849.6
Chasing	1.5	3.4	2.2	8.1	39.5	13.6	6.8	75.1	3.7	12.9	1.3	17.8	51.3	46.7	91.5	57.1	282.3
Gathering	—	0.2	0.7	6.5	30.2	10.9	7.7	56.2	2.8	4.9	1.9	22.5	55.9	46.8	101.3	74.0	310.0
Towing	32.2	46.0	42.3	52.8	194.1	141.1	49.0	557.5	70.4	174.3	58.0	262.7	335.1	270.2	490.6	361.4	2,022.7
Drifting	102.6	100.5	205.5	269.1	416.7	246.3	80.9	1,421.6	481.4	353.4	576.1	409.7	286.0	430.9	452.2	310.5	3,300.2
Resting	1.2	5.7	5.5	190.6	174.0	216.3	82.3	675.9	86.5	16.9	34.8	159.7	147.5	352.4	454.4	452.6	1,704.8
Per cycle (hrs)																	
Catch	1.0	1.0	1.3	4.8	4.7	3.0	6.8	4.0	2.0	2.1	1.3	4.1	6.7	6.0	6.4	8.3	6.0
Navigating	14.6	4.0	2.5	3.6	2.1	5.1	3.8	3.4	4.0	1.1	1.3	0.9	0.7	0.8	1.1	1.3	1.1
Searching	118.3	77.4	143.4	85.3	21.4	30.4	18.4	44.5	170.2	85.9	299.2	35.0	17.3	20.5	11.4	10.2	30.9
Chasing	1.5	1.7	0.6	1.4	1.7	1.4	1.7	1.5	0.7	1.4	0.4	1.2	2.0	1.7	2.0	2.2	1.8
Gathering	—	0.1	0.2	1.1	1.3	1.1	1.9	1.1	0.6	0.5	0.6	1.5	2.2	1.7	2.3	2.8	2.0
Towing	32.2	23.0	10.6	8.8	8.4	14.1	12.3	11.2	14.1	19.4	19.3	17.5	12.9	9.7	10.9	13.9	12.9
Drifting	102.6	50.3	51.4	44.9	18.1	24.6	20.2	28.4	96.3	39.3	192.0	27.3	11.0	15.4	10.0	11.9	21.0
Resting	1.2	2.9	1.4	31.8	7.6	21.6	20.6	13.5	17.3	1.9	11.6	10.4	5.7	12.6	10.1	17.4	10.9
Per day (hrs)																	
Catch	0.1	0.2	0.1	0.7	1.9	0.7	2.1	0.9	0.2	0.3	0.1	1.0	3.1	2.3	3.2	3.4	1.8
Navigating	1.3	0.6	0.3	0.2	0.8	1.3	1.2	0.8	0.3	0.2	0.1	0.2	0.3	0.3	0.5	0.5	0.3
Searching	10.5	11.6	16.4	11.6	8.5	7.4	5.6	10.3	13.3	13.8	13.6	8.9	8.1	7.9	5.7	4.2	9.2
Chasing	0.1	0.3	0.1	0.3	0.7	0.3	0.5	0.4	0.1	0.2	0.0	0.3	0.9	0.6	1.0	0.9	0.5
Gathering	0.0	0.0	0.0	0.1	0.5	0.3	0.6	0.3	0.0	0.1	0.0	0.4	1.0	0.6	1.1	1.2	0.6
Towing	2.8	3.5	1.2	1.2	3.3	3.4	3.7	2.6	1.1	3.1	0.9	4.5	6.0	3.7	5.5	5.8	3.9
Drifting	9.1	7.6	5.9	6.1	7.2	6.0	6.2	6.6	7.5	6.3	8.7	7.0	5.1	5.9	5.0	5.0	6.3
Resting	0.1	0.4	0.2	4.3	3.0	5.3	6.3	3.1	1.4	0.3	0.5	2.7	2.6	4.9	5.1	7.2	3.2
Per whale																	
Navigating	14.6	4.0	2.0	0.7	0.4	1.7	0.6	0.8	2.0	0.5	1.0	0.2	0.1	0.1	0.2	0.2	0.2
Searching	118.3	77.4	114.7	17.6	4.5	10.1	2.7	11.0	85.1	40.7	224.4	8.6	2.6	3.4	1.8	1.2	5.2
Chasing	1.5	1.7	0.4	0.3	0.4	0.5	0.3	0.4	0.4	0.7	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Gathering	0.0	0.1	0.1	0.2	0.3	0.4	0.3	0.3	0.3	0.3	0.5	0.4	0.3	0.3	0.4	0.3	0.3
Towing	32.2	23.0	8.5	1.8	1.8	4.7	1.8	2.8	7.0	9.1	14.5	4.3	3.2	1.6	1.7	1.7	2.2

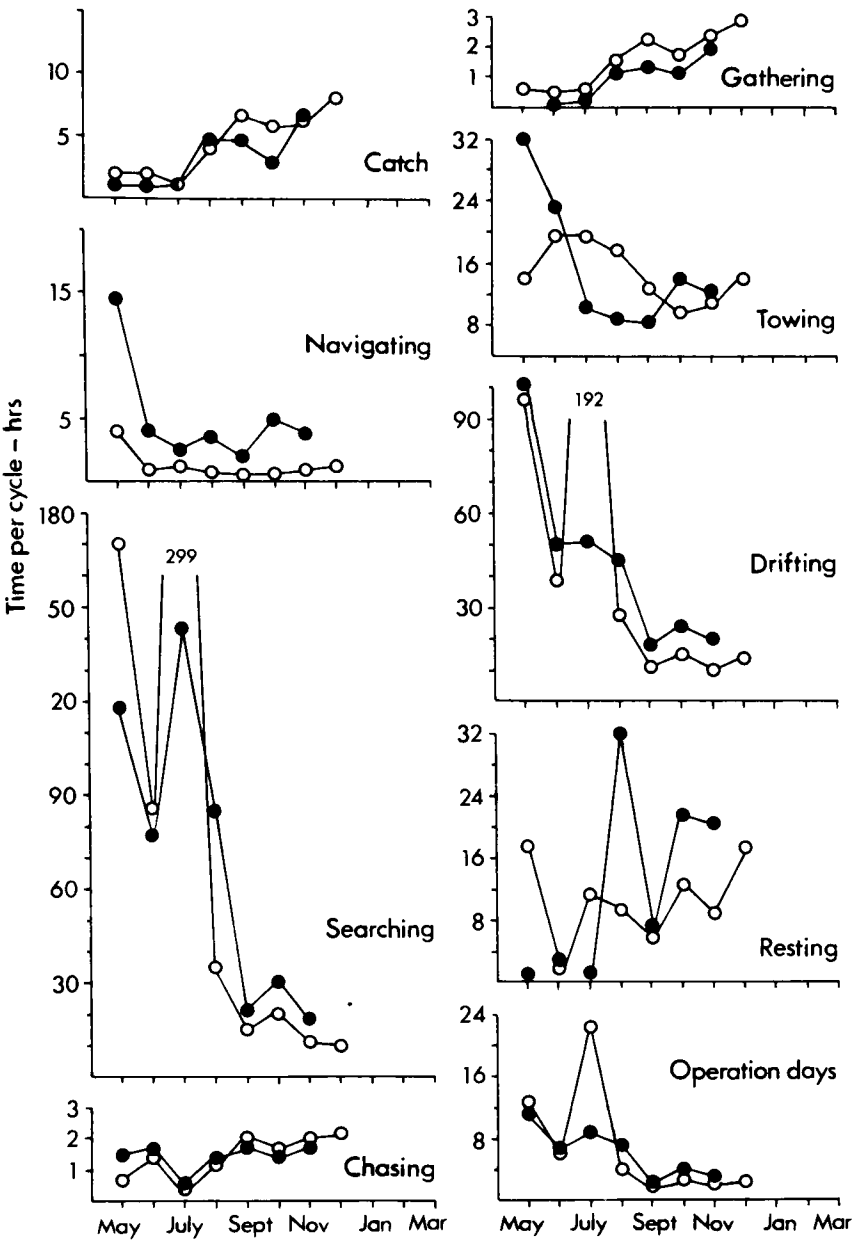


Fig. 4. Time budget data (per cycle) for coastal Japanese sperm whaling: the Nippon Whaling Company. ●—● 1962; ○—○ 1969.

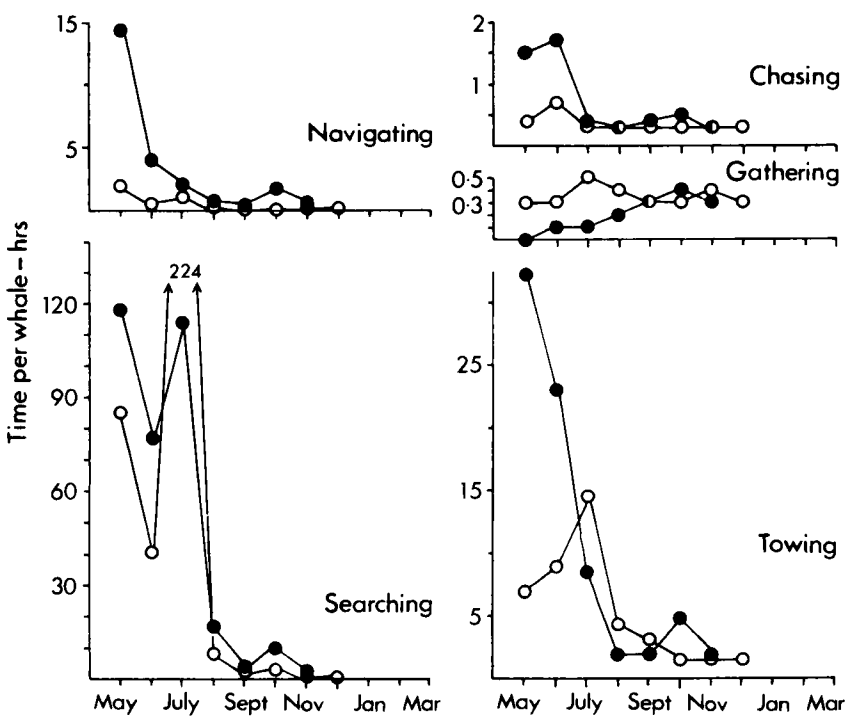


Fig. 6. Time budget (per whale) for coastal Japanese sperm whaling: the Nippon Whaling Company. ●—● 1962; ○—○ 1969.

ANTARCTIC PELAGIC WHALING

During 1956/57 – 1961/62 the whaling grounds were near to the pack ice edge but in 1962/63 the ground moved to the lower latitudinal waters of 30–40°S. The date of the end of sperm whaling operations became earlier as the opening date of the the baleen season became earlier. The Kyokuyo Whaling Company began pelagic whaling in the Antarctic in the 1956/57 season. Time budget data for Japanese pelagic sperm whaling in the Southern Hemisphere are plotted in Fig. 7 and shown in Table 3.

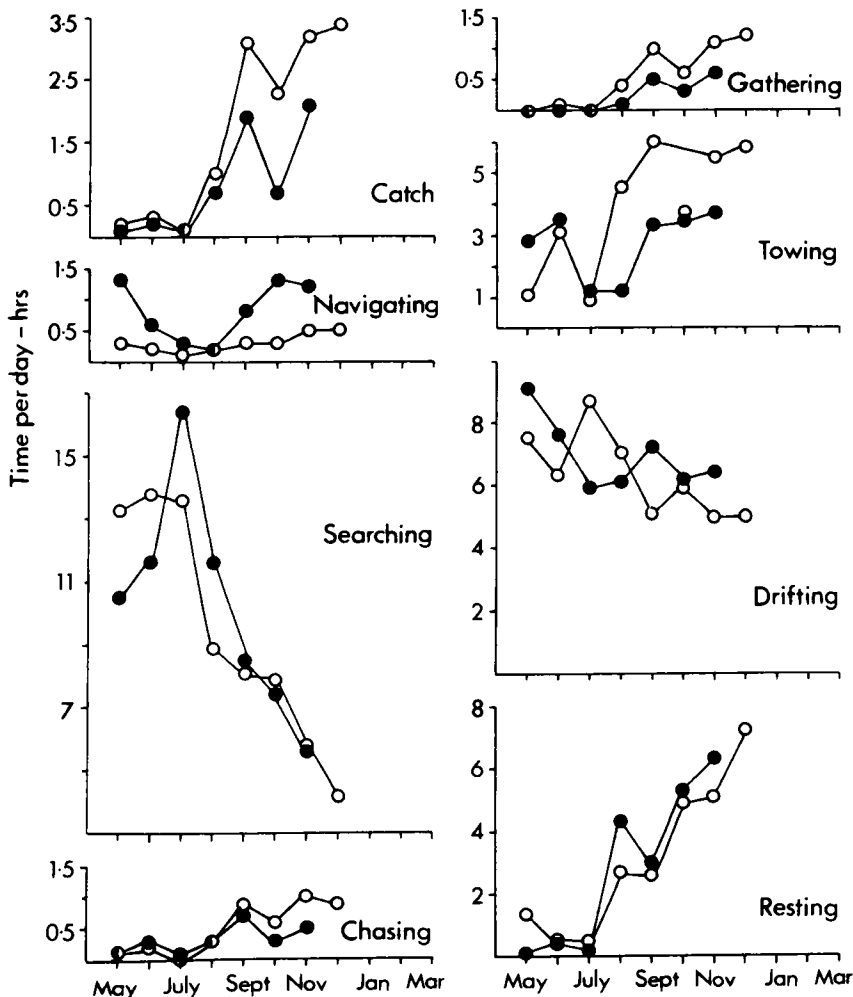


Fig. 5. Time budget data (per day) for coastal Japanese sperm whaling: the Nippon Whaling Company. ●—● 1962; ○—○ 1969.

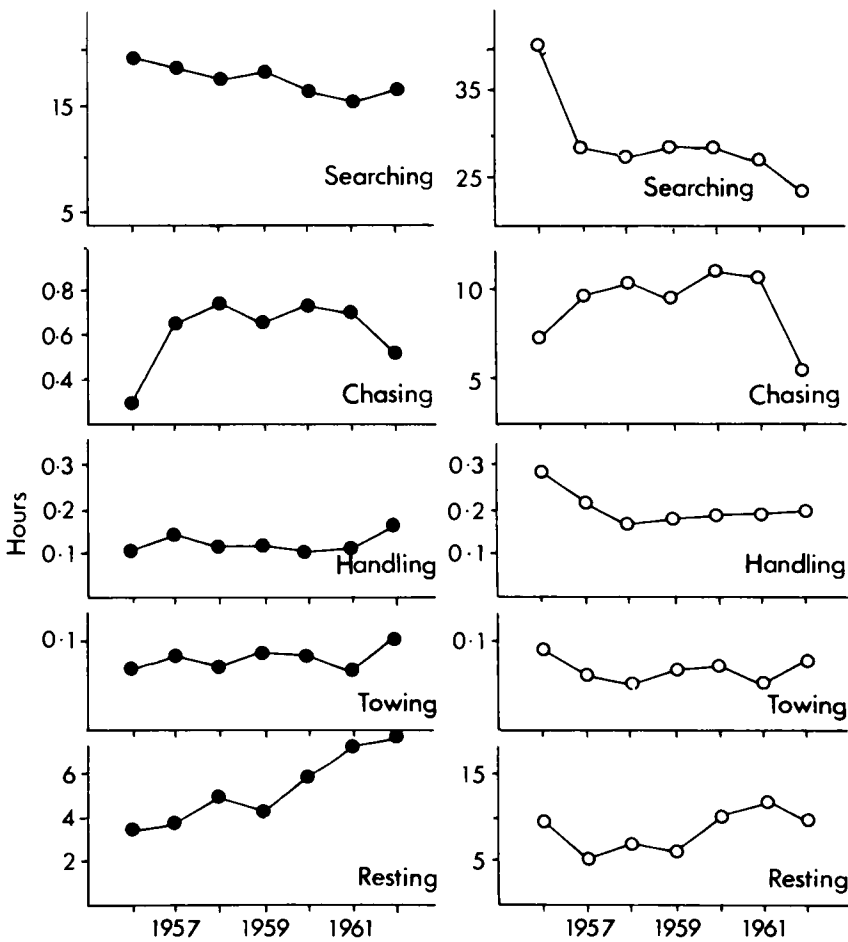


Fig. 7. Time budget data for Japanese pelagic sperm whaling in the Southern Hemisphere. ●—● time per day; ○—○ time per whale.

Searching time

Searching time per day changed from 19.3 hrs in 1956/57 to 14.4 hrs in 1962/63. It was almost constant per whale from 1957/58 to 1961/62. The high value may be due to the fact that it was the first time the fleet had operated in the Antarctic. The low value in 1962/63 was because of the difference in the density of whales when the fleet moved to the lower latitudinal waters.

Chasing time

The value per whale tended to increase from 1956/57 to 1961/62, and it was 0.76 hrs in 1956/57 and 1.17 hrs in 1961/62. The whales caught during these years were all large bulls, and Asdic was gradually introduced over the years. The value in 1962/63 is very short because mixed schools were taken whereas in previous years lone bulls were caught.

Handling time

This is related to the number of whales caught. The value per whale was almost constant at about 0.2 hrs.

Towing time

The value per whale is about 1.0–1.5 hrs.

Resting time

The value per day was not constant, and it increased from 3.65 hrs to 7.85 hrs over the years. This is related to changes in the operation season and the whaling ground.

At the June 1978 IWC meeting a decrease in chasing time of 4.54 hrs was estimated to be the correction factor for Asdic in the Southern Hemisphere. However, the actual chasing time for large bulls in the Antarctic was only 0.98 hrs in 1957/58 when the catcher boats did not have Asdic. The CPUE in this year was 0.68. The current chasing time per whale in the North Pacific is 0.57 hrs. Remembering the increase in the number of smaller whales in the catch in recent years, the decrease in chasing time due to Asdic must be less than 0.41 hrs. The operation time per day was 20.16 hrs in 1957/58. Using these values the correction factor should be less than 0.05.

Fig. 8 shows the distribution of chasing time per whale in each year. In the past most sperm whale bulls were caught within 1.7 hrs and very few whales indeed were chased for 5 hours or more.

NORTH PACIFIC PELAGIC WHALING

Table 4 shows the time budget of the sperm whaling operation in 1978. Bryde's whales were caught in May and June, and the time spent confirming, chasing, handling and towing other species than sperm whales was excluded from the sperm whaling time budget. The time budget in the sperm whaling season was also calculated. Compared with

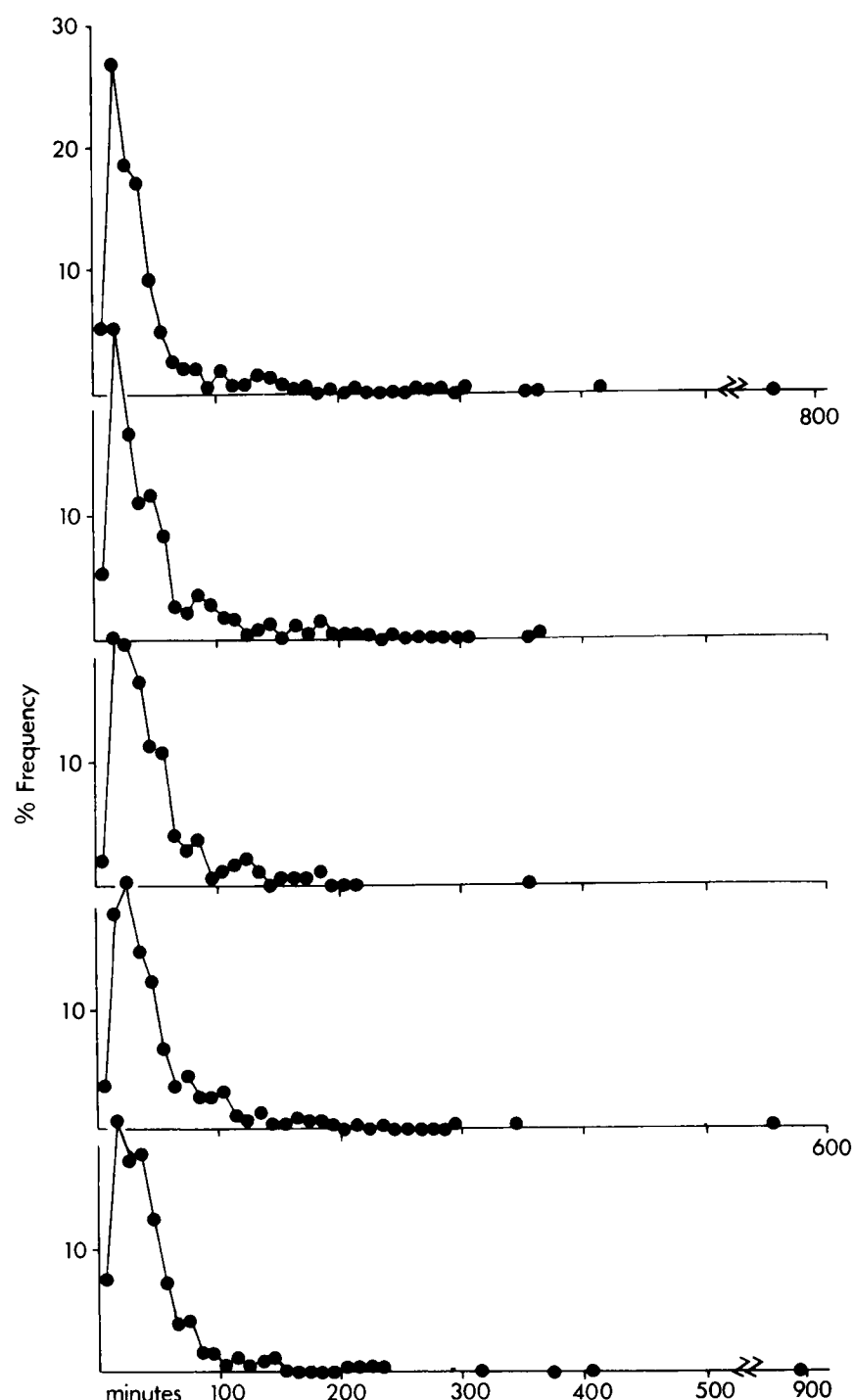


Fig. 8. Chasing time for sperm whales in the Antarctic.

the result in 1977 by Ohsumi (1980b), the searching time per day is 0.77 hrs longer in 1978, and the resting time per day is the same as in 1977. The searching time per whale is much longer in 1978 than that in 1977. The chasing time per whale is almost the same as in 1977. The handling and towing times per whale are 0.14 and 0.10 hrs shorter in 1978 than in 1977, respectively.

REFERENCES

- Ohsumi, S. 1980a. The sperm whale catch by Japanese whaling in the Sanriku Region. Paper SC/SP78/7 (published in this volume).
- Ohsumi, S. 1980b. Criticism on Japanese fishing effort for sperm whales in the North Pacific. Paper SC/SPC/2 (published in this volume).

Table 3
Time budgets of sperm whaling operations by Japanese fleets in the Southern Hemisphere

Year	1956/57	1957/58	1958/59	1959/60	1960/61	1960/61	1961/62	1961/62	1962/63
Fleet	K-2	K-2	K-2	K-2	K-2	K-3	K-2	K-3	K-3
Catcher boats	12	12	12	12	13	11	13	17	10
Date start	XI/20	XI/14	XI/20	XI/25	XI/15	XII/9	XI/2	XI/26	XI/18
Date end	I/7	I/6	I/6	XII/27	XII/27	XII/27	XII/11	XII/11	XII/11
Position	P	P	P	P	P	P	P	P	30-40°S
Catch	167	350	250	182	224	41	212	42	117
Chased but lost	25	69	59	38	55	23	60	18	11
Oper. days	438.3	515.7	361.9	271.8	295.1	151.5	282.0	131.0	141.1
<i>Total, hrs.</i>									
Searching	8,457.2	9,534.2	6,277.4	4,876.5	4,857.7	2,402.4	4,165.5	2,118.0	2,034.0
Chasing	127.6	341.9	274.6	181.0	247.7	89.4	254.6	45.2	74.1
Handling	48.3	75.9	43.4	32.9	41.2	8.8	40.3	8.9	23.5
Towing	306.9	450.4	265.3	243.3	327.2	63.7	204.9	86.9	148.2
Resting	1,600.3	1,979.7	1,828.3	1,193.6	1,615.1	1,075.4	2,108.8	887.0	1,107.7
<i>Per day, hrs.</i>									
Searching	19.30	18.49	17.35	17.94	16.46	15.86	14.77	16.77	14.42
Chasing	0.29	0.66	0.76	0.67	0.84	0.59	0.90	0.35	0.53
Handling	0.11	0.15	0.12	0.12	0.14	0.06	0.14	0.07	0.17
Towing	0.70	0.87	0.73	0.90	1.11	0.42	0.73	0.66	1.05
Resting	3.65	3.84	5.05	4.39	5.47	7.10	7.48	6.77	7.85
<i>Per whale, hrs.</i>									
Searching	50.64	27.24	25.11	26.79	16.46	58.60	19.65	50.43	17.38
Chasing	0.76	0.98	1.10	0.99	1.11	2.18	1.20	1.08	0.63
Handling	0.29	0.22	0.17	0.18	0.18	0.22	0.19	0.21	0.20
Towing	1.84	1.29	1.06	1.34	1.46	1.55	0.97	2.07	1.27
Chased but lost	1.18	1.85	1.89	1.66	1.46	2.20	2.01	1.03	1.96

K-2: *Kyokuyomaru No 2* Fleet, K-3: *Kyokuyomaru No. 3* Fleet, P: Pack ice edge.

Table 4
Time budgets of sperm whaling operations by the Japanese fleet in the North Pacific in 1978

	Total operation					Sperm whaling season
	May	June	July	August	Total	
CDW	45	150	175	66	440	330
Sperm whales/ Schools found	167/28	193/47	452/83	17/4	829/162	577/122
Catch { Males	51	64	215	17	347	290
sperm { Females	47	30	111	0	188	122
Catch Bryde's	55	145	0	0	200	0
CPUE of sperm	2.18	0.62	1.82	0.26	1.22	1.25
<i>Total (hrs)</i>						
Searching	388.63	1,445.32	2,172.90	898.80	4,905.65	4,157.78
Confirming	12.68	24.87	29.87	3.00	70.42	51.40
Chasing	71.20	67.42	198.07	10.98	347.67	256.00
Handling	18.75	22.05	58.27	4.27	103.34	79.30
Towing	29.48	20.25	42.37	0.00	92.10	50.95
Resting	485.13	1,835.27	1,790.87	613.67	4,724.94	3,257.13
Other whales*	74.12	184.83	3.66	5.28	267.89	19.43
<i>Per day</i>						
Searching	8.64	9.64	12.14	13.63	11.15	12.60
Confirming	0.28	0.17	0.17	0.04	0.16	0.16
Chasing	1.58	0.45	1.11	0.17	0.79	0.78
Handling	0.42	0.15	0.33	0.06	0.23	0.24
Towing	0.66	0.14	0.24	0.00	0.21	0.15
Resting	10.78	12.24	10.00	9.30	10.74	9.87
<i>Per whale</i>						
Searching	3.97	15.38	6.67	52.87	9.17	10.09
Confirming	0.13	0.26	0.09	0.18	0.13	0.12
Chasing	0.73	0.72	0.61	0.65	0.65	0.62
Handling	0.19	0.23	0.18	0.25	0.19	0.19
Towing	0.30	0.22	0.13	0.00	0.17	0.12

* Confirming, chasing, handling and towing for other whale species.

Index of Abundance of the Male Sperm Whale in the Pelagic Whaling Ground of the North Pacific

Seiji Ohsumi

Far Seas Fisheries Research Laboratory

ABSTRACT

A method is developed to allow for changes in the whaling ground for sperm whales in the North Pacific in recent years. It is shown that traditional CPUE data tend to overestimate the decline of the whole population. The indices of abundance are calculated and these do not show as strong a decline as the CPUE data. Independent information from sightings and body length data support this. It is proposed that indices of abundance are used for assessments in future.

INTRODUCTION

The sperm whale is widely distributed in the North Pacific. Whaling has never been carried out throughout the whole life range of the sperm whale, and the pelagic whaling ground has gradually moved from waters north of 50°N to lower latitudinal waters since the middle of the 1960s (Ohsumi, 1980a). The change in the pelagic whaling ground of the sperm whale was related to (1) the change in main target species — the baleen whales, (2) the increase in catching of females (3) the decrease in density in the northern whaling ground.

Sexual segregation is clear in the distribution of the sperm whale (Ohsumi, 1966), and the density of adult and large males is higher in the waters around the Aleutian Isles and the Bering Sea than in other regions, but the size of the northern area is smaller than the lower latitudinal zones.

CPUE AND INDEX OF ABUNDANCE

When a part of a population is distributed uniformly in an area (i), the index of abundance (n_i) of the partial population in area i can be represented as follows:

$$n_i = c_i \cdot A_i / W_i \dots \quad (1)$$

where c is the catch, W the fishing effort and A the size of the area (c/W is CPUE). Therefore, the index of abundance of the total exploitable population (N) of a stock can be represented by the following formula:

$$N = c_1 \cdot A_1 / W_1 + c_2 \cdot A_2 / W_2 + \dots + c_i \cdot A_i / W_i \dots \quad (2)$$

However, the CPUE of the total exploitable population is often represented as follows:

$$CPUE = c_1 + c_2 + \dots + c_i / W_1 + W_2 + \dots + W_i \dots \quad (3)$$

These two formulae are clearly different and the latter does not represent the index of abundance.

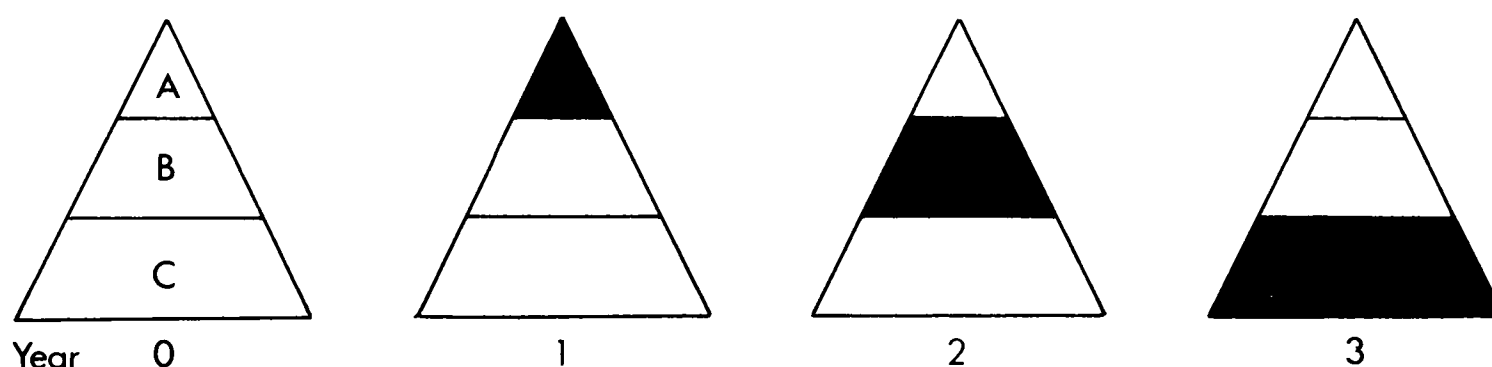


Fig. 1. A model of a stock showing changes in the whaling ground. A, B and C are regions and the whaling grounds are in black.

Even if perfect values could be obtained, CPUE data represent only an index of available density in a particular area and not an index of total abundance or relative population size, unless whaling effort is divided equally throughout the life range of a whale stock. Considering the large changes in the pelagic whaling ground for North Pacific sperm whales, CPUE should not be treated directly as an index of total population abundance as Ohsumi (1980b) pointed out.

Fig. 1 shows a schema of a life range of a stock and a change in the whaling ground. In this schema the population density (CPUE) in the unexploited situation in Zones A, B and C is assumed to be 6.0, 4.0 and 3.0 respectively, and the size of Zones A, B and C are assumed to be 1, 2 and 3 respectively. Fishing effort and catch are assumed as shown in Table 1 for each Zone and each year. The CPUE and index of abundance in a Zone and in a year are calculated from formula (1), and those in the total area

Table 1

Comparison of CPUE and index of abundance in a model population with a change in the fishing ground

Fishing ground	A				B				C				Total			
Size of ground	1				2				3				6			
Year	W	C	CPUE	IA	W	C	CPUE	IA	W	C	CPUE	IA	W	C	CPUE	IA
0			6.0	6.0			4.0	8.0			3.0	9.0				23.0
1	100	600	6.0	6.0			"	"			"	"	100	600	6.0	23.0
2	150	825	5.5	5.5			"	"			"	"	150	825	5.5	22.5
3	200	1,000	5.0	5.0			"	"			"	"	200	1,000	5.0	22.0
4	250	1,125	4.5	4.5			"	"			"	"	250	1,125	4.5	21.5
5	300	1,200	4.0	4.0			"	"			"	"	300	1,200	4.0	21.0
6	100	350	3.5	3.5	200	800	"	"			"	"	300	1,150	3.8	20.5
7			(3.0)	(3.0)	300	1,050	3.5	7.0			"	"	300	1,050	3.5	19.0
8			"	"	100	300	3.0	6.0	200	600	"	"	300	900	3.0	18.0
9			"	"			(2.5)	(5.0)	300	750	2.5	7.5	300	750	2.5	15.5
10			"	"			"	"	200	400	2.0	6.0	200	400	2.0	14.0

W: Fishing effort, C: Catch, CPUE: Catch per unit of effort, IA: Index of abundance.

in the year are calculated from formulae (2) and (3) respectively (Table 1).

Fig. 2 shows the yearly change in the relative CPUE and index of abundance based on those in year 1. The trends differ from each other, and it is clear that the yearly change in CPUE does not represent the real change in the relative abundance of the population in the whole life range under the given conditions. The movement of pelagic whaling operations for North Pacific sperm whales is similar to the above model (see the Appendix figures) and so an index of abundance must be used for population assessments of the North Pacific sperm whale instead of simply using CPUE.

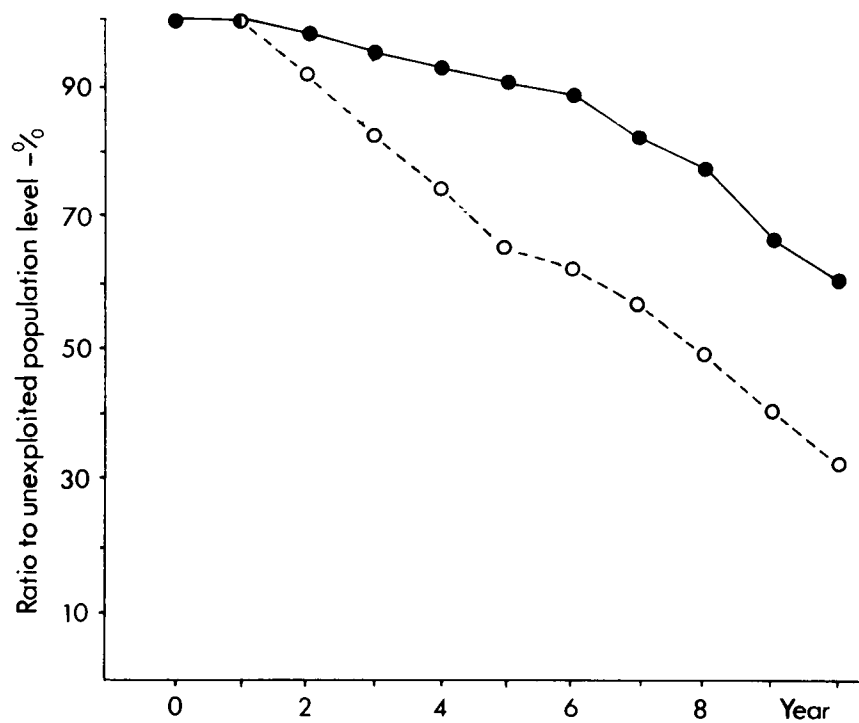


Fig. 2. Yearly change in CPUE and index of abundance (1A) of the model population (see Table 1). ○- - ○ CPUE, ●—● 1A.

MATERIALS AND METHODS

The IWC Scientific Committee divided the North Pacific into Western and Eastern Divisions (Fig. 3) for the purposes of sperm whale assessments at its meeting in June, 1978. The present paper follows this division, although it is possible that more than two stocks exist in the North Pacific (Bannister and Mitchell, 1980; Wada, 1980).

The Japanese and Soviet pelagic whaling grounds have moved gradually (see the Appendix figures), and have

covered most of the waters of the North Pacific as shown in Figs 4a and b, although the waters south of 20°N have not yet been covered, despite the fact that the sperm whale is found there. Japanese pelagic whaling is forbidden by the Government to operate in the waters west of 159°E in order to protect Japanese coastal whaling, and thus does not cover the main sperm whaling ground of the North Pacific. Therefore, the material dealt with in this paper does not cover the whole life range of the North Pacific sperm whale.

Catch and fishing effort are available from the NP 1 and NP 2 Forms which were circulated among the North Pacific

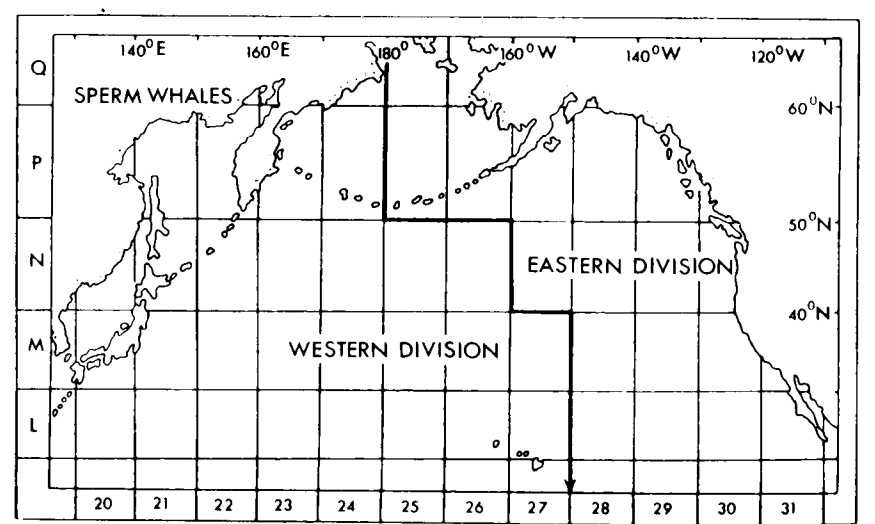


Fig. 3. Sperm whale Divisions in the North Pacific.

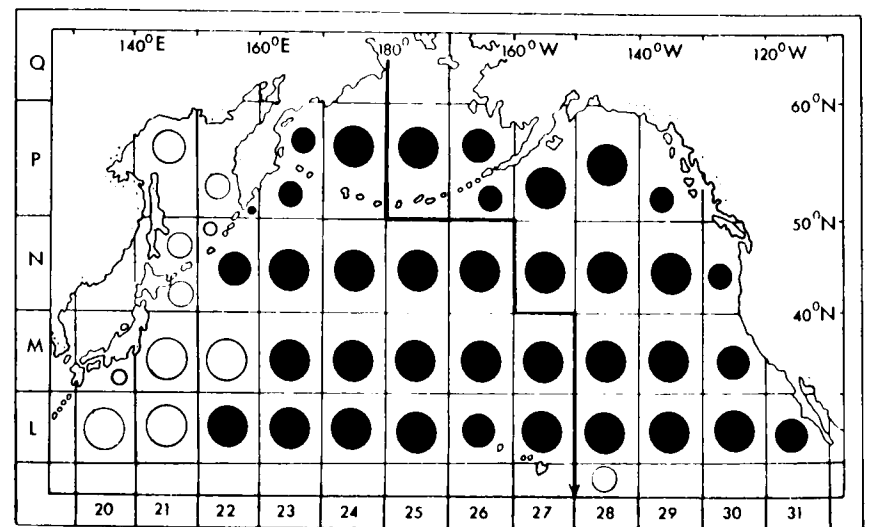


Fig. 4. Pelagic whaling grounds. ● Japanese 1954-78 and Soviet 1954-57, ○ Soviet only 1954-77.

Working Group. Japanese and Soviet data from 1954–77 and Japanese pelagic data for 1978, tabulated by 10° square, by month and by year are used in this paper. As the sperm whale is a migratory animal its density distribution is not uniform in every region, so that ideally one would use data for as small a region as possible for as short a time as possible in order to obtain a good index of abundance. However, it is difficult to obtain enough data to determine a reliable result, especially when data for only one month, for example August, are used for the calculation. I have used data for all months in each 10° square as a unit region. Japanese and Soviet data are dealt with independently, because the operational methods of their fleets are different, making it difficult to standardise the fishing effort.

Searching hours were used as a measure of the fishing effort for sperm whale population assessments at the IWC Scientific Committee Meeting (IWC, 1979), but in practice, it is difficult to obtain actual CSW (catcher's searching hour's work) values from past years, because such data were not stored. Therefore, CSW values must be estimated and this is done using the following equation:

$$CDW(24\text{ hrs}) = T_s + T_c + T_h + T_t + T_r$$

where, T_s is searching time, T_c is chasing time, T_h is handling time, T_t is towing time and T_r is resting time. However, it is also difficult to determine these time budget values and here I follow the method used by the Scientific Committee (IWC, 1979). The T_r value is obtained by taking an integer value for the mean day length of three mid-season months and varies by Zone (IWC, 1979, Annex E, Table 1). The T_c , T_h and T_t values are regarded as being proportional to the number of whales caught, although they are also related to the efficiency of the catcher boats, the weather, the body length of the whales caught, etc. In this paper I use values of 0.6 hrs for males and 0.4 hrs for females estimated from the relationship between body length and chasing time (Ohsumi, 1980b). It is possible that the chasing time in earlier years, when larger males were taken, would be longer than this (Ohsumi, 1980d). The T_h and T_t values used are 0.3 and 0.2 hrs, respectively, for both males and females. Thus, T_s is estimated from the following formula:

$$CSW = T_s = CDW i - 1.1 C_m - 0.9 C_f \dots \quad (4)$$

where, i is an integer value, C_m is the catch of males and C_f is the catch of females. The integer values are 24, 18, 16, 15 and 14 hrs for Zones Q, P, N, M and L, respectively. The T_s value obtained is used as the fishing effort in this paper.

The CPUE and index of abundance of males in each 10° square in each year are calculated from formula (1) using catch, CSW and size of the unit region of each 10° square. The CPUE and index of abundance in both Divisions are then calculated from formulae (2) and (3). One problem is the estimation of the index of abundance for those years when no whaling operations took place. I have taken the index to be the average of those for the first three years for the unexploited situation. When whaling ceased in a unit region, the average of the available data for the last three years is used. If for one or more years, whaling operations are encased within a series of operation years, then I have taken the average of the previous and following years as the index of abundance for those years.

Formula (4) has not only been applied to the Japanese data but also to the Soviet data, although the time budgets of Soviet fleets may differ from those of Japanese fleets.

The comparison of actual data for the time budgets of the Soviet fleets and Japanese fleets will aid the understanding of the differences in fishing efficiency of the two fleets.

REGIONAL DISTRIBUTION OF INDEX OF ABUNDANCE

The index of abundance was calculated by 10° square and by years for Japanese and Soviet fleets. The results are shown in Tables 2–5, on pages 191–194.

Figs. 5a and b show the regional distribution of the index of abundance in 1955, 1965 and 1975 for the Japanese and Soviet fleets, respectively. They show that although the male sperm whale is distributed widely in the North Pacific, it is not equally abundant in each region. As

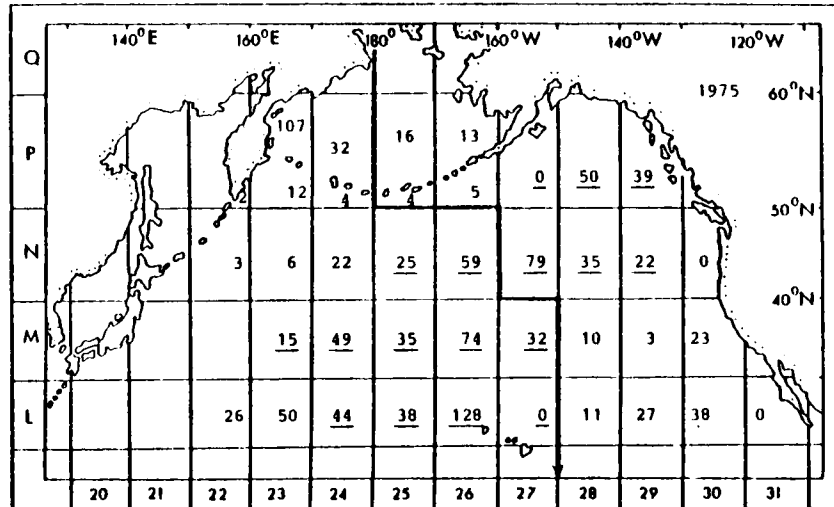
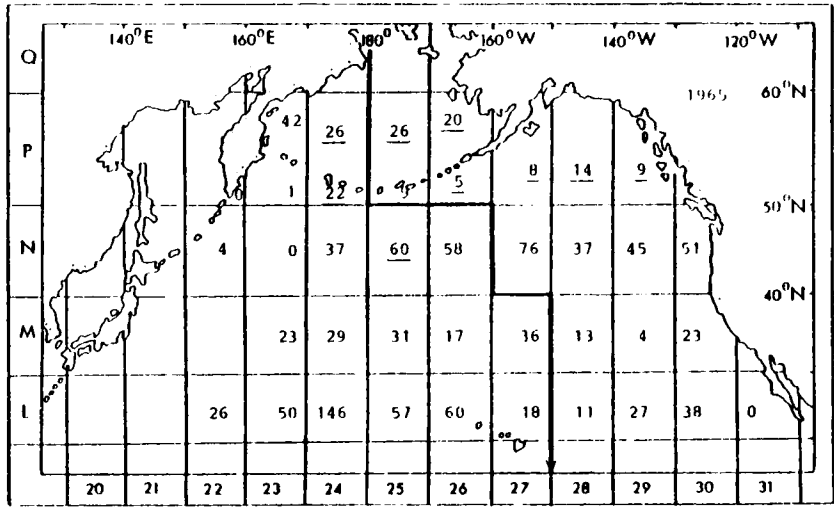
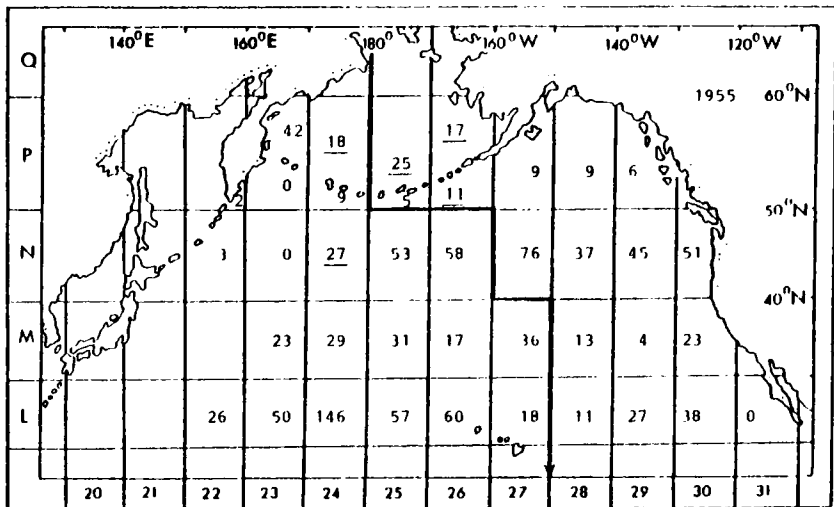


Fig. 5a. Index of abundance of males by 10° square. Data from Japanese fleets. Values not underlined are extrapolations from other years.

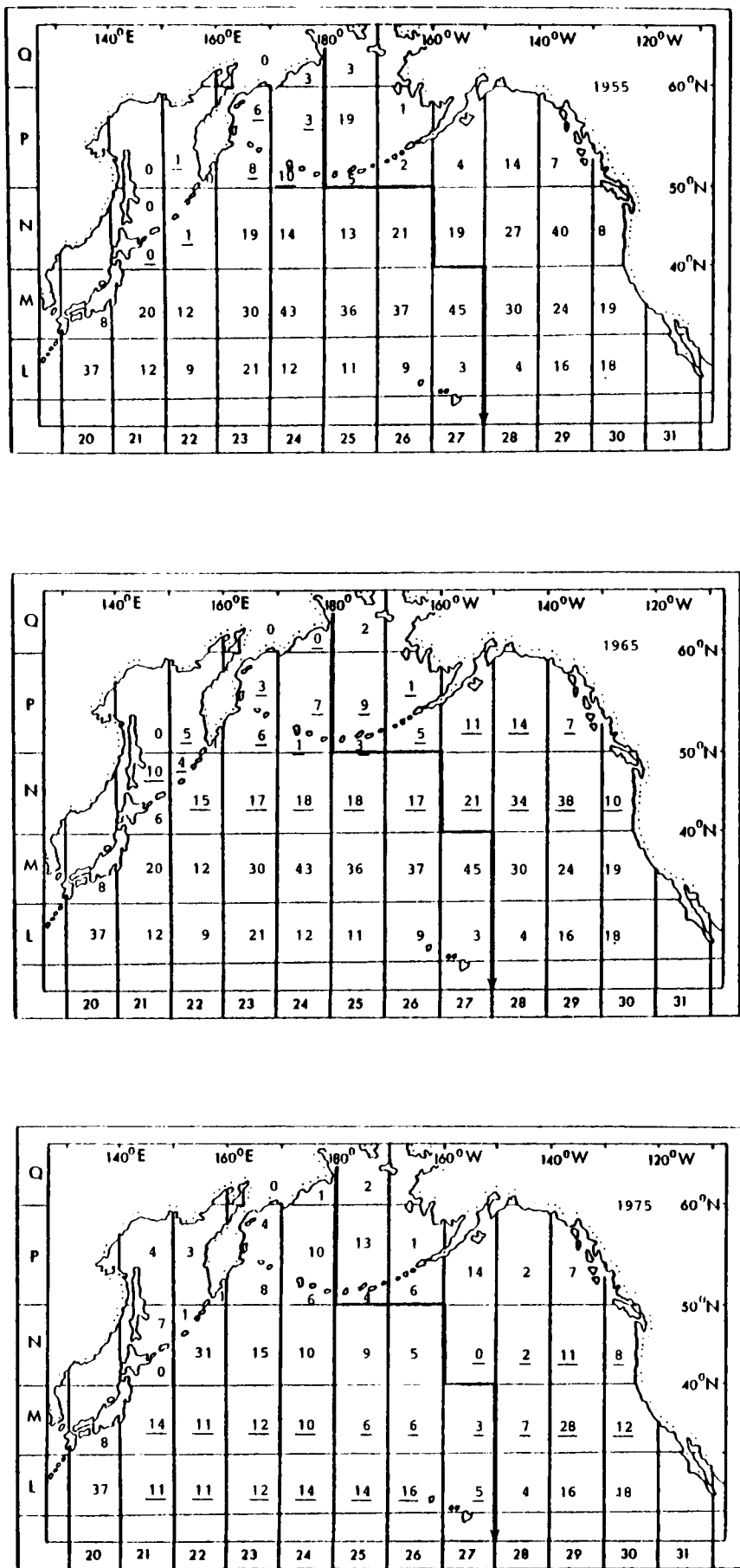


Fig. 5b. As for Fig. 5a except data from Soviet fleets.

the Japanese fleets have not covered all the regions of the Western Division, the index of abundance of male sperm whales in that Division calculated from Japanese data is less than the real value. It is again difficult to compare the index of abundance values of the USSR with those of Japan directly, because the fishing efforts of the fleets are not standardised.

COMPARISON OF YEARLY CHANGE IN INDEX OF ABUNDANCE WITH CPUE

Figs 6–11 compare the yearly change in relative values of CPUE with index of abundance (IA) in the Western and Eastern Divisions and the whole of the North Pacific from

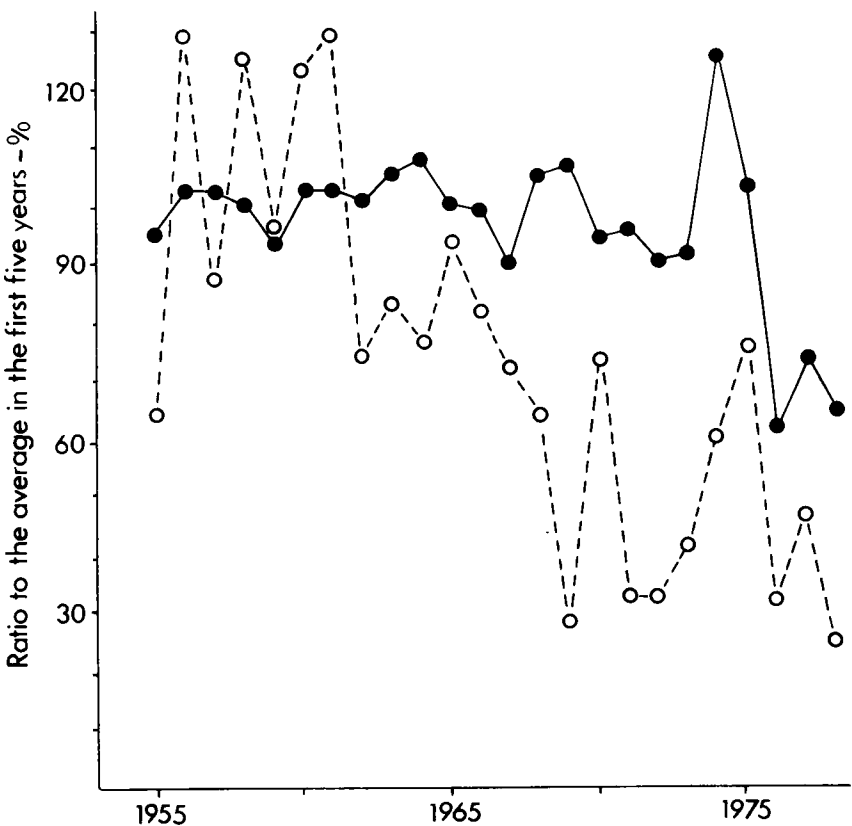


Fig. 6. Yearly change in relative CPUE and IA for males caught by Japanese fleets in the Western Division. ○- -○ CPUE; ●- -● IA.

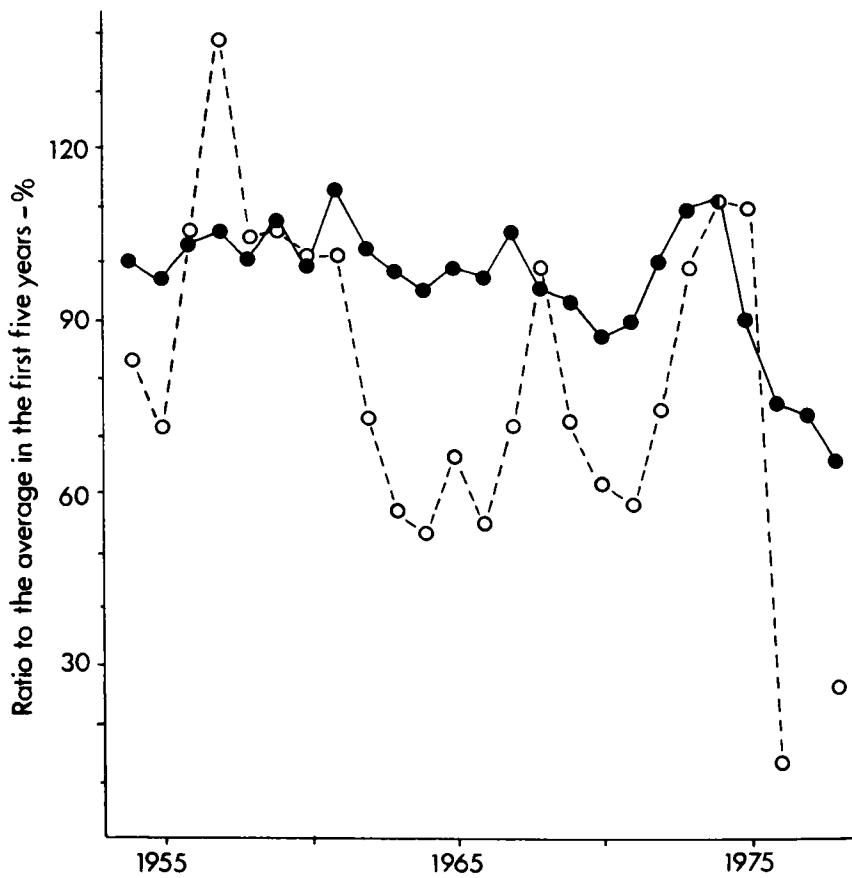


Fig. 7. Yearly change in relative CPUE and IA for males caught by Japanese fleets in the Eastern Division. ○- -○ CPUE; ●- -● IA.

Japanese and Soviet data. The ratio of the change in CPUE in recent years to that in the 1950s is lower than that of the IA in general, and the pattern of yearly change in CPUE is different from that in IA. The patterns in Fig. 6 resemble those in Fig. 2, and it can be seen that the yearly change in CPUE does not represent the real change in population abundance. The Soviet CPUE in the Western Division shows a remarkable increase until 1968, which is very difficult to explain. However, when the IA is calculated it becomes similar to the IA from Japanese data.

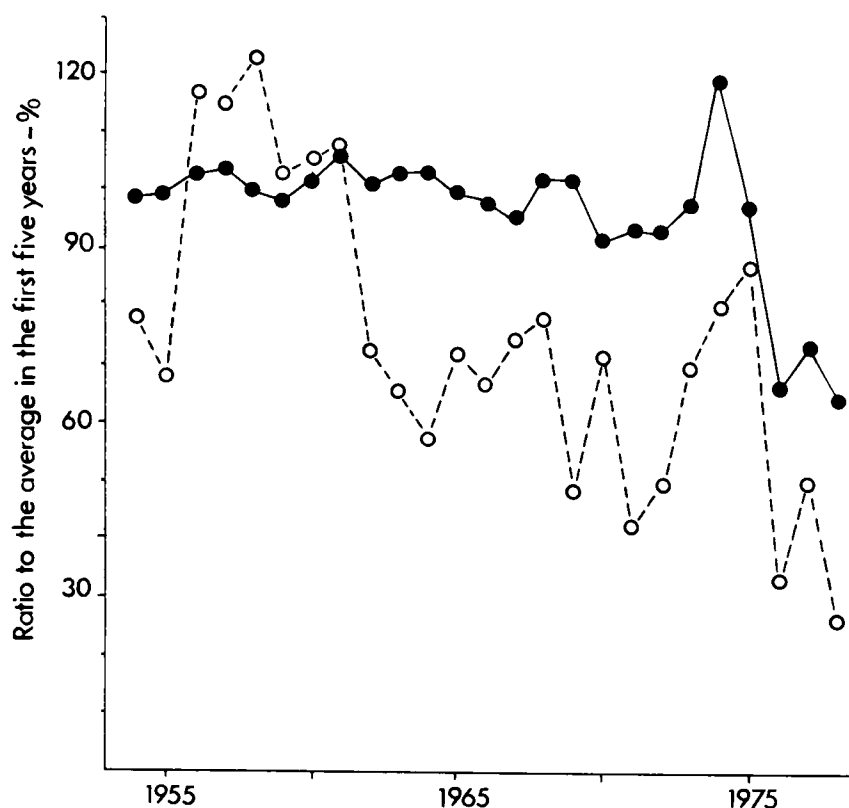


Fig. 8. Yearly change in relative CPUE and IA for males caught by Japanese fleets in the whole North Pacific. $\circ - - \circ$ CPUE; $\bullet - \bullet$ IA

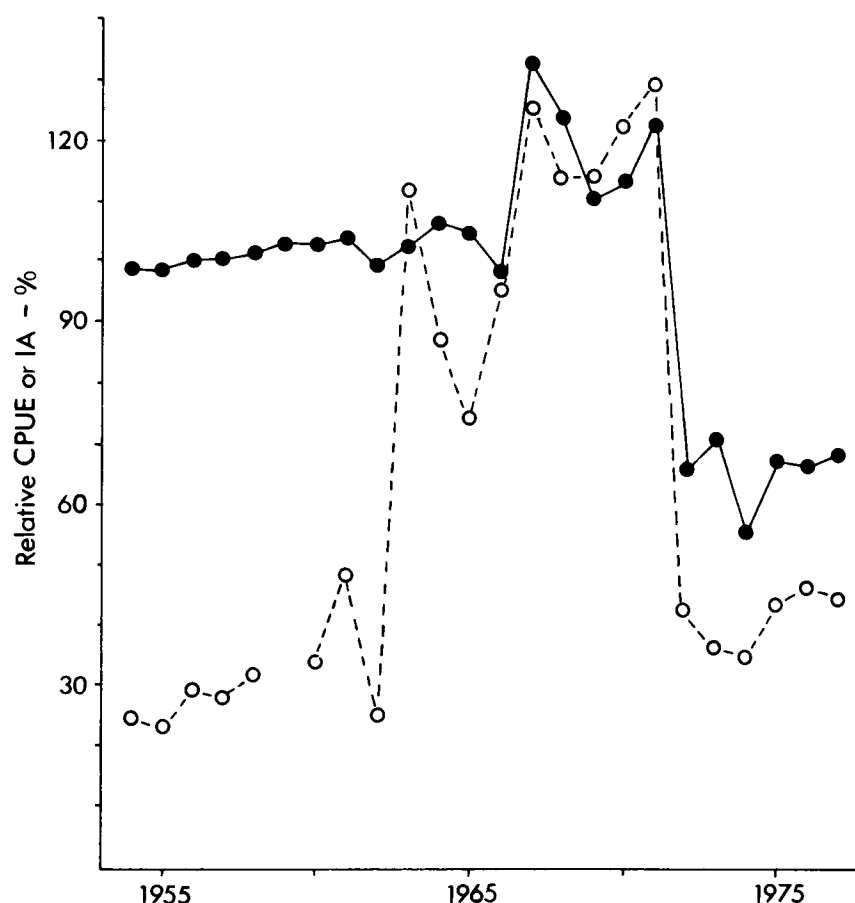


Fig. 9. Yearly change in relative CPUE and IA for males caught by Soviet fleets in the Western Division. $\circ - - \circ$ CPUE; $\bullet - \bullet$ IA.

YEARLY CHANGE IN INDEX OF ABUNDANCE

Figs 12–14 show the comparison of the yearly change in relative IA in the Western and Eastern Divisions and the whole of the North Pacific obtained for the Japanese and Soviet fleets. In the Western Division, the Japanese IA has gradually declined to 61–74% of its value in the 1950s, while the Soviet IA gradually increased until 1971, after which it declined rapidly to 56–71% of its value in the 1950s and since then has remained almost constant. Both results agree on the recent population level, and it is estimated to be about 65–70% of that in the 1950s.

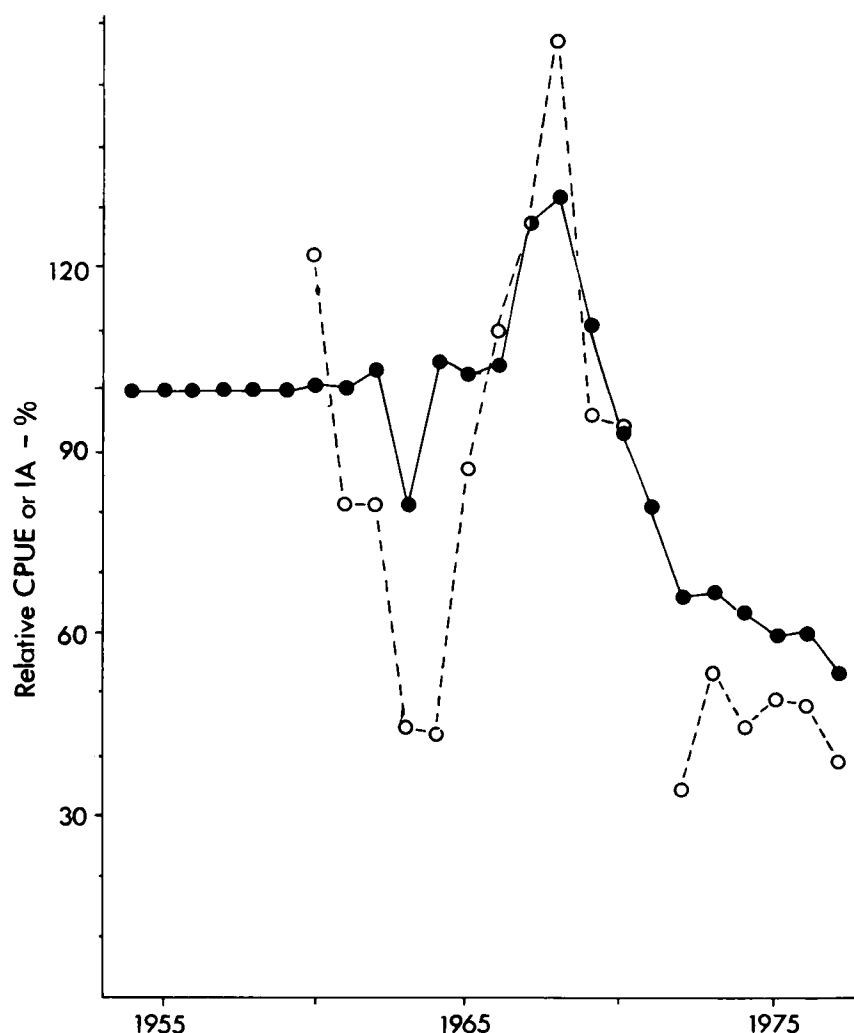


Fig. 10. Yearly change in relative CPUE and IA for males caught by Soviet fleets in the Eastern Division. $\circ - - \circ$ CPUE; $\bullet - \bullet$ IA.

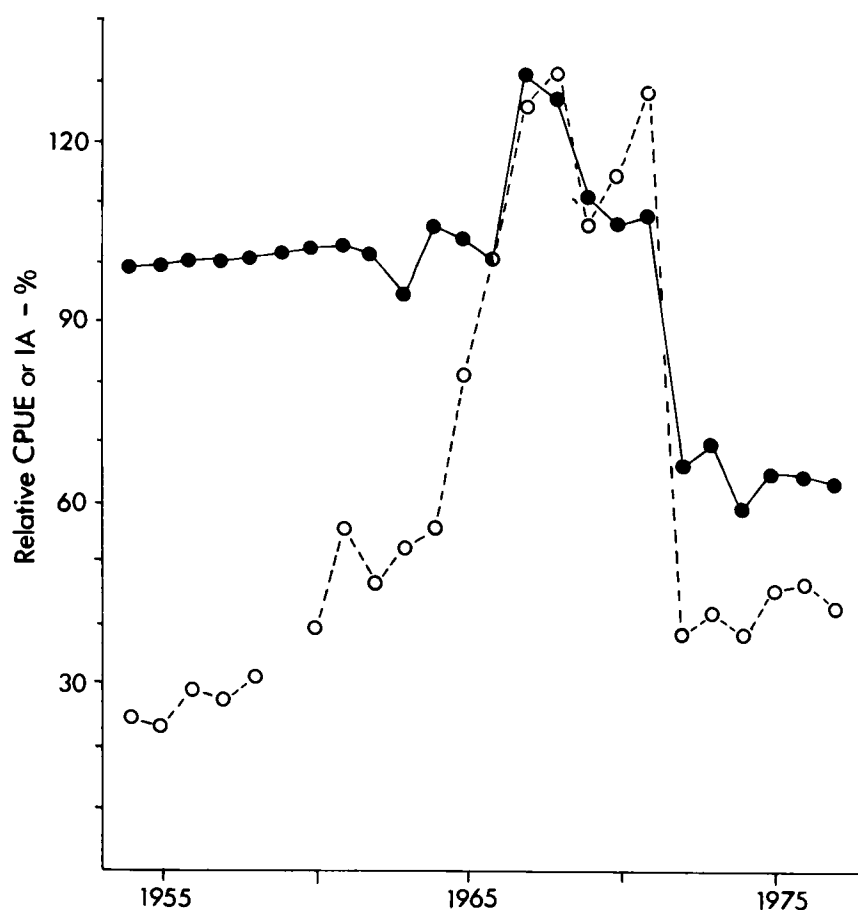


Fig. 11. Yearly change in relative CPUE and IA for males caught by Soviet fleets in the whole North Pacific. $\circ - - \circ$ CPUE; $\bullet - \bullet$ IA.

In the Eastern Division, the Japanese IA in recent years has gradually declined to 65–73% of its value in the 1950s. The pattern of the Soviet IA is somewhat different from that of Japan: it increased until 1968 and since then has declined remarkably to 54–60% of its value in the 1950s.

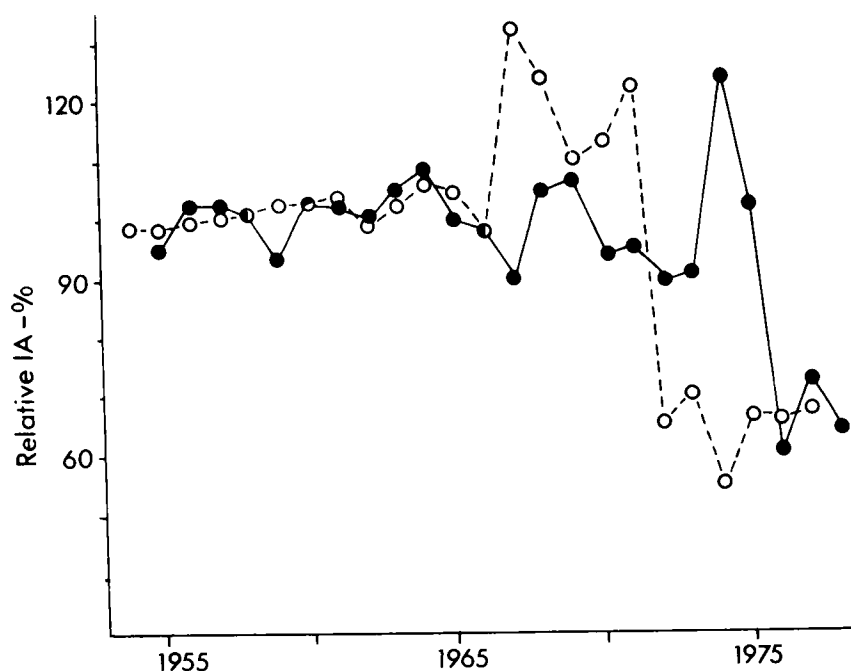


Fig. 12. Comparison of the yearly change in the relative IA for males in the Western Division for Japanese and Soviet data. ●—● Japan; ○---○ USSR.

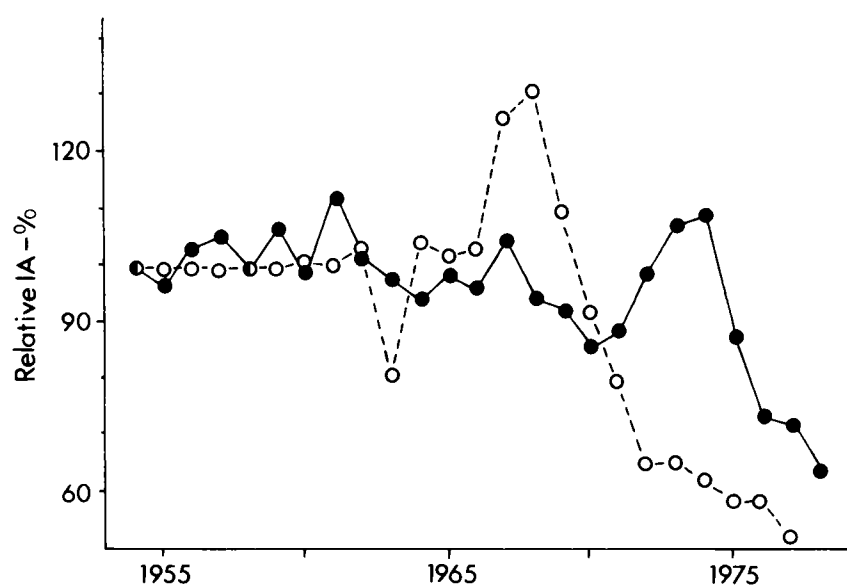


Fig. 13. Comparison of the yearly change in the relative IA for males in the Eastern Division for Japanese and Soviet data. ●—● Japan; ○---○ USSR.

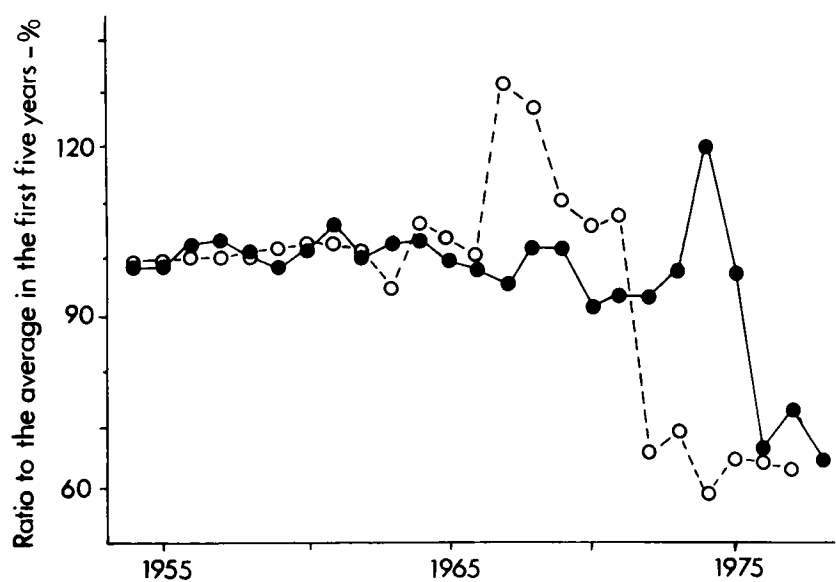


Fig. 14. Comparison of the yearly change in the relative IA for males in the whole North Pacific for Japanese and Soviet data. ●—● Japan; ○---○ USSR.

The Japanese IA in the whole of the North Pacific has gradually declined to 65–74% of its value in the 1950s. The pattern of yearly change in the Soviet IA is somewhat different from that of Japan: it increased until 1968, after which it declined, but it has remained almost constant at about 63–65% of its value in the 1950s since 1972.

RATIO OF THE INDEX OF ABUNDANCE IN THE WESTERN DIVISION TO THAT IN THE WHOLE NORTH PACIFIC

Although it is impossible to estimate the relative population size in each region from CPUE data, it is possible to do so by using IA data.

Fig. 15 shows the yearly change in the ratio of the IA in the Western Division to that in the whole North Pacific. As the Japanese IA does not include the IA in the Asian coastal waters which is a part of the Western Division, the apparent ratio we obtain will be less than the true one. No remarkable change in the ratio of the IA in the Western Division is observed for either the USSR or Japan: it has remained almost constant at 62–64% of the whole North Pacific.

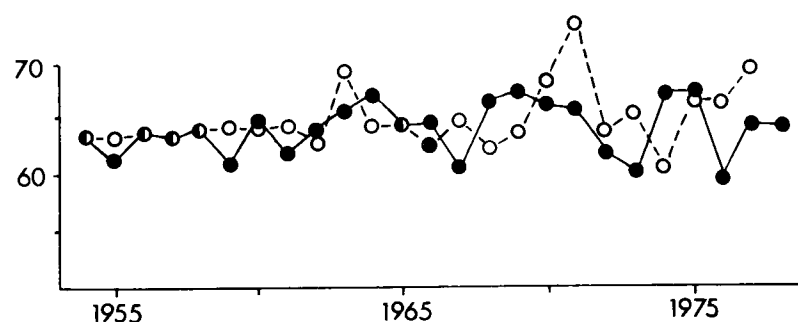


Fig. 15. Yearly change in the ratio of IA in the Western Division to that in the whole North Pacific. ●—● Japanese data; ○---○ Soviet data.

DISCUSSION

From this study we have found that the actual population level of the male sperm whale in the North Pacific has not declined as much as is indicated by the yearly change in CPUE.

Whale sighting provides independent information on population levels. Wada (1979) reports on the yearly change in the index of abundance of the sperm whale in the North Pacific from 1965 to 1977 using whale sighting data from Japanese scouting boats. Although it is impossible to separate the whale sighting data by sex, the yearly change in the index of abundance from this data for the whole North Pacific is very similar to the IA obtained from Japanese CPUE data in this paper (Fig. 16).

Ohsumi (1979d) has shown that the yearly change in the CPUE of male sperm whales caught by Japanese coastal

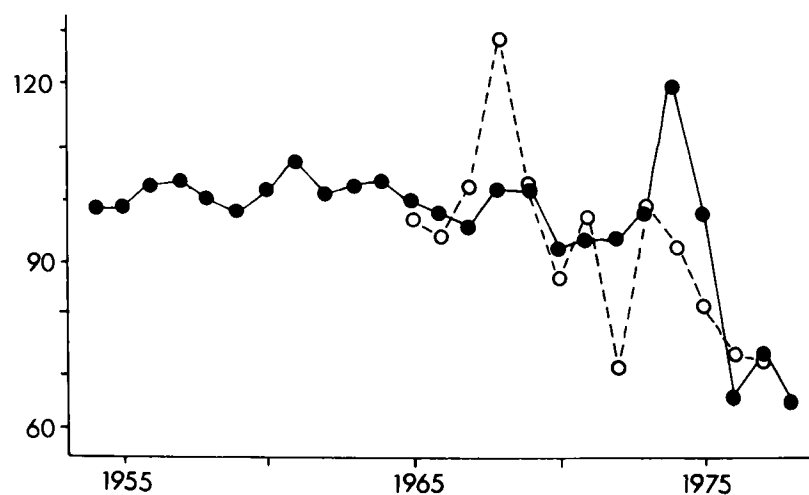


Fig. 16. Comparison of the yearly change in IA for the whole North Pacific between CPUE data and sightings data collected by Japanese fleets. ●—● from CPUE data (males); ○---○ from sightings data (males and females).

whaling in Sanriku region does not indicate any decline. If the sperm whales in the Sanriku region belong to the Western Stock, and if that stock has declined, then we would expect the CPUE to decline but this is not the case.

The yearly change in the average body length of male sperm whales is another indication of the change in population level. Fig. 17 shows yearly change in average body length of the male sperm whales caught in the whole North Pacific from 1946 to 1977. The average body length had been almost constant until 1972 when the legal size limit was changed from 38 feet for pelagic whaling and 35 feet for coastal whaling to 30 feet for both operations. If the population level had declined by as much as the CPUE

These independent phenomena all indicate that there has not been as large a decline in the population level of the male sperm whale in the North Pacific as had been thought, and support the conclusion that index of abundance should be used instead of CPUE for the assessment of the sperm whale population in the North Pacific.

REFERENCES

Bannister, J. L. and Mitchell, E. D. 1980. North Pacific sperm whale stock identity: distributional evidence from Maury and Townsend charts. Paper SC/SP78/16 (published in this volume).
 International Whaling Commission, 1979. The Report of the Sub-Committee on Sperm Whales (Annex E.) Cambridge, June 1978. *Rep. int. Whal. Commn* 29: 65-74; and reprinted in this volume.
 Ohsumi, S. 1966. Sexual segregation of the sperm whale in the North Pacific. *Sci. Rep. Whales Res. Inst., Tokyo* 20: 1-16.
 Ohsumi, S. 1979a. Catches of sperm whales by modern whaling in the North Pacific. Paper SC/SPC/1 (published in this volume).
 Ohsumi, S. 1979b. Review of Japanese fishing effort of sperm whale in the North Pacific. Paper SC/SPC/2 (published in this volume).
 Ohsumi, S. 1979c. Population assessment of the sperm whale in the North Pacific. Paper SC/SPC/3 (published in this volume).
 Ohsumi, S. 1979d. Sperm whale catch by Japanese coastal whaling in the Sanriku region. Paper SC/SP78/7 (published in this volume).
 Wada, S. 1979. Indices of abundance of large-sized whales in the North Pacific in the 1977 whaling season. *Rep. int. Whal. Commn*: 253-64.
 Wada, S. 1979b. On the genetic uniformity in the North Pacific sperm whale. Paper SC/SP78/12 (published in this volume).

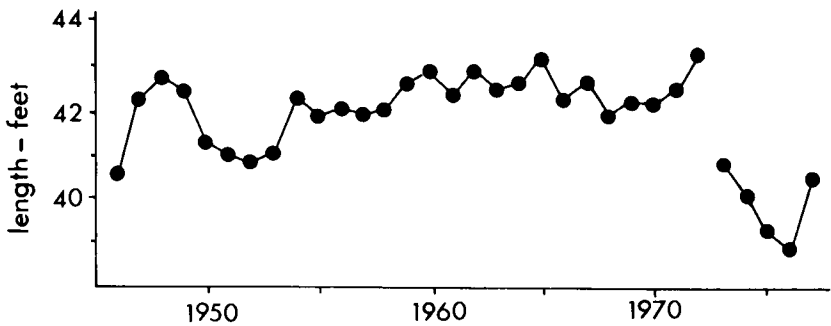


Fig. 17. Yearly change in the average body length of males in the whole North Pacific.

data indicate, the average body length would also decline significantly, but again this is not the case.

Table 2

Index of abundance of male sperm whales by 10° square from Japanese data, Eastern Division

10° square	P25 NP	P25 BS	P26 NP	P26 BS	P27	P28	P29	N27	N28	N29	N30	M28	M29	M30	L28	L29	L30	L31	Total	%
Size*	4	19	9	10	17	21	15	26	26	26	15	29	29	26	33	33	33	28	399	
1954	5	42	21	5	9	9	6	76	37	45	51	13	4	23	11	27	38	0	422	100.2
1955	5	25	11	17	9	9	6	76	37	45	51	13	4	23	11	27	38	0	407	96.7
1956	6	46	11	22	9	9	6	76	37	45	51	13	4	23	11	27	38	0	434	103.1
1957	13	53	13	16	9	9	6	76	37	45	51	13	4	23	11	27	38	0	444	105.5
1958	9	44	5	13	9	9	6	76	37	45	51	13	4	23	11	27	38	0	420	99.8
1959	9	38	37	18	9	9	6	76	37	45	51	13	4	23	11	27	38	0	451	107.1
1960	11	36	0	21	9	9	6	76	37	45	51	13	4	23	11	27	38	0	417	99.0
1961	57	38	7	24	8	9	6	76	37	45	51	13	4	23	11	27	38	0	474	112.6
1962	4	31	9	31	14	8	6	76	37	45	51	13	4	23	11	27	38	0	428	101.7
1963	9	28	2	25	6	10	7	76	37	45	51	13	4	23	11	27	38	0	412	97.9
1964	5	26	4	20	8	8	2	76	37	45	51	13	4	23	11	27	38	0	398	94.5
1965	9	26	5	20	8	14	9	76	37	45	51	13	4	23	11	27	38	0	416	98.8
1966	5	23	9	15	16	5	8	76	37	45	51	13	4	23	11	27	38	0	406	96.4
1967	4	18	8	5	18	33	8	100	37	45	51	13	4	23	11	27	38	0	443	105.2
1968	9	3	5	13	35	19	8	75	30	37	51	13	4	23	11	27	38	0	401	95.2
1969	3	4	14	13	29	5	6	52	29	68	51	13	4	23	11	27	38	0	390	92.6
1970	1	16	5	13	6	25	10	37	52	31	51	13	4	23	11	27	38	0	363	86.2
1971	4	27	9	13	5	13	2	44	34	36	72	13	4	23	11	27	38	0	375	89.1
1972	4	16	0	13	20	24	66	17	66	44	32	13	4	23	11	27	38	0	418	99.3
1973	4	16	5	13	10	34	31	54	64	53	48	20	6	23	11	27	38	0	457	108.6
1974	4	16	5	13	10	113	21	46	55	43	24	10	3	23	11	27	38	0	462	109.7
1975	4	16	5	13	0	50	39	79	35	22†	0	10	3	23	11	27	38	0	375	89.1
1976	4	16	5	13	7	66	39	16	0	22	24	0	3	23	11	27	38	0	314	74.6
1977	4	16	5	13	7	66	39	8	0	22	24	0	3	23	11	27	38	0	306	72.7
1978	4	16	5	13	7	66	39	0	0	0	24	0	0	23	11	27	38	0	273	64.8

* 10⁴ mile².

† Excluded the actual figure and inserted the average for 1974 and 1978, as the actual figure is extraordinarily high.

Table 3
Index of abundance of male sperm whales by 10° square from Japanese data, Western Division

10° square	P22 NP	P23 NP	P23 BS	P24 NP	P24 BS	N22 NP	N23	N24	N25	N26	M23	M24	M25	M26	M27	L22	L23	L24	L25	L26	L27	Total	%
Size*	2	11	7	5	15	22	26	26	26	26	29	29	29	29	29	33	33	33	33	33	32	508	
1954	2	0	42	0	28	3	0	46	53	58	23	29	31	17	36	26	50	146	57	60	18	725	97.7
1955	2	0	42	9	18	3	0	27	53	58	23	29	31	17	36	26	50	146	57	60	18	705	95.0
1956	2	0	42	21	46	0	0	46	53	58	23	29	31	17	36	26	50	146	57	60	18	761	102.6
1957	2	0	42	24	20	4	0	65	53	58	23	29	31	17	36	26	50	146	57	60	18	761	102.6
1958	2	0	42	22	35	4	0	37	53	58	23	29	31	17	36	26	50	146	57	60	18	746	100.5
1959	2	0	42	14	30	4	0	37	15	58	23	29	31	17	36	26	50	146	57	60	18	695	93.7
1960	2	0	42	10	47	4	0	37	72	58	23	29	31	17	36	26	50	146	57	60	18	765	103.1
1961	2	0	42	18	37	4	0	37	72	58	23	29	31	17	36	26	50	146	57	60	18	763	102.8
1962	2	0	42	2	37	4	0	37	72	58	23	29	31	17	36	26	50	146	57	60	18	747	100.7
1963	2	33	42	15	24	7	0	37	72	58	23	29	31	17	36	26	50	146	57	60	18	783	105.5
1964	2	5	42	9	25	4	0	37	129	58	23	29	31	17	36	26	50	146	57	60	18	804	108.4
1965	2	1	42	22	26	4	0	37	60	58	23	29	31	17	36	26	50	146	57	60	18	745	100.4
1966	2	15	9	9	25	4	0	37	87	57	23	29	31	17	36	26	50	146	57	60	18	738	99.5
1967	1	13	9	7	19	4	0	8	43	73	23	29	31	17	36	26	50	146	57	60	18	670	90.3
1968	2	10	108	9	41	4	4	27	36	45	23	29	31	17	36	26	50	146	57	60	18	785	105.8
1969	2	22	206	8	24	4	10	18	11	8	23	29	31	17	36	26	50	146	57	60	18	796	107.3
1970	2	36	6	4†	35	4	23	16	37	44	23	29	31	17	36	26	50	146	57	60	18	702	94.6
1971	2	0	107	0	33	0	15	17	24	23	23	29	31	17	36	26	50	146	57	60	18	714	96.2
1972	3	1	107	4	27	3	7	16	30	36	6	16	28	4	24	26	50	146	57	60	18	669	90.2
1973	2	12	107	4	32	3	0	20	4	17	28	30	41	3	16	26	50	175	31	60	18	679	91.5
1974	2	12	107	4	32	3	10	31	38	42	35	40	23	43	68	26	50	218	101	29	18	932	125.6
1975	2	12	107	4	32	3	6	22	25	59	15	49	35	74	32	26	50	44	38	128	0	763	102.8
1976	2	12	107	4	32	3	6	22	22	0	7	26	3	15	20	26	77	18	6	22	27	457	61.6
1977	2	12	107	4	32	3	6	22	22	34	9	37	15	5	10	52	50	23	48	29	27	549	74.0
1978	2	12	107	4	32	3	6	22	22	34	16	12	4	10	0	0	22	12	48	60	53	481	64.8

* 10⁴ mile².
† Excluded the actual figure and inserted the average for 1969 and 1971, as the actual figure is extraordinarily high.

Table 5

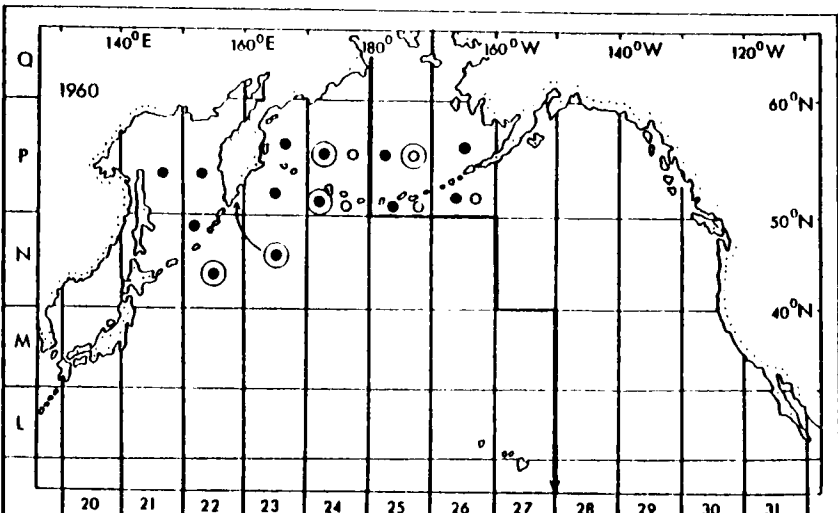
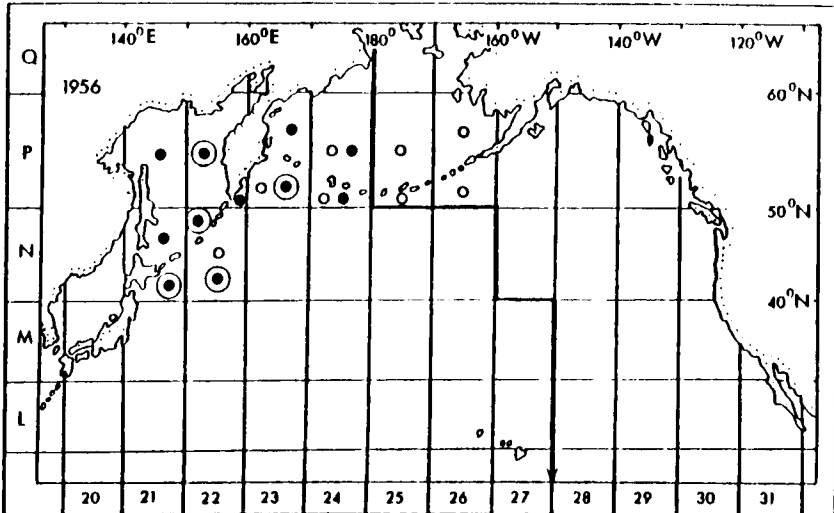
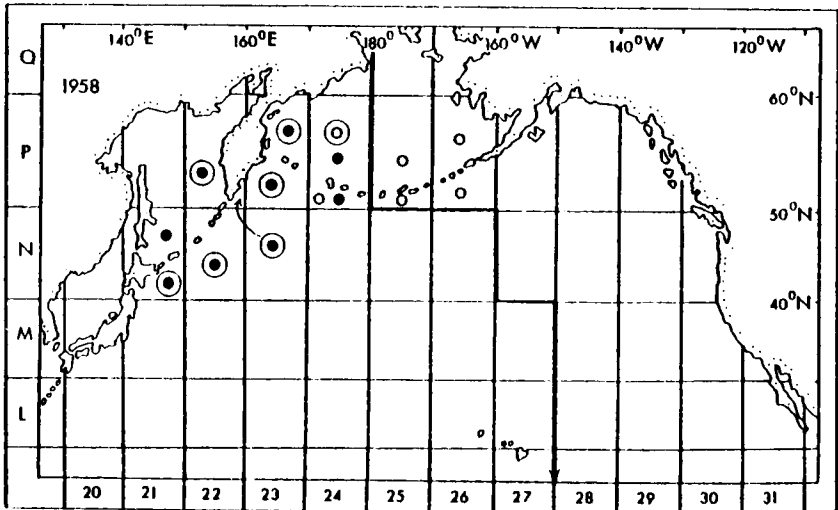
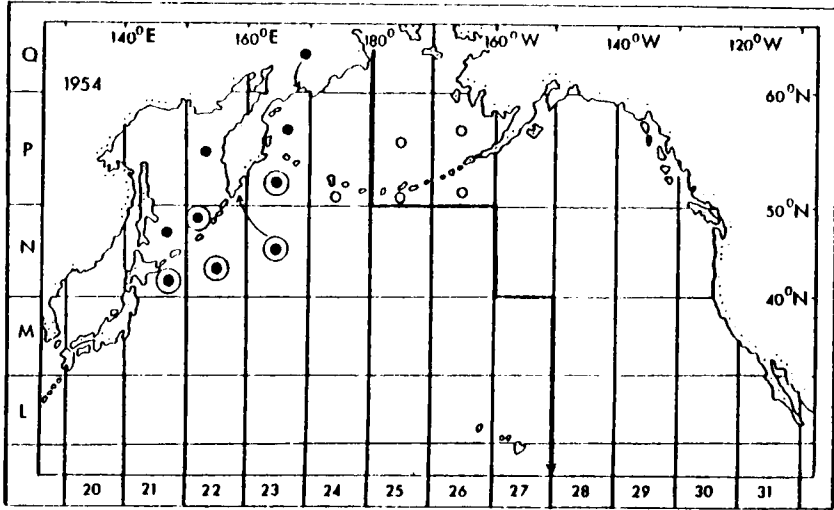
Index of abundance of male sperm whales by 10° square from Soviet data, Eastern Division

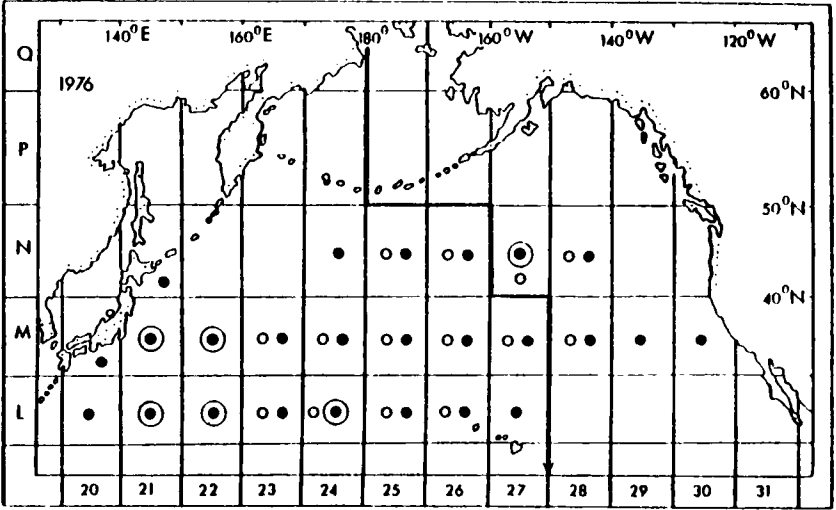
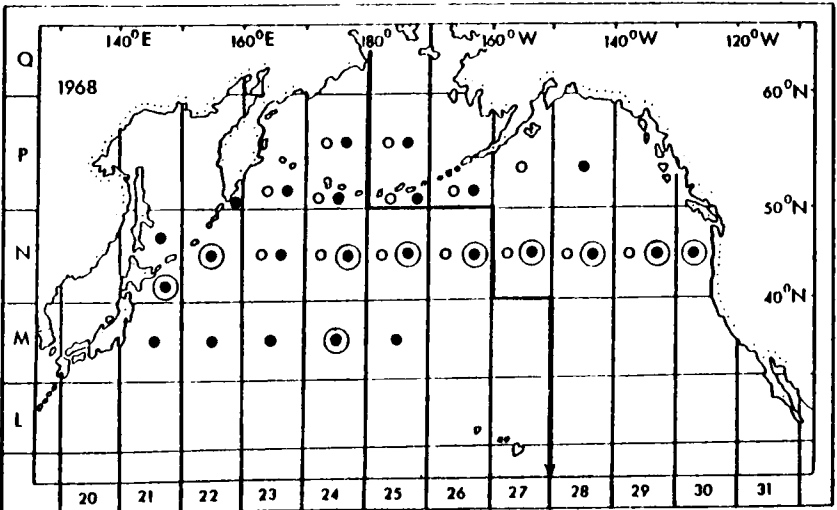
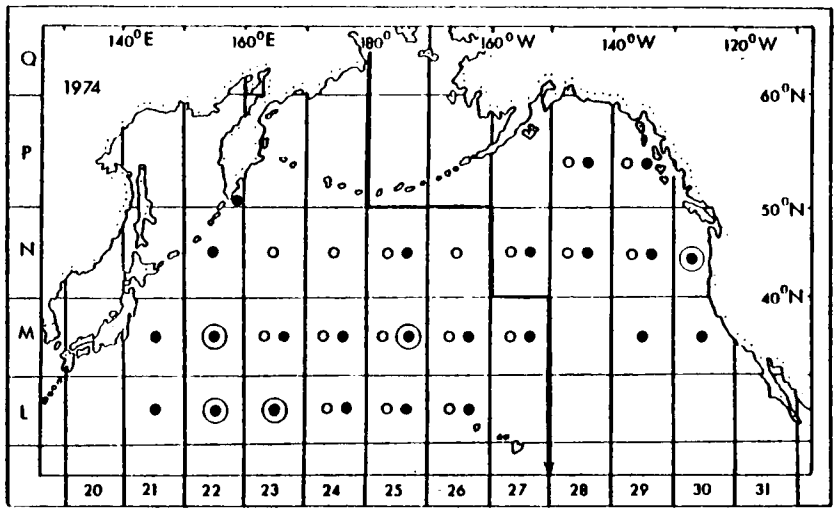
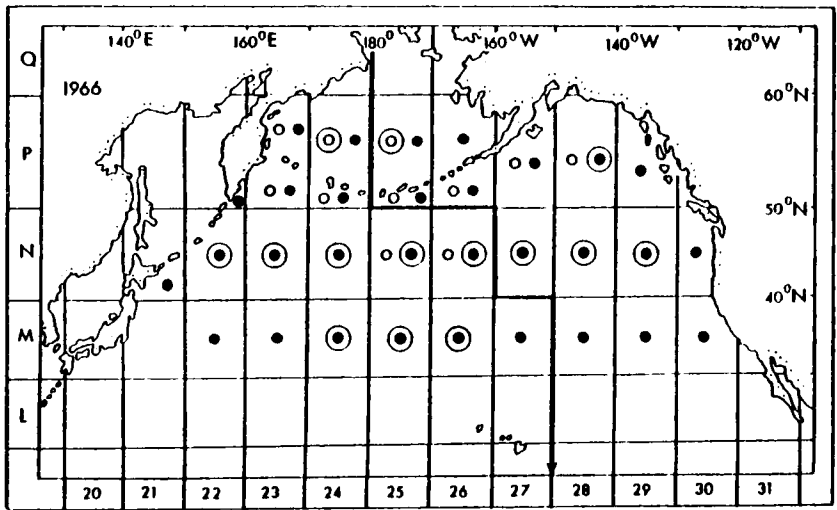
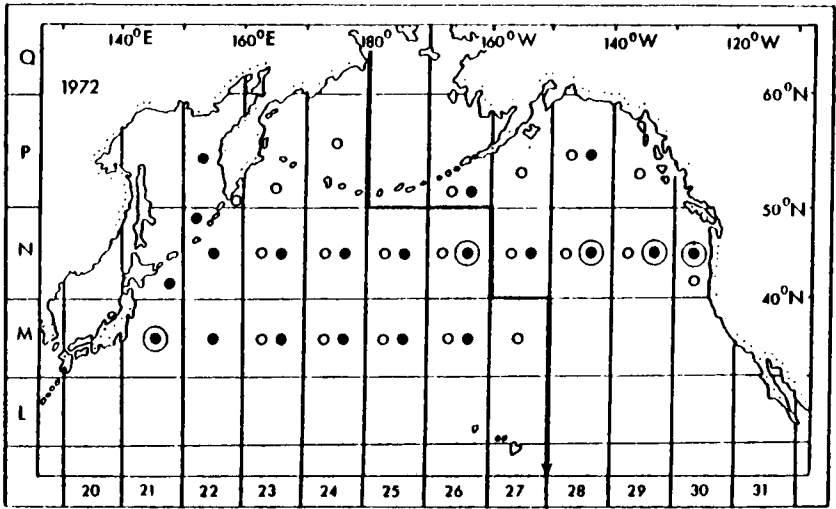
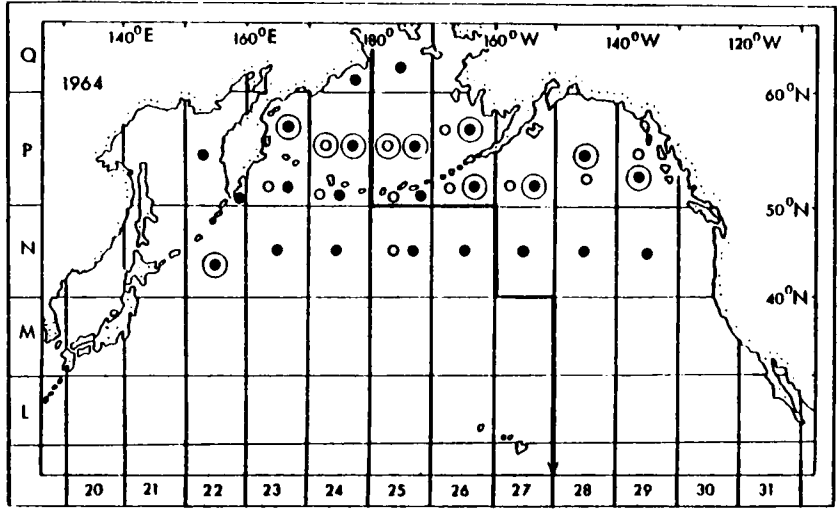
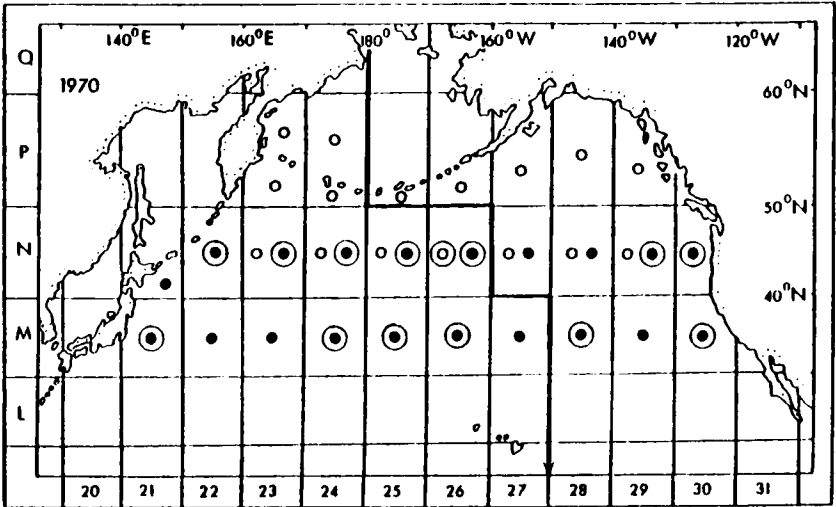
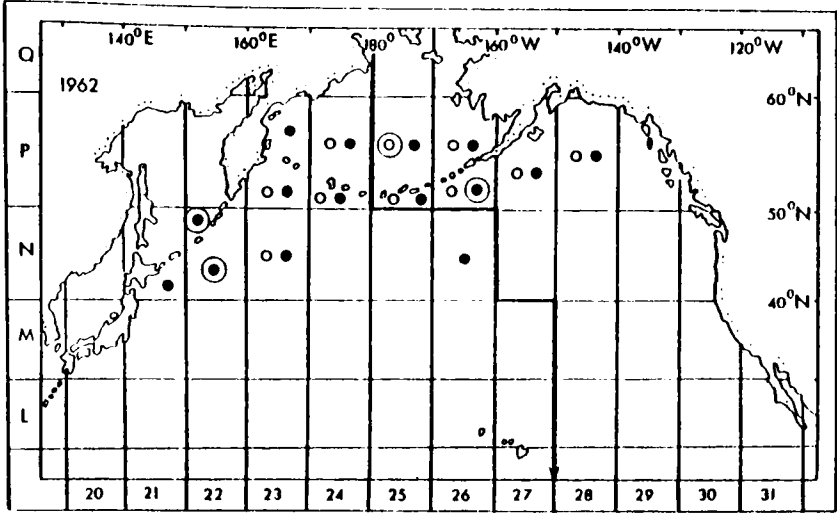
10° square	Q25	P25 NP	P25 BS	P26 NP	P26 BS	P27	P28	P29	N27	N28	N29	N30	M28	M29	M30	L28	L29	L30	Total	%
Size*	8	4	19	9	10	17	21	15	26	26	26	15	29	29	26	33	33	33	379	
1954	3	5	19	2	1	4	14	7	19	27	40	8	30	24	19	4	16	18	260	100.0
1955	3	5	19	2	1	4	14	7	19	27	40	8	30	24	19	4	16	18	260	100.0
1956	3	5	19	2	1	4	14	7	19	27	40	8	30	24	19	4	16	18	260	100.0
1957	3	5	19	2	1	4	14	7	19	27	40	8	30	24	19	4	16	18	260	100.0
1958	3	5	19	2	1	4	14	7	19	27	40	8	30	24	19	4	16	18	260	100.0
1959	3	5	19	2	1	4	14	7	19	27	40	8	30	24	19	4	16	18	260	100.0
1960	3	2	26	1	1	4	14	7	19	27	40	8	30	24	19	4	16	18	263	101.2
1961	3	4	21	1	2	4	14	7	19	27	40	8	30	24	19	4	16	18	261	100.4
1962	3	10	10	4	1	5	23	7	19	27	40	8	30	24	19	4	16	18	268	103.1
1963	5	5	7	3	3	4	11	4	19	10	22	5	30	24	19	4	16	18	209	80.4
1964	2	2	7	3	1	4	8	10	17	38	61	8	30	24	19	4	16	18	272	104.6
1965	2	3	9	5	1	11	14	7	21	34	38	10	30	24	19	4	16	18	266	102.3
1966	2	3	4	7	2	21	27	12	18	35	35	11	29	11	15	4	16	18	270	103.8
1967	1	2	16	7	0	9	26	21	32	40	38	18	30	31	21	4	16	18	330	126.9
1968	2	6	19	5	1	14	24	16	34	48	38	15	30	31	21	4	16	18	342	131.5
1969	2	3	3	5	1	14	27	11	22	27	24	9	30	50	21	4	16	18	287	110.4
1970	2	4	13	6	1	14	14	8	33	14	20	10	30	7	27	4	16	18	241	92.7
1971	2	4	13	6	1	14	14	8	21	14	14	6	19	13	22	4	16	18	209	80.4
1972	2	4	13	6	1	14	0	8	8	13	8	2	19	13	22	4	16	18	171	65.8
1973	2	4	13	6	1	14	2	8	8	2	12	9	19	13	22	4	16	18	173	66.5
1974	2	4	13	6	1	14	3	4	5	7	8	7	19	18	16	4	16	18	165	63.5
1975	2	4	13	6	1	14	2	7	0	2	11	8	7	28	12	4	16	18	155	59.6
1976	2	4	13	6	1	14	2	7	11	18	6	8	11	11	3	4	16	18	155	59.6
1977	2	4	13	6	1	14	2	7	6	7	0	8	5	6	19	4	16	18	138	53.1

* 10⁴ mile².

Appendix

Appendix figures. Yearly change in the pelagic whaling ground for sperm whales. ○ Japanese fleets, ● Soviet fleets ○ or ● less than 200 CDW, ⊙ or ⊙ more than 200 CDW. The thick black line shows the Divisional boundary adopted by the IWC in June, 1978.





Appendix figs. (continued).

Theoretical Aspects Analysed by Introducing Age-Specific Maturity and Age-Specific Availability into Population Analysis – III. Sperm Whales in the North Pacific

Takeyuki Doi, Seiji Ohsumi and Jun Tedor

ABSTRACT

Stock assessments are usually carried out using catch per unit effort. However, we believe that generally speaking catching efforts are one of the most insignificant, arbitrary and vague concepts not only in whaling but also in other fisheries. In a previous paper Doi tried to analyse the minke whale population in the Antarctic without using effort data by introducing an age-specific maturity function and an age-specific availability function into the analysis. Here using the same method (DOIPOP), we examine the sperm whale in the North Pacific. The population size in each year by sex and by age can be estimated using this method. Recruitment is also computed, and replacement yields in future years can be obtained. Estimated results for the 1910 and 1977 season are as follows:

Total number in the sea:	Female	446 – 557,000	1910	411 – 525,000	1977
	Male	446 – 557,000		360 – 474,000	
Available number:	Female	200 – 250,000	1910	176 – 226,000	1977
	Male	211 – 264,000		168 – 229,000	
Mature number:	Female	245 – 306,000	1910	232 – 297,000	1977
	Male	93 – 117,000		38 – 61,000	
Replacement yield:	Female	0	1910	1,500	1977
	Male	0		6,000	

INTRODUCTION

In past reports on the stock assessment of whale populations, many incomplete or unrealistic parameters and data are used which should be examined both theoretically and actually, such as catching effort, age at first capture, age at maturity etc. In this paper we would like to present some theoretical aspects obtained from introducing an age-specific maturity function instead of age at maturity and an age-specific availability function instead of age at first capture, in order to try and compare an analytical hypothesis with actual features of biology and whaling. Moreover we do not use any type of effort data, which are the most difficult to examine when fully taking into account actual whaling operations under different biological, industrial (e.g. type of equipment), meteorological, and other circumstances.

If we use effort data of any kind (especially CPUE with

the wide range of values in its estimation) the results obtained seem to be uncertain or unbelievable somewhere. DOIPOP was first applied to the minke whale population in the Antarctic (Doi, 1979). Here, we try to apply this model to the sperm whale population in the North Pacific. Some modifications were necessary due to the different ecology of the sperm whale and the different status of North Pacific whaling from Antarctic pelagic whaling.

1. CONCEPTION AND BIRTH IN CONNECTION WITH WHALING IN THE NORTH PACIFIC

As the gestation period of sperm whales (15 months) is longer than one year, to formulate the model taking this into account is more complex than for baleen whales. Fig. 1a shows the actual pattern of mating, gestation and birth and coastal and pelagic whaling. For the purposes of the model this has been simplified this as shown in Fig. 1b.

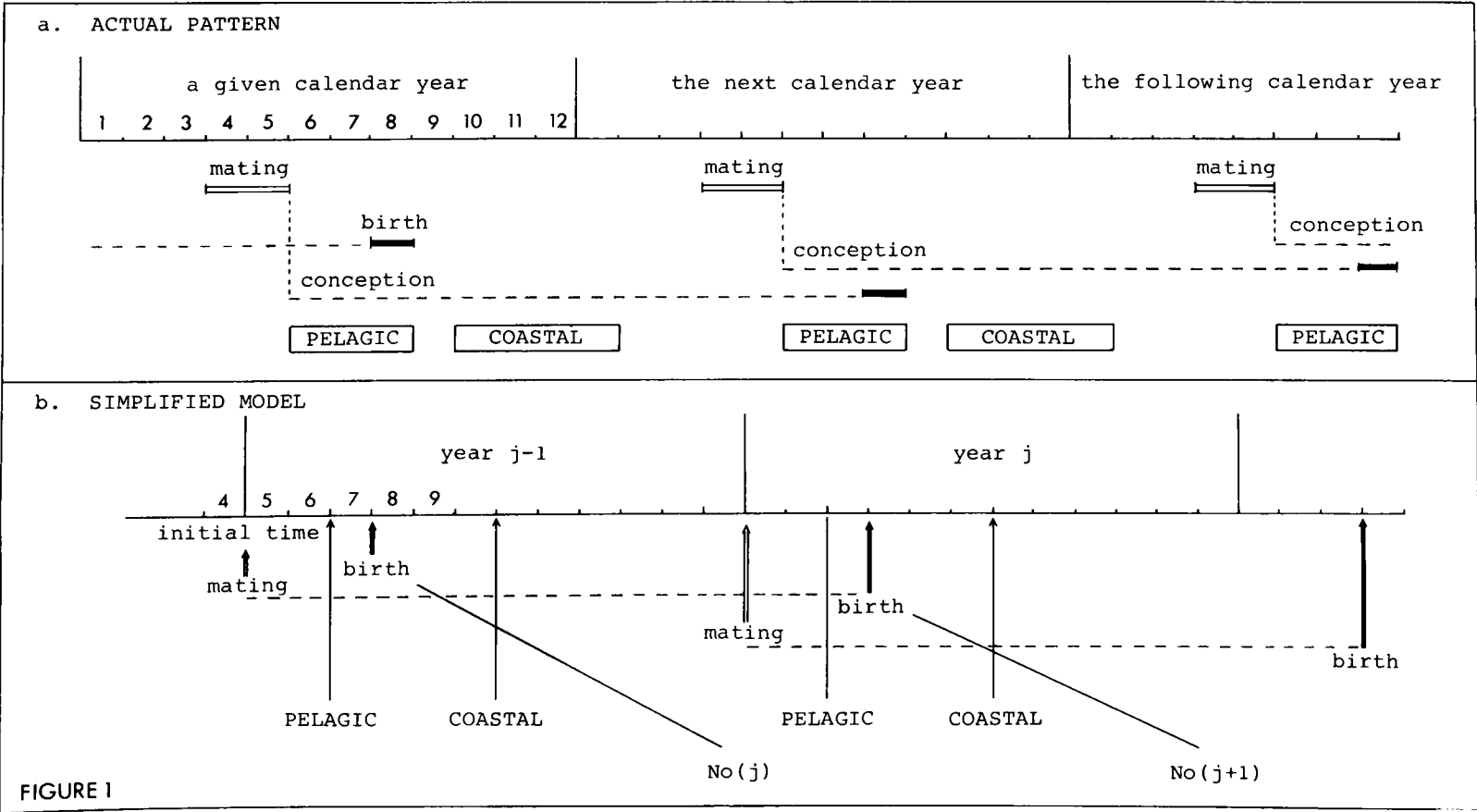


FIGURE 1

2. HOW TO CHANGE NATURAL MORTALITY, MATURITY, AVAILABILITY, AND PREGNANCY RATE BY AGE

In this paper we use the following notations and definitions:

Age: x (see Fig. 1 to understand exactly)
 $x_{\max} = 73$ years old.

Coefficient of natural mortality: $M(x) = \begin{cases} M' & \text{at } 0 \leq x \leq a \\ M & \text{at } a < x \end{cases}$
 (the same for both sexes)

Maturity function: $MTR(x) = \begin{cases} 0 & \text{at } x \leq b \\ \text{linear} & \text{at } b < x < c \\ 1 & \text{at } c \leq x \end{cases}$
 (differs by sex)

Availability function: $Q(x) = \begin{cases} 0 & \text{at } x \leq d \\ \text{linear} & \text{at } d < x < e \\ 1 & \text{at } e \leq x \end{cases}$
 (Differs by sex and the size limit)

Pregnancy rate: P
 (P is defined at birth)

The schematic models for the above equations are shown in Fig. 2. Natural mortality is considered a step function changing at age (a). Age-specific maturity is linear between age (b) when the first whale is mature and age (c) when all whales are mature. Age-specific availability is also linear between first availability at age (d) and full availability at age (e). The actual values of (a), (b), (c), (d) and (e) adopted in this paper are shown in Table 1. A generalised distribution pattern of the population by age in the sea showing the available and mature populations by age is given in Fig. 3.

3. ASPECTS RELEVANT TO HAREMS

A social structure based on a harem system is one of the most characteristic features of the sperm whale. Here we assume that one harem has 15 mature female whales and not 1 but 1.5×1.3 socially mature male whales in order to maintain a constant pregnancy rate with safety. If the number of mature males decreases below this value the pregnancy rate decreases linearly in proportion to the number of mature males.

4. CATCH

In the North Pacific the whaling pattern is not as simple as in the Antarctic minke whale fishery because there are both coastal and pelagic operations with different fishing seasons. Another problem is that although we can obtain the age composition for males from length data and an age-length key, females stop growing at an early age thereby making age determination of females extremely difficult by this method. The third problem is that exact catch data are not known for the early seasons and so the total catch has been divided into coastal and pelagic whaling and by sex in accordance with the ratios shown in Table 1.

5. POPULATION MODEL

By using the maturity and availability functions noted above a population model can easily be set up logically and biologically as follows:

$N_i(x)$: number of age- x in year i

$C_i(x)$: catch of age- x in year i

$B_i(x)$: available number of age- x in year i

$A_i(x)$: mature number of age- x in year i

$A_i(x) : N_i(x), MTR(x)$

$B_i(x) : N_i(x), Qi(x)$

Total number of available stock $B = \sum_x B_i(x)$

Total number of mature stock $A = \sum_x A_i(x)$

The calculation for the next year is:

$N_{i+1}(x+1) = (N_i(x) - C_i(x)) e^{-M(x)}$

assuming only a short whaling season in one year.

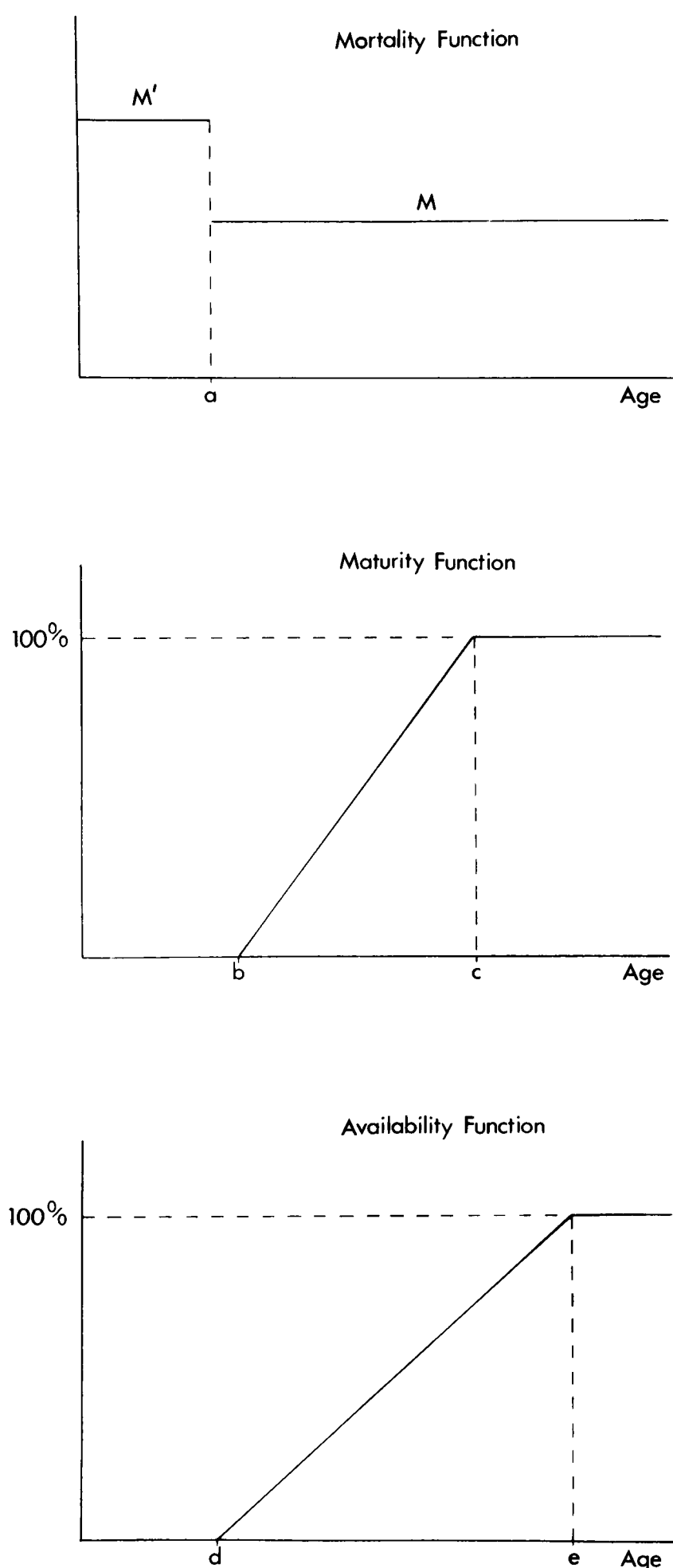


Fig. 2. Change in natural mortality, maturity and availability with age.

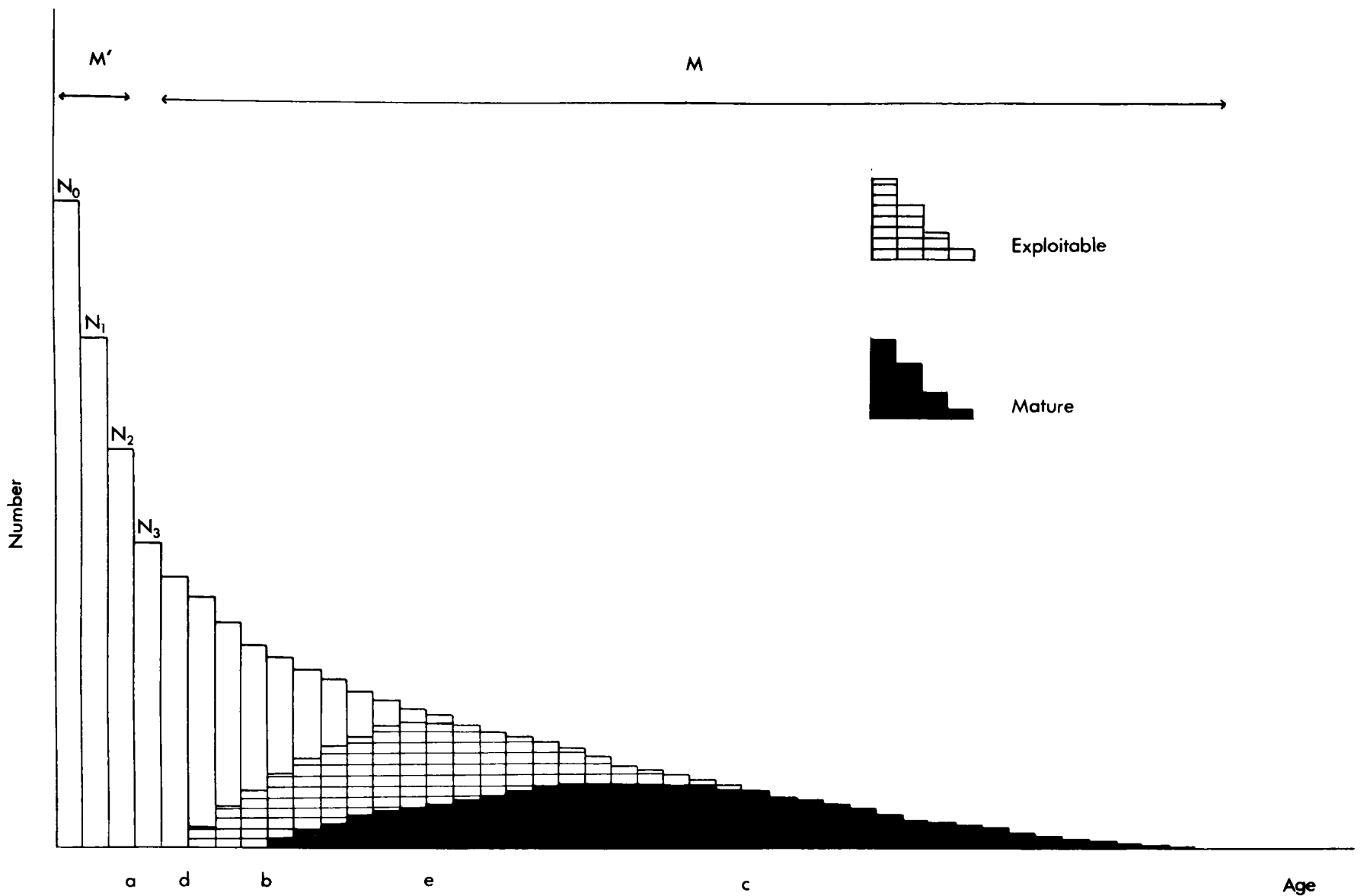


Fig. 3. Generalized population composition showing the mature population and exploitable population, and the parameters given in Fig. 2.

The number of 0-age in year $(i + 1)$ is:

$$N_{i+1}(0) = \sum_x P\{N_i(x) - C_i(x)\} MTR_i(x) e^{-M}$$

This is the basic principle of the model but we must describe this in detail month by month, because of the complex relationship between the whaling season and life cycle (Fig. 1).

However, the thinking behind the equation is very simple, and therefore we can set up adequate models and equations for practical use.

The following points should be noted:

(a) Catch $C_i(x)$

$C_i(x)$ is not completely derived from direct observations, (especially the age composition of females) and in this report we must assume that it is proportional to the exploitable female stock. The size composition of males is converted into an age composition using an age-length key.

(b) Whaling season and catch allocation

The whaling season is represented by T1 (pelagic) and T3 (coastal) as shown in Fig. 1. T1 and T3 are not constant but change by year. In addition to this the ratio of the catch of T1 to the total is not constant either. T1, T3 and the ratio are shown in Table 1.

(c) Legal size limit

The legal size limit is an important factor for the Q function, and therefore greatly influences the exploitable stock size. Sometimes the calculated number of the

exploitable stock suddenly apparently falls or rises and this can be attributed to changes in the legal size limit.

(d) Males and females

The sex ratio at birth in the calculation is 1:1. First we calculate the number of females and then males in a given year and then we calculate for the following years.

6. EQUILIBRIUM CONDITION (WITH NO CATCH)

Given that the population is stable in the initial year, the relationship between the population parameters will be as above. The equilibrium condition can be derived from the following:

Number of adult females at the beginning of May

$$A = \sum_x A(x) = \sum_x N_f(x) MTR(x) \\ = \text{Nof} \sum_x [e^{-\sum_x M(x)} MTR(x)]$$

Number of births (both sexes combined) at the beginning of August.

$$\text{No} = A P e^{-\frac{3}{12} M} \\ = \text{Nof} P e^{-\frac{3}{12} M} \sum_x [e^{-\sum_x M(x)} MTR(x)]$$

Number of 0-age females of $\text{Nof} = \frac{\text{No}}{2} e^{-\frac{2}{12} M'}$

$$\therefore \frac{1}{2} P e^{-(\frac{3}{12} + \frac{2}{12} M')} \sum_x [e^{-\sum_x M(x)} MTR(x)] = 1$$

The above equation is the equilibrium condition for the sperm whale. The calculated results are shown in Table 2¹ for several conditions of the initial year as shown in Table 1. The natural mortality coefficient of juveniles (M') should be larger than that of adults (M). Those values marked with an asterisk are reasonable and those without are not, on this basis.

For the rest of the calculations in this paper we adopt the values of $M = 0.060$, $M' = 0.09603$ and $P = 0.25$ from Table 2.

7. YEARLY CHANGE IN THE TOTAL NUMBER OF WHALES IN THE SEA, THE EXPLOITABLE STOCK SIZE AND THE MATURE STOCK SIZE

We carried out calculations for the total sperm whale stock in the North Pacific. Yearly changes in the total number in the sea, the exploitable stock size and the mature stock size can be calculated successively and transiently from the population model described in the previous section and recruitment and rate of recruitment are easily obtained. In actually carrying out the calculations, an assumption about the exploitable stock size in the initial period is necessary. Here we try five situations for the initial year, 1910; 10×10^4 ; 15×10^4 ; 20×10^4 ; 25×10^4 and 30×10^4 females in equilibrium state in the initial year.

The results are summarised in Fig. 4, from Phase 2 of DOIPOP-SP. Looking at these results, some values for the exploitable population are negative in recent years, if a small initial exploitable stock size is adopted. This is clearly unreasonable and unrealistic. When under this condition of 'catch > available' the curves in Fig. 4 are not complete until the recent year. Therefore such a value for the initial abundance must be rejected. Comparison of the theoretical age composition with the actual age distribution of the catch is one method of verification of DOIPOP-SP.

8. ESTIMATION OF POPULATION SIZE

Estimations of the population size can be made by verification of the assumed values adopted for the exploitable stock size in the initial year. To do this, actual male age distributions are compared with calculated ones for several years by a visual (graphical) method and by using the χ^2 test. (Table 3 shows the age distribution of the actual catch and the theoretical age composition of the exploitable stock for each situation as obtained from PHASE 2, for 1977 as an example).

Fig. 5 shows a graphical comparison of them and clearly indicates that situations 15×10^4 and 30×10^4 do not fit as well as situations $20 - 25 \times 10^4$

General trends in the exploitable stock during recent years, for example is it decreasing, stable or increasing, is another possible method or verification. General trends as shown in Fig. 4 are also useful for verification, if any independent information about sperm whales (e.g. sighting by scouting boats) is available.

From the above results situations 20×10^4 or 25×10^4 seem to be the most likely. This means that the exploitable female stock in 1977 in the total North Pacific is between 176,000 and 226,000 and the exploitable male stock is between 168,000 and 229,000.

¹The calculation programme in this report is called DOIPOP-SP. Table 2 is Phase 1 of DOIPOP-SP.

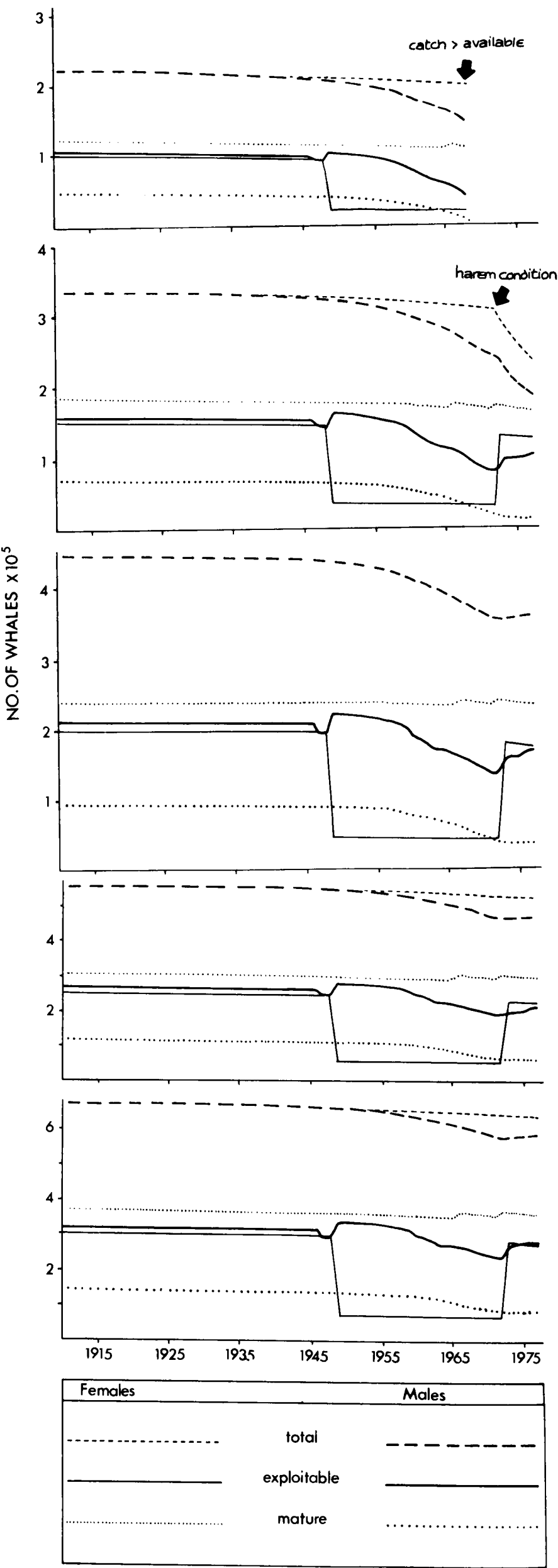


Fig. 4. Results from five situations, from top to bottom: initial exploitable populations of 100,000; 150,000; 200,000; 250,000; 300,000.

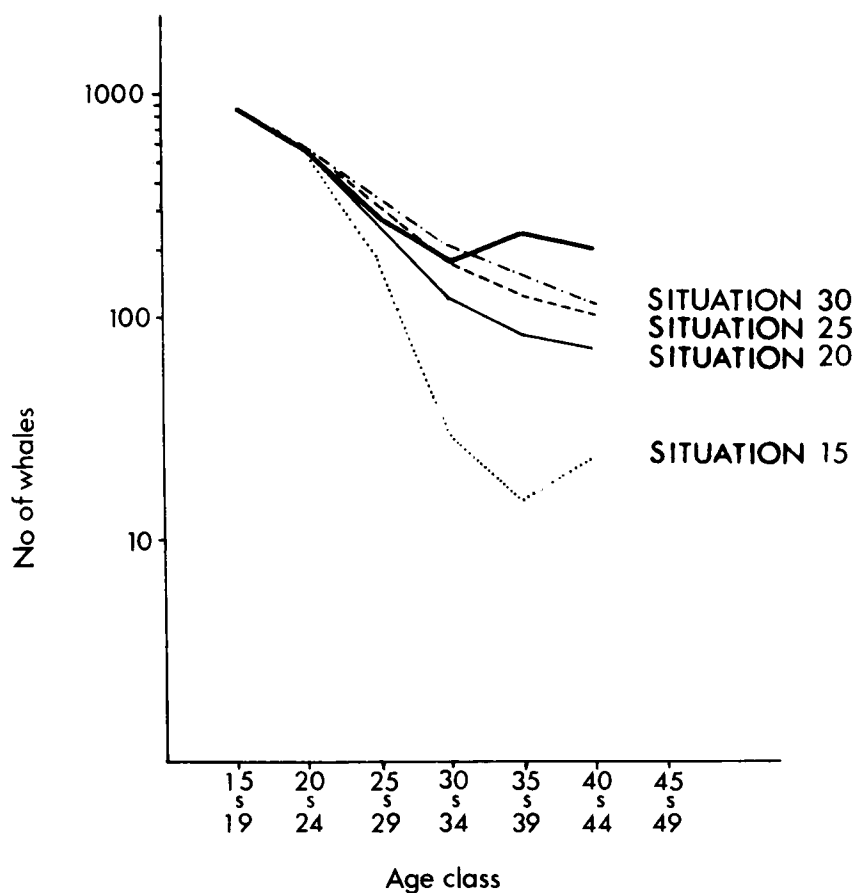


Fig. 5. Comparison of the actual age distribution of the catch with the expected distribution from the four situations.

9. FUTURE TRENDS AND THE REPLACEMENT YIELD

In Phase 2 of DOIPOP–SP, calculations are carried out from 1910 to 1977. The next problem is how the population will change in the future as a result of catches after 1978. Assuming various values for the exploitation the population size in the following years can be predicted using the same model. The results are summarised in Table 4 which is Phase 3 of DOIPOP–SP. The replacement yield and rational exploitation rate can easily be found by examining these results and selecting the rate at which exploitable numbers do not vary widely after 1977.

The estimated replacement yield for each situation is shown in Table 5 and from this the replacement yield is about 1,500 females and 6,000 males.

The replacement yield of females is less than that of males because it is near to the virgin stock level shown in Fig. 4.

SUMMARY

- (1) The DOIPOP–SP population model is simple and logical. It does not require the use of catching efforts which are always uncertain in whaling and thus any regression analysis concerning effort and CPUE can be excluded.

DOIPOP was originally formulated for minke whales. DOIPOP–SP is for sperm whales which have a more complicated behaviour than baleen whales, as shown in Fig. 1 and thus the model is a little more complex.

- (2) Phase 1 of DOIPOP is the relationship between juvenile and adult natural mortality. Phase 2 is the yearly change in the total population in the sea, the exploitable stock size, the mature stock size, the number of recruits etc.
Phase 3 examines future trends and the replacement yield.
- (3) Verification can be carried out by comparing the actual age distribution (in the catch) with the theoretical age composition of the exploitable population.
- (4) Calculations were carried out for female and male sperm whales in the North Pacific. The age-specific availability function, mortality function and pregnancy rate are shown in Fig. 2 and Table 1.
- (5) The output of Phase 1 is given in Table 2, summarised results from Phase 2 are given in Fig. 4 and the summarised output from Phase 3 is given in Table 4. Calculations were made for five situations: the initial available numbers of females in 1910 as 10×10^4 ; 15×10^4 ; 25×10^4 and 30×10^4 .
- (6) Situation 10×10^4 was clearly rejected because of negative age composition in recent years and situations 15×10^4 and 30×10^4 were rejected after comparison with actual age data from the catch.
- (7) The estimated exploitable stock size and replacement yield are shown in Table 5 and summarised results in Table 6.
- (8) Sightings data could be another independent method of verification.
- (9) From the results, the status of the sperm whale in the North Pacific in 1977 seems to be:

Population size	{ female	411,000 – 525,000
	{ male	376,000 – 474,000
Mature stock	{ female	176,000 – 226,000
	{ male	168,000 – 229,000
Exploitable stock	{ female	232,000 – 297,000
	{ male	38,000 – 61,000
Replacement yield	{ female	1,500
	{ Male	6,000

REFERENCE

Doi, T. 1979. Theoretical aspects analysed by introducing age-specific maturity and age-specific availability into population analysis of minke whales in the Antarctic. II *Rep. int. Whal. Comm* 29: 439–45.

Table 1

Biological parameters and whaling characteristics

Year	a	b _f	c _f	d _f	e _f	Q _{max}	b _m	c _m	d _m	e _m	p ²	T1	T3	Ratio ¹		Notes
														f	m	
1910	1	4	15	6	20	1.0	20	30	6	18	0.25	1	5	0.45	0.33	Equilibrium state (at case I)
1938																Size limit: 30 feet
1945																
1946	1	4	15	6	20	1.0	20	30	6	18	0.25			0.45	0.33	Equilibrium state (at case I)
1947				6	20	1.0				20						
1948				6	20	1.0				20						
1949				15	35	0.5				15					0.26	Size limit: 35 feet
1950														0.46	0.36	
1951														0.45	0.47	
1952														0.49	0.31	Size limits {coastal: 35 feet pelagic: 38 feet
1953												4		0.51	0.28	
1954														0.52	0.44	
1955														0.29	0.46	
1956														0.52	0.30	
1957														0.60	0.21	
1958														0.55	0.23	
1959									6	15				0.64	0.19	
1960									5	18				0.64	0.17	
1961										18			5	0.65	0.25	
1962										19		2	4	0.66	0.25	
1963										20		1	4	0.49	0.16	
1964										19			4	0.49	0.31	
1965			15										4	0.56	0.40	
1966			14										5	0.50	0.29	
1967													5	0.53	0.22	
1968													4	0.51	0.21	
1969													5	0.36	0.19	
1970														0.36	0.22	
1971			14						5					0.34	0.15	
1972			13	15	35	0.5			4	19				0.20	0.06	
1973				6	20	1.0				16		2		0.34	0.28	Size limit: 30 feet
1974										16		2		0.37	0.29	
1975										16		2		0.31	0.33	
1976										15		1	7	0.21	0.33	
1977	1	4	13	6	20	1.0	20	30	4	15	0.25	2	7	0.32	0.38	

¹Proportion of catch during T1 against total catch during T1 + T3.

²Pregnancy rate may change when the reserve male ratio falls below the given proportion.

Table 2

Relationship between maturity, pregnancy, and natural mortality¹

Natural mortality rate	Pregnancy rate						
	(0.100)	(0.150)	(0.200)	(0.250)	(0.300)	(0.350)	(0.400)
(0.040)	−0.05895	0.08849*	0.19310*	0.27424*	0.34054*	0.39660*	0.44515*
(0.045)	−0.10664	0.04080	0.14542*	0.22656*	0.29286*	0.34891*	0.39747*
(0.050)	−0.15214	−0.00470	0.09992*	0.18106*	0.24736*	0.30341*	0.35197*
(0.055)	−0.17560	−0.04816	0.05645	0.13760*	0.20390*	0.25995*	0.30851*
(0.060)	−0.23717	−0.08973	0.01489	0.09603*	0.16233*	0.21838*	0.26694*
(0.065)	−0.27698	−0.12954	−0.02493	0.05622	0.12251*	0.17857*	0.22713*
(0.070)	−0.31517	−0.16773	−0.06312	0.01802	0.08432*	0.14038*	0.18893*

¹Only asterisked juvenile mortality rates are acceptable.

Table 3
Comparison of actual catch with calculated available number in 1977

Age interval	Catch	Situation 15		Situation 20		Situation 25		Situation 30	
15-19	886	29,193	886	41,001	886	52,810	886	64,617	886
20-24	522	17,354	526	26,103	564	34,851	584	43,598	597
25-29	293	6,102	185	12,582	272	19,063	320	25,544	350
30-34	180	961	29	5,763	125	10,564	177	15,364	210
35-39	243	487	15	4,042	87	7,601	127	11,156	153
40-44	202	746	23	3,382	73	6,016	100	8,651	119

Table 4
Examples of the effect of different exploitation rates (ER) on population levels in future years under situation 20 × 10⁴

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
<i>(a) Males</i>										
Total population	361,039	360,762	360,187	359,365	358,334	357,123	355,758	354,264	352,661	350,965
Catch with ER 3.5%	5,937	5,596	5,974	5,989	6,002	6,012	6,019	6,023	6,025	6,023
Exploitable population	170,181	170,675	171,105	171,477	171,765	171,972	172,096	171,236	172,096	171,977
Effect	+	+	+	+	+	+	+	+	+	+
Total population	361,039	360,219	359,080	357,680	356,066	354,271	352,325	350,255	348,085	345,831
Catch with ER 4.0%	6,785	6,789	6,792	6,793	6,792	6,789	6,784	6,776	6,766	6,753
Exploitable population	169,729	169,792	169,816	169,804	169,733	169,604	169,411	169,148	168,818	168,418
Effect	+	+	+	-	-	-	-	-	-	-
<i>(b) Females</i>										
Total population	409,760	409,852	410,005	410,206	410,444	410,710	410,996	411,294	411,600	411,892
Catch with ER 0.5%	876	878	880	882	884	886	887	889	890	892
Exploitable population	175,639	176,019	176,401	176,775	177,133	177,471	177,781	178,064	178,325	178,552
Effect	+	+	+	+	+	+	+	+	+	+
Total population	409,760	409,240	408,756	408,302	407,872	407,461	407,063	406,676	406,296	405,922
Catch with ER 1.0%	1,753	1,751	1,750	1,749	1,749	1,748	1,747	1,747	1,746	1,745
Exploitable population	175,132	175,023	174,938	174,864	174,797	174,732	174,659	174,580	174,494	174,390
Effect	-	-	-	-	-	-	-	-	-	-

Table 5
Estimated replacement yield for the next 10 years for each Situation

Situation x 10 ⁴	Present available no. (at the end of 1977)	Exploitation rate	Replacement yield	Notes
10	-	-	-	Rejected by negative age distribution
15 [♀]	125,168	-	-	Rejected by verification of comparison
15 [♂]	106,926	-	-	between actual age composition and calculated age distribution
20 [♀]	175,275	0.5%-1.0%	879-1,753	Acceptable
20 [♂]	169,618	3.5%-4.0%	5,937-6,785	
25 [♀]	225,383	0.5%-1.0%	1,127-2,254	Acceptable
25 [♂]	231,193	3.0%-3.5%	5,780-6,936	
30 [♀]	275,492	0.5%-1.0%	1,377-2,755	Rejected by verification of comparison
30 [♂]	292,769	2.0%-2.5%	5,855-7,319	between actual age composition and calculated age distribution

Table 6
Summary Table of the estimated available number, mature number and raplacement yield

Situation		10 x 10 ⁴		15 x 10 ⁴		20 x 10 ⁴		25 x 10 ⁴		30 x 10 ⁴	
Catch > Available		×									
Harem condition		Δ		Δ							
		Available	Mature	Available	Mature	Available	Mature	Available	Mature	Available	Mature
Female	1910	10	12.3	15	18.4	20.0	24.5	25.0	30.6	30.0	36.8
	1946	9.6	11.8	14.6	17.9	19.6	24.1	24.6	30.2	29.6	36.3
	1960	2.1	11.3	3.4	17.5	4.6	23.6	5.8	29.7	7.0	35.9
	1970	1.9	10.9	3.1	17.2	4.3	23.5	5.5	29.8	6.8	36.1
	1973	8.1	10.8	13.1	17.3	18.1	23.8	23.2	30.3	28.1	36.8
	1977	7.5	9.7	12.6	16.7	17.6	23.2	22.6	29.7	27.6	36.2
Male	1910	10.6	4.7	15.8	7.0	21.1	9.3	26.4	11.7	31.7	14.0
	1946	10.0	4.3	15.3	6.7	20.6	9.0	25.8	11.3	31.1	13.7
	1960	8.1	3.1	13.5	5.4	19.0	7.8	24.5	10.1	29.9	12.4
	1970	3.6	0.3	8.6	2.3	13.9	4.7	19.2	7.0	24.5	9.3
	1973	4.8	0.2	9.7	1.5	15.6	3.8	21.6	6.2	27.6	8.5
	1977	5.3	0.2	10.6	1.4	16.8	3.8	22.9	6.1	29.1	8.4
Pattern check		×		×						×	
RY [♀] _♂		×				879–1,753 5,937–6,785		1,127–2,254 5,780–6,936		1,377–2,755 5,855–7,319	

× Rejected
Δ Harem condition is less than 1.5 x 1.3

On the Genetic Uniformity in the North Pacific Sperm Whale

Shiro Wada

Far Seas Fisheries Research Laboratory

ABSTRACT

Electrophoretic study of three genetic loci was performed to examine the genetic structure of the North Pacific sperm whale. Genetic control on three enzymes was elucidated by starch gel electrophoresis, and the most common allele, the N gene, was used as a genetic marker. The N gene frequency in each 10° square showed large fluctuations. Significant deviation from Hardy-Weinberg equilibrium was found more frequently than the expected frequency, which was apt to occur in a particular 10° square. The specimens from the lower central Pacific were considered to have been collected from a heterogeneous population. The idea of heterogeneity was also supported by the recent tag recapture data. More extensive population studies are needed for a thorough resolution of this problem.

INTRODUCTION

Many opinions have been put forward concerning the stock identification of the North Pacific sperm whale. Mitchell (1978) reviewed the previous studies and gave a synthetical conclusion. Earlier, Fujino (1963) had shown the occurrence of genetically isolated sperm whale stocks in the North Pacific, but his biochemical study was discontinued after that. In this study, the sperm whale has been examined with regard to population genetics using three enzymatic proteins. Recent tag recapture data has given some new information on the females' migration to the lower Pacific waters.

MATERIALS AND METHODS

Electrophoresis

Three enzymes were examined electrophoretically to detect genetic variations. These enzymes, 6-phosphogluconate dehydrogenase (6-PGD), sorbitol dehydrogenase (SDH) and α-glycerophosphate dehydrogenase (α-GDH), were chosen solely because of the good resolution and clarity of

banding. 6-PGD and SDH were isolated from cell-lysates of liver tissue diluted with an equal amount of distilled water, while α-GDH was isolated from that of skeletal muscle. These tissue specimens from sperm whales were collected in the Japanese North Pacific pelagic whaling ground in the summer seasons from 1974 to 1977. After the 1976 whaling season, sampling from all sperm whales caught became routine work on the factory ship deck. The number of specimens examined are shown in Table 1. Electrophoresis was performed in the same way as for the Antarctic minke whale (Wada and Numachi, 1979).

The reaction mixture for α-GDH was prepared according to Numachi (1971).

The system for allele nomenclature used in this study is as follows: the allele encoded with the molecule which is observed at the highest frequency in the population is called the 'N' gene. The other alleles were named according to the relative electrophoretic mobility of their products to that of the 'N' gene. If one variant allele produced a molecule migrating more anodally than that from the 'N' gene, it was called the 'F' gene, and if it migrated cathodally, it was called the 'S' gene.

Table 1
Number of sperm whale tissue specimens used in this study

Sampling season		6-PGD			SDH			α-GDH		
		Male	Female	Total	Male	Female	Total	Male	Female	Total
1974	May	19	27	46	15	4	19	—	—	—
	June	77	24	101	55	12	76	—	—	—
	July	32	16	48	19	8	27	—	—	—
	August	40	22	62	39	19	58	—	—	—
	Total	168	89	257	128	52	180	—	—	—
1975	May	2	—	2	2	—	2	—	—	—
	June	99	76	175	94	72	166	—	—	—
	July	43	18	61	42	16	58	—	—	—
	August	41	10	51	40	10	50	—	—	—
	Total	185	104	289	178	98	276	—	—	—
1976	May	—	—	—	—	—	—	—	—	—
	June	168	81	249	164	80	244	—	—	—
	July	125	266	391	116	258	374	—	—	—
	August	172	208	380	168	200	368	—	—	—
	Total	465	555	1,020	448	538	986	—	—	—
1977	May	18	28	46	18	28	46	24	57	81
	June	263	135	398	260	134	394	265	140	405
	July	320	65	385	315	65	380	320	67	387
	August	94	3	97	94	3	97	98	2	100
	Total	695	231	926	687	230	917	707	266	973
Grand total		1,513	979	2,492	1,441	918	2,359	707	266	973

Tagging

Ohsumi and Masaki (1977) reviewed Japanese marking data from 1949 to 1975. From 1976 to 1978, seven tags were recovered by Japanese whalers from one male and six female sperm whales. Two tags from the females and the one from the male were Russian. Details of these recovered tags are shown in Table 2. A total of fifty-three Russian tags (twenty-six from males and twenty-seven from females) recovered by Japanese whalers from 1963 to 1978 were also taken into consideration.

Polymorphism in SDH was more complicated than in 6-PGD. During the experiments on 2,359 specimens, three alleles (*Sdh^S*, *Sdh^N* and *Sdh^F*) were counted from five phenotypes designated as Forms S, S-N, S-F, N and N-F (Fig. 1). Form S and Form N, both having a single band, were interpreted as being homozygotes of the *Sdh^S* and *Sdh^N* genes respectively. Unlike 6-PGD, heterozygotes of SDH (i.e. Forms S-N, S-F and N-F) showed a five-banded pattern, which is clear evidence for a tetrameric structure of SDH.

Table 2
The list of marked sperm whales recovered by Japanese whalers in the North Pacific during years 1976-78

Tag No.	Sex	Date marked	Date recovered	Position marked	Position recovered
<i>Japanese tags</i>					
J 6407	F	6/8/55	9/6/76	41-16N, 150-00E	29-36N, 168-36E
J 6416	F	6/8/55	9/6/76	41-16N, 150-00E	29-30N, 168-33E
J 10423	F	18/5/67	16/8/76	48-00N, 177-56E	25-01N, 166-27W
J 11961	F	16/3/73	24/11/76	24-12N, 155-47E	36-54N, 143-01E
<i>Russian tags</i>					
610058	F	6/8/60	16/8/76	43-40N, 137-44W	25-01N, 166-28W
610206	F	17/8/63	29/7/76	38-54N, 142-50W	31-21N, 161-29W
651226	M	19/5/67	20/11/76	30-36N, 156-05E	36-37N, 142-29E

Chi-square test

Two different chi-square tests were applied in this study using the following formulae:

$$\chi^2_a = \sum_i \frac{(O_i - E_i)^2}{E_i} \text{ d.f.} = (n-1) - (k-1) \tag{1}$$

for detecting significant deviation from the Hardy-Weinberg equilibrium.

- where, O_i : observed phenotype frequency
 E_i : expected phenotype frequency
 n : the number of phenotypes
 k : the number of alleles

$$\chi^2_b = \frac{\sum_{i=1}^k 2 n_i (P_i - P_T)^2}{P_T (1 - P_T)} \text{ d.f.} = k - 1 \tag{2}$$

for detecting the significant difference in allele frequency among samples.

- where, n_i : the number of specimens in i sample
 p_i : allele frequency in i sample
 P_T : allele frequency in total samples
 k : the number of samples.

RESULTS

Protein polymorphisms

A total of 2,492 specimens were analysed for 6-PGD activity and were classified without exception into three distinct phenotypes, which were designated as Forms N, N-F and F (Fig. 1) based on the system of allele nomenclature described earlier. Form N had a single band and was interpreted to be a homozygote of the common allele, *Pgd^N* gene. Form F also had a single band which migrated more anodally than Form N, and was interpreted to be a homozygote of a variant allele, *Pgd^F* gene. The three-banded pattern of Form N-F which was interpreted to be a heterozygote between *Pgd^N* and *Pgd^F* genes indicates that the sperm whale 6-PGD has a dimeric structure as is the case for other vertebrates including man.

A total of 973 muscle specimens were examined for α -GDH and three phenotypes (Forms S, S-N and N) were observed among them (Fig. 2). In the case of α -GDH, the variant allele (*Gdh^S*) produced a more positively charged

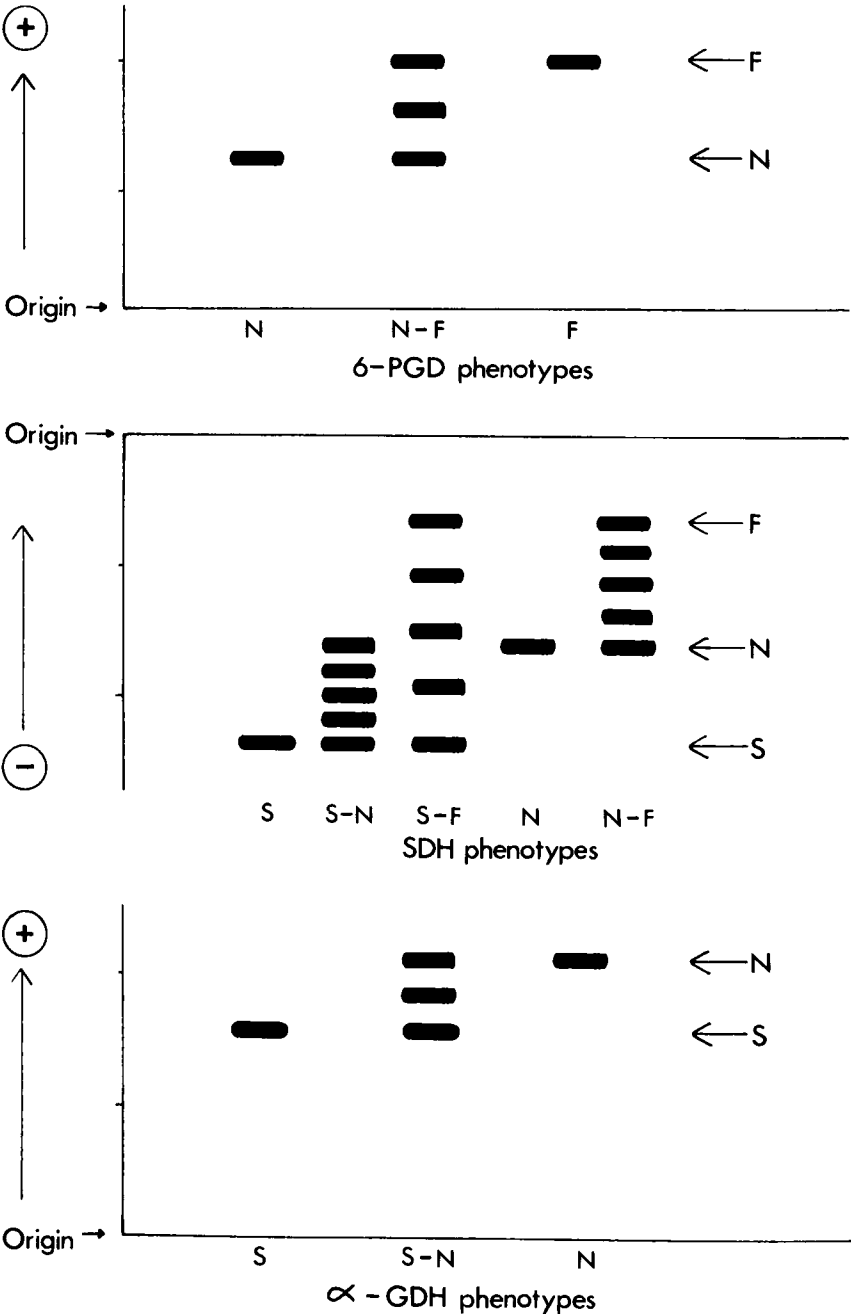


Fig. 1. Diagrammatic representation of phenotypic variation found in the North Pacific sperm whale.

molecule than that from the common allele (*Gdh^N*). A dimeric structure was also revealed in the heterozygous Form S–N.

Phenotype and allele frequencies of three polymorphic proteins found in the North Pacific sperm whale are shown in Table 3. No significant differences in N gene frequency between male and female whales were observed (chi-square value (χ^2_b) was 2.53 in 6–PGD, 1.27 in SDH and 0.86 in α –GDH). In addition, every homozygote of each allele appeared in both sexes. This indicates that there is no essential difference in the hereditary mechanism between male and female. Therefore, it is obvious that all sets of alleles in these three enzyme systems are located on an autosomal locus.

Geographic distribution of allele frequency

Allele frequencies of the N gene in the three enzymes calculated from the observed phenotype frequencies in each 10° square and the sample sizes are shown in Figs 2–7.

Insufficient samples from females from the American area were obtained and the majority of these were from the lower central Pacific (Figs 2–4). One sample from a female

taken in Square P 27 was included in Square P 28. Even for the males the sampling area did not cover the whole North Pacific (Figs 5–7). One sample from a male from Square P 29 was included in Square P 28. Genetic information from α –GDH is limited to within the lower central Pacific area since the sampling for skeletal muscle began in 1977 when the Japanese pelagic whaling ground had already moved into the Bryde’s whale grounds (Figs 4, 7). Except for a few squares from where less than 10 samples were taken, the observed range of the N gene frequencies were:

Proteins	Females	Males
6–PGD	0.800–0.956	0.794–0.917
SDH	0.417–0.614	0.348–0.600
α –GDH	0.500–0.518	0.461–0.650

No gradual change of N gene frequency is found except male α –GDH (Fig. 7) which shows a south-eastward cline from Square M 23. However, it is noteworthy that N gene frequencies of female 6–PGD and SDH both show the highest value in Square M25. A similar tendency is found for males in Square N 25. The lowest values of the N gene

Table 3a
Phenotype and allele frequencies for three enzymes in the North Pacific sperm whale
6–PGD

Sex		Phenotypes			Sample size	Alleles		χ^2_a (d.f. = 1)
		N	N–F	F		<i>Pgd^N</i>	<i>Pgd^F</i>	
Male	Obs.	1,138	346	29	1,513	.866	.134	0.22
	Exp.	1,135.7	350.4	26.9				
Female	Obs.	705	254	20	979	.850	.150	0.26
	Exp.	706.9	250.0	22.0				
Total	Obs.	1,843	600	49	2,492	.860	.140	0.00
	Exp.	1,842.6	600.6	48.8				

$\chi^2_b = 2.53$ (d.f. = 1)

Table 3b

SDH

Sex		Phenotypes						Sample size	Alleles			χ^2_a (d.f. = 3)
		S	S–N	S–F	N	N–F	F		<i>Sdh^S</i>	<i>Sdh^N</i>	<i>Sdh^F</i>	
Male	Obs.	365	673	7	385	11	0	1,441	.489	.505	.006	4.89
	Exp.	344.9	711.4	8.8	366.8	9.1	0.1					
Female	Obs.	243	419	12	237	7	0	918	.500	.490	.010	5.49
	Exp.	229.0	449.5	9.5	220.6	9.3	0.1					
Total	Obs.	608	1,092	19	622	18	0	2,359	.493	.499	.008	8.22
	Exp.	573.4	1,160.7	18.6	587.4	18.8	0.1					

$\chi^2_b = 1.27$ (d.f. = 1)

Table 3c

α –GDH

Sex		Phenotypes			Sample size	Alleles		χ^2_a (d.f. = 1)
		S	S–N	N		<i>Gdh^S</i>	<i>Gdh^N</i>	
Male	Obs.	167	358	182	707	.489	.511	0.12
	Exp.	169.3	353.3	184.4				
Female	Obs.	61	143	62	266	.498	.502	1.50
	Exp.	66.0	133.0	67.0				
Total	Obs.	228	501	244	973	.492	.508	0.86
	Exp.	235.2	486.5	251.3				

$\chi^2_b = 0.82$ (d.f. = 1)

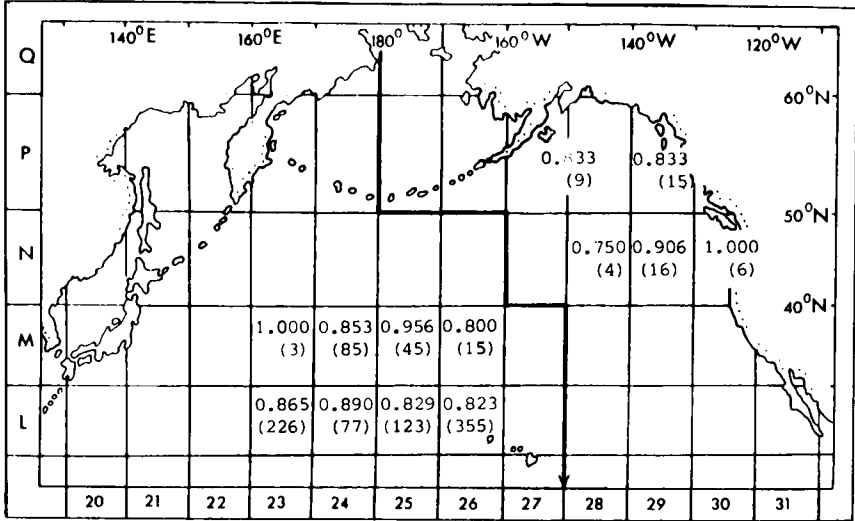


Fig. 2. Allele frequencies of 6-PGD-N gene and sample size (in parentheses) in female sperm whale.

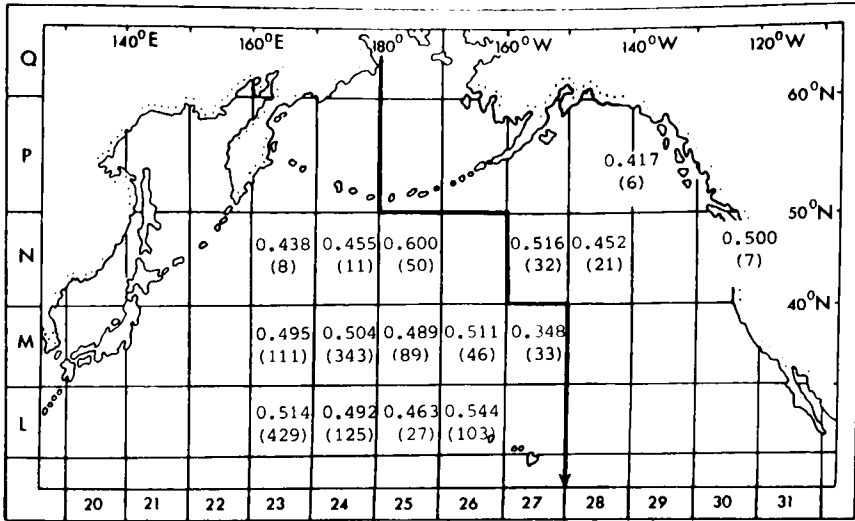


Fig. 6. Allele frequencies of SDH-N gene and sample size (in parentheses) in male sperm whale.

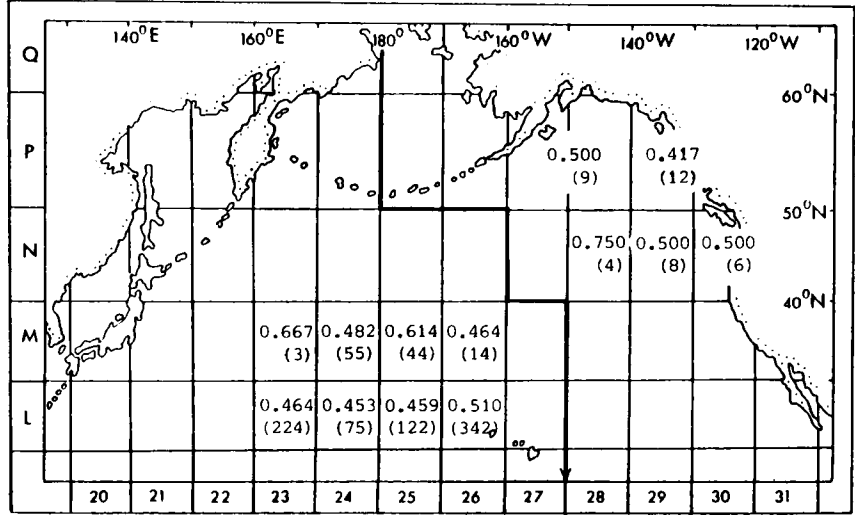


Fig. 3. Allele frequencies of SDH-N gene and sample size (in parentheses) in female sperm whale.

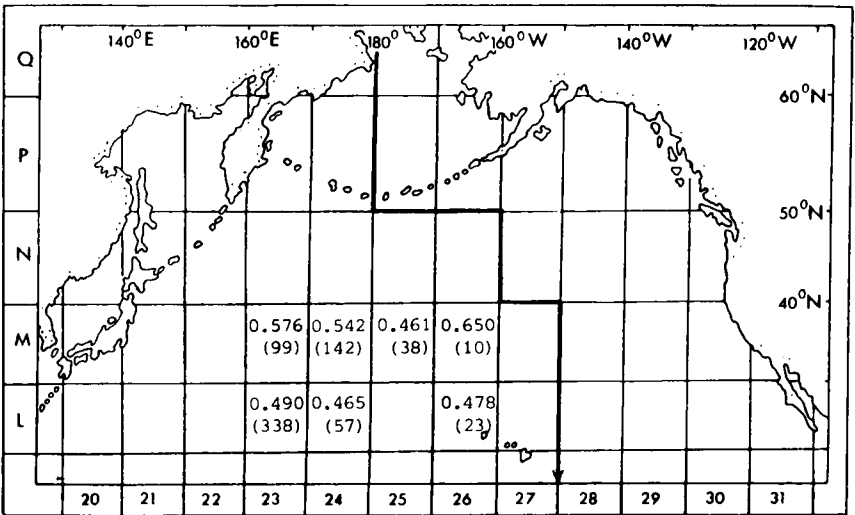


Fig. 7. Allele frequencies of α-GDH-N gene and sample size (in parentheses) in male sperm whale.

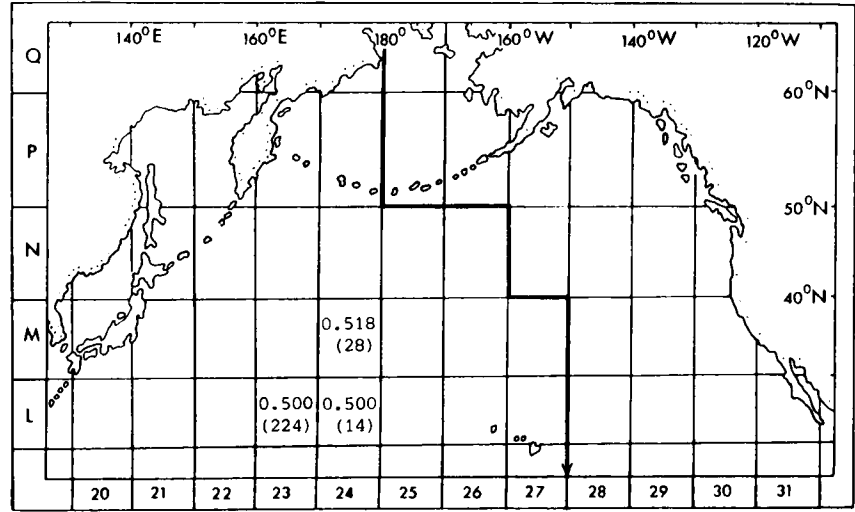


Fig. 4. Allele frequencies of α-GDH-N gene and sample size (in parentheses) in male sperm whale.

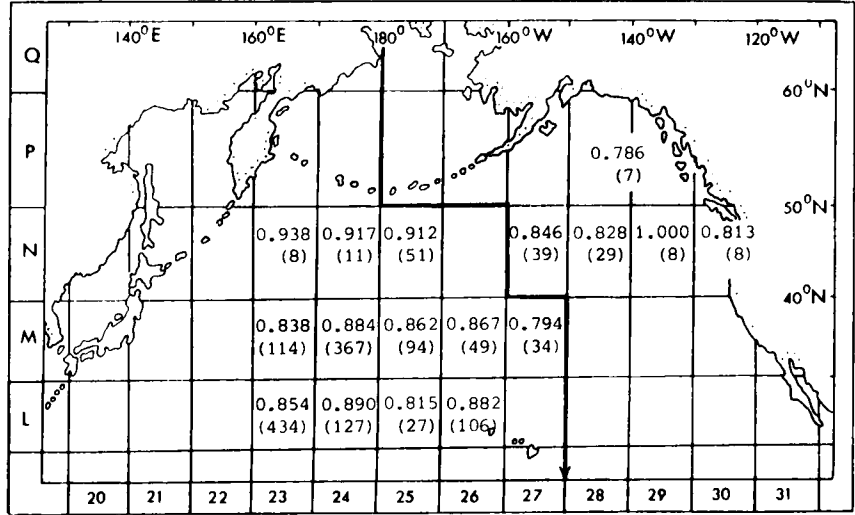


Fig. 5. Allele frequency of 6-PGD-N gene and sample size (in parentheses) in male sperm whale.

frequency for both 6-PGD and SDH in males are found in Square M 27.

Genetic uniformity
The non-gradual geographical distribution of the N gene frequency suggests the possibility of the existence of several populations in the North Pacific as a whole. Having confirmed that there is no significant difference in the N gene frequencies between male and female, genetic uniformity was examined separately by sex using the chi-square test (χ^2_a). This test is not sensitive if the expected frequency in a class is less than five and so two variant alleles of SDH were combined as *Sdh^V* to keep a sufficient number of individuals in each phenotype. Consequently, the number of phenotypes decreased from six to three (Forms N, N-V and V.), and the degrees of freedom (d.f.) also decreased from three to one.

(1) Females
N gene frequencies calculated from total samples (P_T) were 0.85 in 6-PGD, 0.490 in SDH and 0.502 in α-GDH. Supposing that all thirteen female samples were collected from one Mendelian population, the deviation between observed phenotype frequency and expected phenotype frequency calculated from P_T , was examined by 10° square using the chi-square test (χ^2_a). It was found that for several squares the P_T value was not acceptable as their gene frequency (Table 4). In Square M 25, the deviation was significant at the 1% level for both 6-PGD and SDH. Another significant deviation at the 1% level was found for the SDH sample in Square L23. Significant deviations in

Table 4
Summary of the data on the genetic uniformity of female sperm whales in the North Pacific

Protein	Deviated square			Whole North Pacific		Central Pacific area*		American area*
	Address	P _i	n _i	X _a ²	P _T	X _a ²	P _C	
6-PGD	M25	0.956	45	8.11‡	0.850	8.11‡	0.849	P _A = 0.870 ± 0.034 (n = 50)
	L25	0.829	123	3.96†		3.96†		
	L26	0.823	355	4.94†		4.61†		
SDH	M25	0.614	44	11.42‡	0.490	11.42‡	0.490	P _A = 0.500 ± 0.057 (n = 39)
	L23	0.464	224	12.74‡		12.74‡		
Uniformity				heterogeneous		heterogeneous		homogeneous

* According to the 30th IWC line.
† Significant at the 5% level.
‡ Significant at the 1% level.

6-PGD at the 5% level were found in Squares L 25 and L26. No significant deviation was found for α-GDH within three squares. For both 6-PGD and SDH, significant deviation was found in samples more frequently than the expected frequency ($13 \times 0.05 = 0.65$). Therefore the female samples tested are not considered to have been collected from a pure population. In order to clarify where major deviation occurs, the chi-square test (χ_a^2) was carried out on eight lower central Pacific samples and on five American samples separately, in accordance with the boundary line adopted at the 30th IWC meeting (IWC, 1979) and shown in Figs 2-7. Supposing that the two sample groups are from different Mendelian populations, the phenotype distribution of the American samples all showed a good fitness with the expected phenotype distribution for both 6-PGD and SDH. While remembering, as noted earlier, that the American sample size is too small for any firm conclusions to be drawn, at present, they can be considered to have been collected from a homogeneous population. The N gene frequency which represents the American population (P_A) was calculated as 0.870 ± 0.034 for 6-PGD and 0.500 ± 0.057 for SDh. On the other hand, for the lower central Pacific samples, the same result as before dividing the samples was obtained because the N gene frequency which represents the lower central Pacific samples (P_C) did not change at all for SDH and only changed very slightly (0.001) for 6-PGD when compared with P_T. Taking all this into account it seems clear that the major deviation in the females exists in the lower central Pacific samples, and they are considered to have been collected from a mixed (heterogeneous) population.

(2) Male

Genetic uniformity for the male samples was tested in the same way as for the female samples and they were also divided into American samples and lower central Pacific samples. The chi-square test (χ_a^2) was made before and after dividing the samples, but similar results were obtained since the difference between P_T and P_C is almost negligible. All the significant deviations were found at the 5% level except for the SDH samples from Square M27 where the deviation occurred at the 1% level. Significant deviations for 6-PGD were found in Squares N 25, M 23 and M 27, and for SDH in Squares N 24, N 25 and M 27 and even in the α-GDH samples, a significant deviation was found in Square M 23. As the significant deviations were found more frequently in the three enzymes than the expected frequencies (6-PGD and SDH : $12 \times 0.05 = 0.6$, α-GDH : $7 \times 0.05 = 0.35$), the male samples from the lower central Pacific area are considered to have been collected from a heterogeneous population. It is noteworthy that the samples from Squares N 25 and M 27 showed significant deviation in both 6-PGD and SDH. No significant deviations were found for the samples from the American area, and so they are considered to have been collected from a homogeneous population as in the case of the females. P_A is 0.846 ± 0.027 for 6-PGD and 0.485 ± 0.043 for SDH.

Tagging results

Ohsumi and Masaki (1977) illustrated the movements of marked sperm whales separately by sex using recovered Japanese tag data from 1949 to 1975. However, fifty

Table 5
Summary of the data on the genetic uniformity of male sperm whale in the North Pacific

Protein	Deviated square			Whole North Pacific		Central Pacific area*		American area*
	Address	P _i	n _i	X _a ²	P _T	X _a ²	P _C	
6-PGD	N25	0.912	51	6.11†	0.866	6.00†	0.868	P _A = 0.846 ± 0.027 (n = 91)
	M23	0.838	114	3.88†		4.26†		
	M27	0.794	34	4.31†		4.39†		
SDH	N24	0.455	11	4.70†	0.505	4.70†	0.506	P _A = 0.485 ± 0.043 (n = 66)
	N25	0.600	50	4.20†		4.20†		
	M27	0.348	33	13.42‡		13.42‡		
α-GDH	M23	0.576	99	4.25†	0.511	4.25†	0.511	
Uniformity				heterogeneous		heterogeneous		homogeneous

* According to the 30th IWC line.
† Significant at the 5% level.
‡ Significant at the 1% level.

Russian tags did not appear in their illustrations, and since 1976 four Japanese tags and three Russian tags have been recovered by Japanese whalers. Figs 8 and 9 show the revised illustrations taking into account fifty-three Russian tags and four Japanese tags in addition to the data used in the earlier paper. With regard to the Russian tags, thirteen of the twenty-six tags from the males were marked and recovered in the Japanese coastal area, as were twenty-one of the twenty-seven tags from the females, but the remaining six tags from females gave some new information about female movement in the lower latitudes of the Pacific. Of the three tags recaptured in Area IVC, two were Russian, one tag (No. 610058) from a female marked in Area IIB and the other (No. 610206) from a female marked in

Area IIIC. Another two Russian tags from females marked in Area IVC (No. 610440) and in Area VC (No. 650811) were recovered in the Japanese coastal area and one female (No. J10423) was found to have moved from VB to IVC. These results show that the discreteness of the female distribution is not as complete as it has been considered.

DISCUSSION

Heterogeneity in male and female sperm whales in the North Pacific which was suggested by recent marking data has been revealed by the current biochemical data. Considering the fact that homogeneity was found in the American samples for both sexes, in spite of the presence of

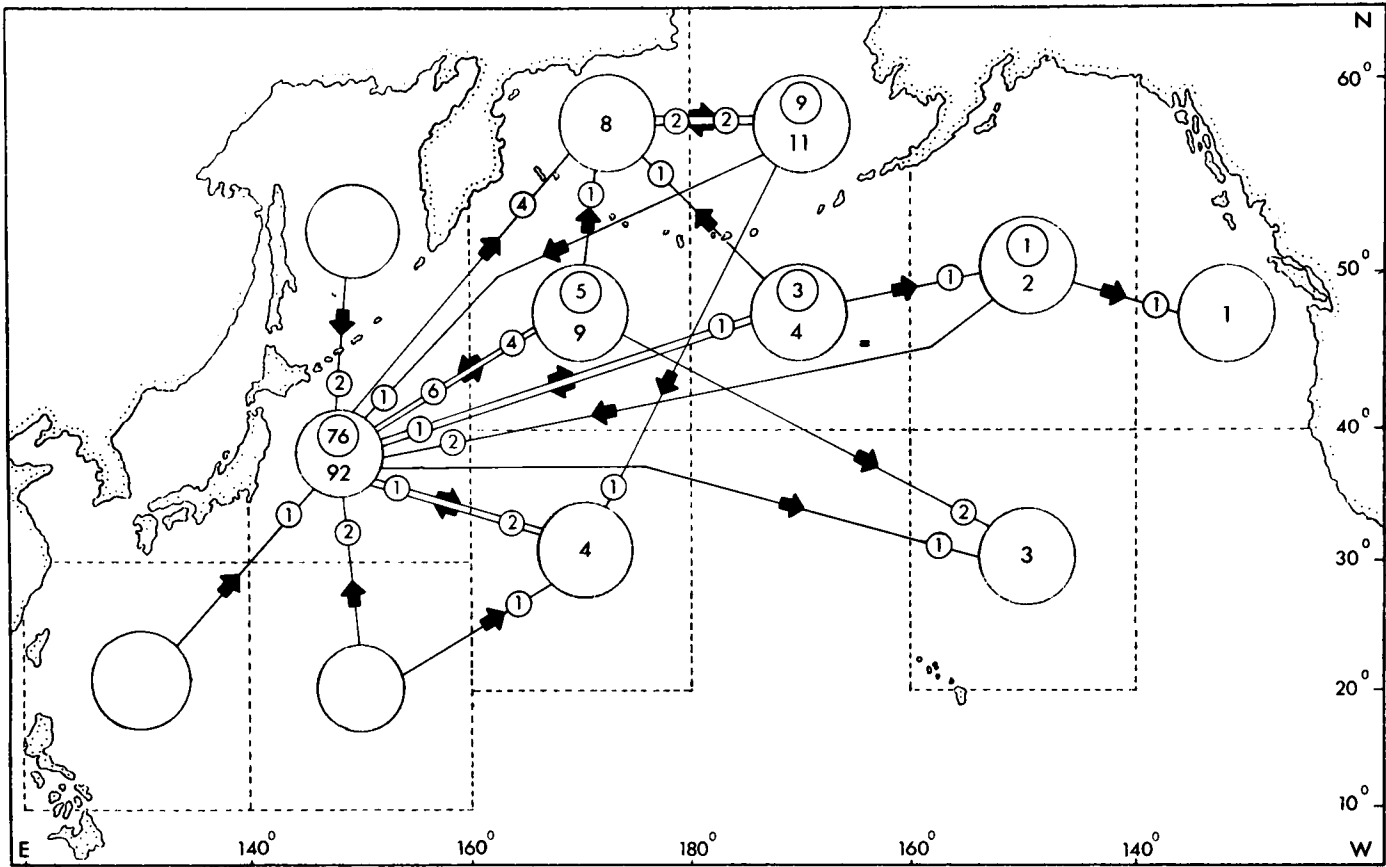


Fig. 8. Movements of marked male sperm whales. Numerals in large circle: Number of marked whales recaptured in each area. Numerals in small circle: Number recaptured in marked area. Numerals in small circle with arrow: Number of whales moved to different areas.

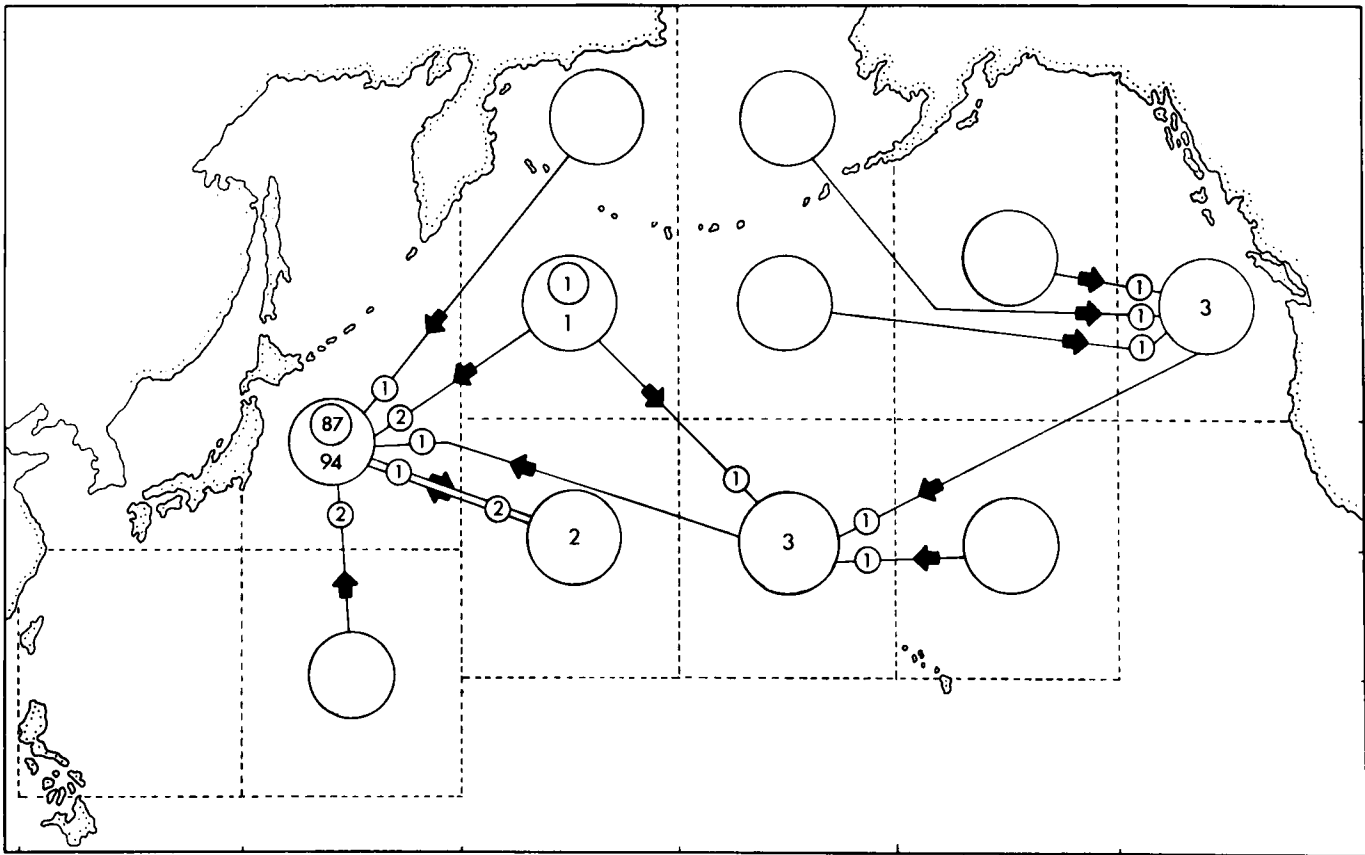


Fig. 9. Movements of marked female sperm whales. Notations are the same as in Fig. 8.

two Russian tags which showed movements from the American area to the lower central Pacific area, few of the lower central Pacific sperm whales are likely to migrate towards the American area. Heterogeneity in the lower central Pacific area can be attributed to whales migrating from the American, Aleutian and Japanese coastal areas. However, it was impossible from the current biochemical data to determine the number and the genetic structure of the populations present in the lower central Pacific area since pure samples from them were only obtained from the American stock. Samples from Japanese coastal whaling are now being collected, but considering the recent status of Japanese pelagic whaling it is unlikely that further information can be found for the Aleutian area. Although the propriety for the line adopted at the 30th IWC meeting could not be tested due to an insufficient number of samples from around the line, it seems rather appropriate for Square M 27 to be included in the lower central Pacific group. Anyway, it is notable that the N gene frequency in Square M 27 shows a very different value to those from adjacent squares for not only SDH but also for 6-PGD. Future examination of the samples collected in the 1978 whaling season from the lower American area and the Japanese coastal area will provide further information on the genetic structure of the North Pacific sperm whale.

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to Dr K. Numachi of the Ocean Research Institute, the University of Tokyo for his invaluable guidance. I also thank Miss M. Kubo and Mr S. Hisamatsu of Tokai University for their help with the electrophoretic analyses.

REFERENCES

- Fujino, K. 1963. Identification of breeding subpopulation of the sperm whales in the waters adjacent to Japan and around Aleutian Islands by means of blood typing investigations. *Bull. Jap. Soc. Sci. Fish.* 29 (12): 1057-63.
- Mitchell, E. 1978. Alternative interpretations of three stock units of North Pacific sperm whales, *Physeter catodon*. Paper SC/SPC/20 presented at the Special Meeting on North Pacific sperm whale assessments, Cronulla, 1977.
- Numachi, K. 1971. Genetic polymorphism of α -glycerophosphate dehydrogenase in Saury, *Coloabis Saira-I*. Seven variant forms and genetic control. *Bull. Jap. Soc. Sci. Fish.* 37: 755-60.
- Ohsumi, S. and Masaki, Y. 1975. Japanese whale marking in the North Pacific, 1963-72. *Bull. Far Seas Fish. Res. Lab., Shimizu*, 12: 171-219.
- Ohsumi, S. and Masaki, Y. 1977. Stock and trends of abundance of the sperm whale in the North Pacific. *Rep. int. Whal. Commn* 27: 167-79.
- Wada, S. and Numachi, K. 1979. External and biochemical characters as an approach to stock identification for the Antarctic minke whale. *Rep. int. Whal. Commn* 29: 421-32.

The Effect of Adult Sex Ratio and Density on the Fecundity of Sperm Whales*

R. M. May

Department of Biology, Princeton University, Princeton NJ 08540, USA

J. R. Beddington

Department of Biology, University of York, York YO1 5DD, UK

INTRODUCTION

In an earlier paper (Beddington and May, 1980) we derived a model for predicting the effect of changes in adult sex ratio and density on the fecundity of sperm whales. This model involved the assumption that socially mature whales search randomly for pods of females, that when a male finds a pod he stays with it for the duration of the breeding season and that all available females in the pods become pregnant. In this paper we consider a generalisation of this model which permits males to leave pods once they have been found, after some characteristic time has elapsed. Available females in pods which have males with them during the season are assumed to become pregnant.

In the first part of the paper the model form is described and the two limiting cases of this form are discussed. In the second part the implications of this model for the fecundity of sperm whales are presented and discussed. Appendix I gives the derivation of the model from its assumptions and Appendix II is a Fortran subroutine for calculating pregnancy rates for different input parameters of the model. This latter subroutine can be incorporated into both the SPDYN and SVAP programs for sperm whale assessment.

DEFINITIONS AND MODEL FORM

The notation of the model is that used in Beddington and May (1980) with some extensions.

$p_1(t)$ = Probability that an available female will not encounter a mature male and become pregnant up to time t .

$p_1(0)$

$p_1(T)$ = p_1 where T is duration of the breeding season.

n_1 = Number of pods of females.

η = Characteristic pod size.

N_1 = ηn_1 = Number of females.

$p_2(t)$ = Probability that a male is looking for a pod at time t .

$p_2(0) = 1$.

$p_2(T) = p_2$.

N_2 = Number of males.

r = N_2/n_1 = Number of males/number of female pods.

$a\delta t$ = Probability that a male finds a given female pod in interval δt .

$\lambda\delta t$ = Probability that a male leaves a given pod in the interval δt .

Two further parameter conglomerates are defined.

α = an_1T is the ratio between the length of breeding season and the typical time to encounter a pod ($\sim 1/an_1$).

β = λT is the ratio between the length of the breeding season and the average time a male spends with a pod ($\sim 1/\lambda$).

MODEL FORM

It is shown in Appendix I that the expression for p_1 is given by

$$p_1 = \frac{A - B}{(1 - B) \exp(r\alpha A) - (1 - A) \exp(r\alpha B)}$$

$$\text{with } A, B = \frac{(r - 1 - \beta/\alpha) \pm ((r - 1 - \beta/\alpha)^2 + 4r\beta/\alpha)^{1/2}}{2r}$$

Note that for $\beta \rightarrow 0$ the original form of the Beddington and May model is obtained with

$$\bar{p}_1 = (r - 1)/(r \exp((r - 1)\alpha) - 1)$$

and for $\beta \rightarrow \infty$

$$p_1 = \exp(-r\alpha) \\ = \exp(-aN_2T)$$

(This latter form is the other limit of the process and is the familiar expression for the proportional survival of prey subject to predation by N_2 predators with searching efficiency a for duration T , e.g. Rogers, 1972.) Biologically $\beta = 0$ implies the assumptions of the original Beddington and May model that once a male finds a pod he stays with it. $\beta = \infty$ implies that a male enters a pod and services all females in an infinitesimally small period of time. Together these two results span the mathematical possibilities for the process. Biologically the use of parameter values tending towards the (predator-prey) case is going to overestimate the pregnancy rate as it implies that males are able to spend an extremely short period of time with a pod, but still impregnate all available females. Hence if some allowance was made for this, the parameter values should be adjusted to be more similar to those of the original model.

DISCUSSION

Three parameters now determine the proportion of available females that get pregnant.

r The number of socially mature males per pod of females.

α Which may be thought of as being determined by the efficiency of males in finding females.

β The ratio of breeding season length to the characteristic time spent with a pod.

It is assumed that β is unaffected by changes in the population. As the population of females decreases so does α , similarly as the sex ratio of socially mature males to

*This research was completed with the aid of a grant from the Centre for Environmental Education, USA.

sexually mature females changes so does the parameter r . The values of r and α in the pre-exploitation state are given by the equilibrium solution to the dynamic equations describing the population process (Beddington and May, 1980). These equations determine r directly as

$$r = \eta S^{j-k}$$

where S is the yearly survival rate, j the age of social maturity in males and k the age of sexual maturity in females.

α is basically determined by noting that assumed pregnancy rates and survival rates in the unexploited stock do not produce an equilibrium. Usually the balance is achieved by changing the juvenile survival rate. The procedure used in Beddington and May was to calculate the value of α which will produce a particular value for p_1 at equilibrium. An alternative procedure is to set some arbitrary minimum level for p_1 and derive α values. Table 1 gives typical values of α obtained from this exercise.

Table 1

		β		
		100	10	1
P_1	0.05	0.729	0.764	0.842
	0.01	1.126	1.199	1.335
	0.005	1.297	1.391	1.55

In Beddington and May (1979) the α value used was 0.978 and of course $\beta = 0$.

Figs 1–3 illustrate the relationship between the probability of an available female getting pregnant and the sex ratio r (number of males per pod) for different values of α for the two extremes of the model. These figures may be compared with the model currently used in IWC assessments which has the pregnancy rate constant until a critical sex ratio is reached. Both extremes of the model of this paper allow reduced density of females to reduce the pregnancy probability by reducing α . Hence if α is approximately unity at equilibrium, reduction in female density to $\frac{3}{4}$ of the initial level will shift the pregnancy probability surface from Fig. 2 to Fig. 3. This change in female density has of course the effect of increasing the proportion of females available to get pregnant, hence both mechanisms will influence the observable pregnancy rate F . Figs 4–6 illustrate the change in pregnancy rate with the change in male and female mature population size. The expression used was

$$F = (1 - p_1) (p_0 + Q (1 - (\frac{N_1}{N_1^*})^Z))$$

where P_0 is the proportion of females available for pregnancy in the unexploited state of the female stock N_1^* . Q determines the pregnancy rate at the ‘zero’ population level and Z is the density dependent exponent. Note that as females are reduced the numerical values obtained for the two extremes become practically identical. This is an important result as together these models span a wide range of possible behaviour.

In conclusion we re-emphasise the central difference between the model of this paper and the one in current use by the IWC. Our model assumes a specific searching mechanism of males for females and notes how the

Figs 1–3. The relationship between the probability of available females becoming pregnant ($1 - p_1$) and the sex ratio r , defined as the number of males per female pod.
Dotted line: Beddington and May Model $\beta = 0$
Unbroken line: ‘Random Predictor Model’ $\beta = \infty$
Pod size $\eta = 10$.

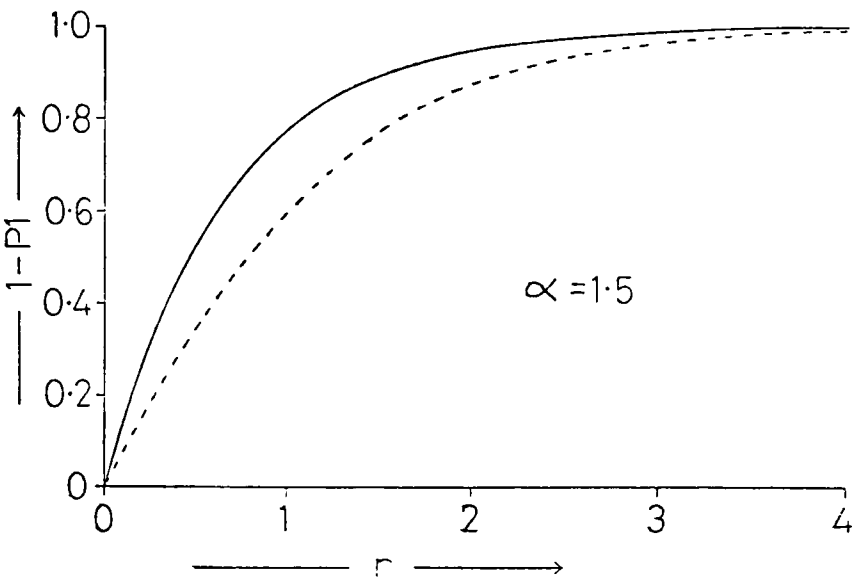


Fig. 1. $\alpha = 1.5$.

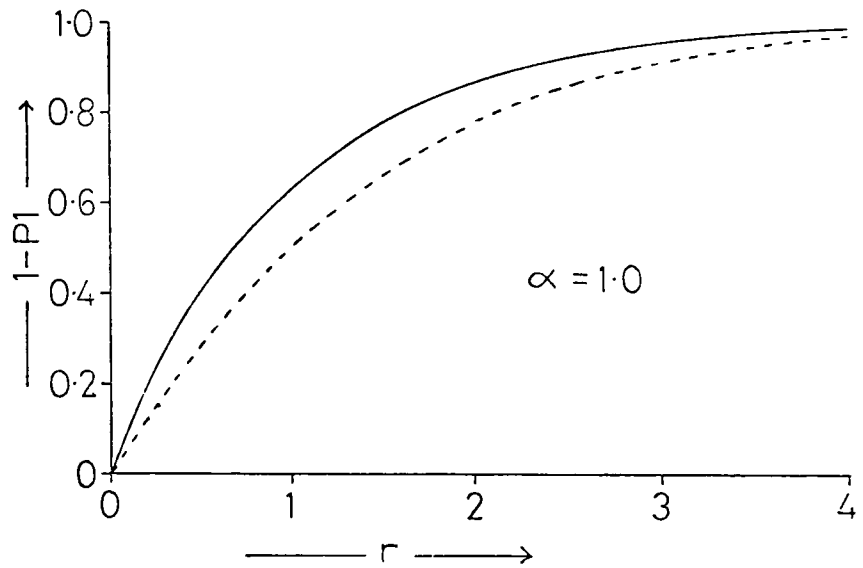


Fig. 2. $\alpha = 1.0$.

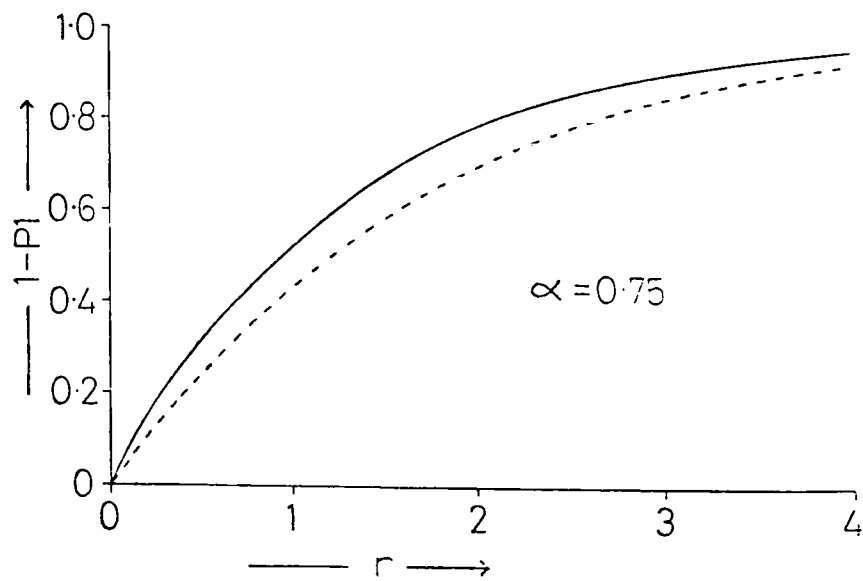


Fig. 3. $\alpha = .75$.

Figs 4–6. The relationship between observable pregnancy rate and the reduction in male socially mature and female sexually mature population sizes, assumes $p_1 = .18$ at an unexploited level. $S = .9428$, $p_0 = .21$, $Q = 104$, $k = 10$, $j = 25$, $Z = 2.39$, $u = 10$.

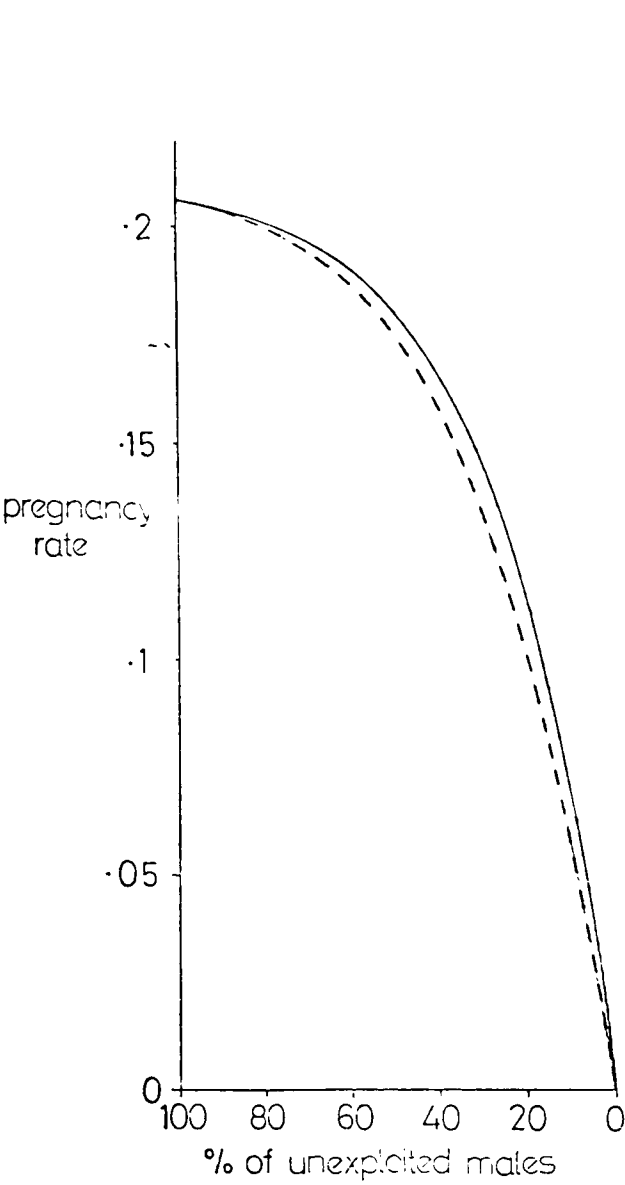


Fig. 4. Females at 100% of unexploited stock.

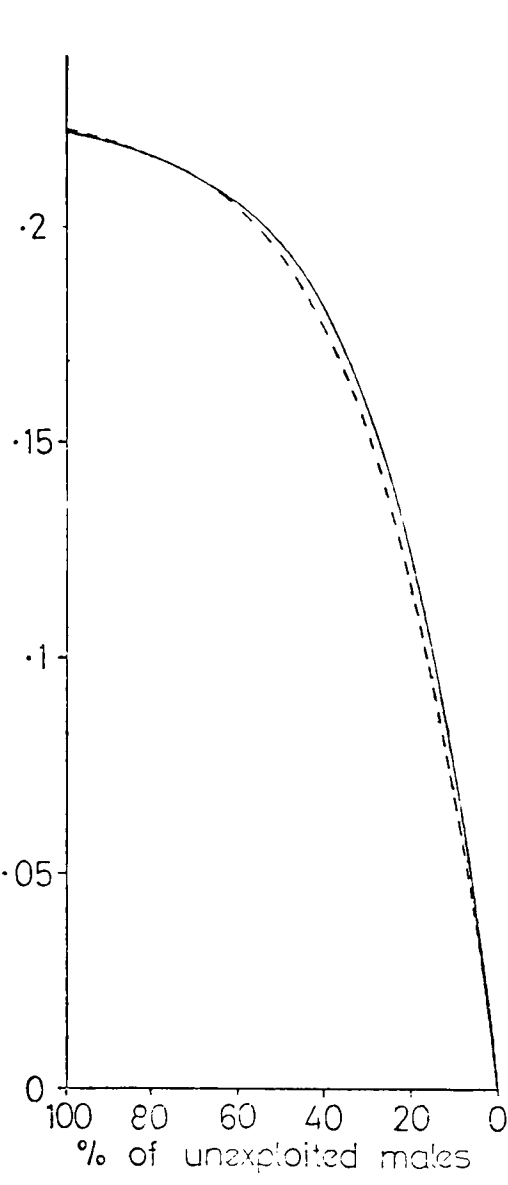


Fig. 5. Females at 80% of unexploited stock.

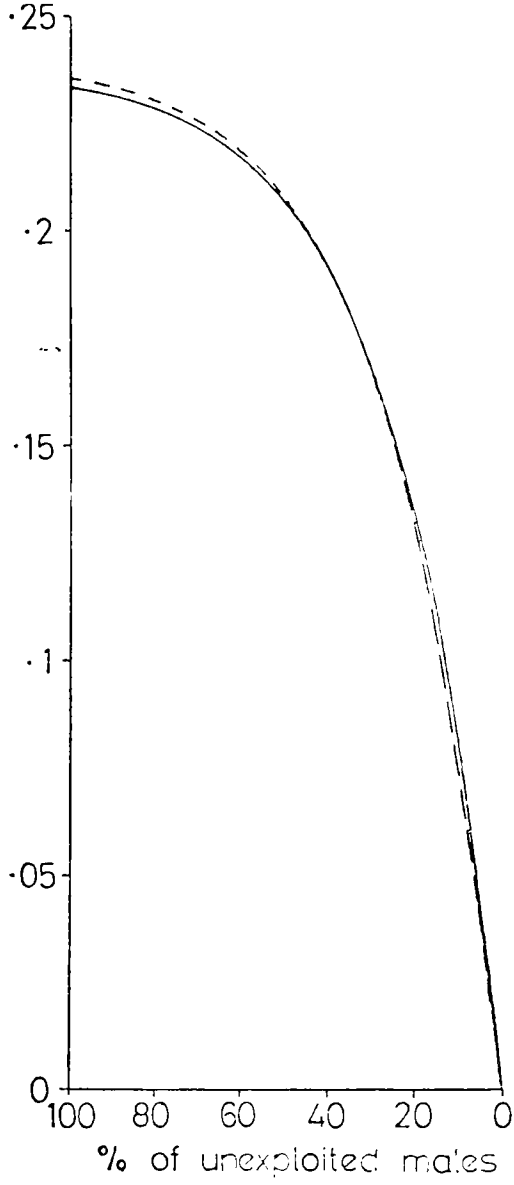


Fig. 6. Females at 60% of unexploited stock.

efficiency of this mechanism is lessened by reduction both in female density and in the ratio of males to females. The current IWC model involves no underlying mechanism and assumes that pregnancy rates fall only when socially mature males are reduced below a critical threshold.

REFERENCES

Beddington, J. R. and May, R. M. 1980. A possible model for the effect of adult sex ratio and density on the fecundity of sperm whales. Paper SC/30/Doc 4 (published in this volume).
Rogers, D. J. 1972. Random search and insect population models. *J. Anim. Ecol.* 41: 369–83.

Appendix I

By definition, the probability of a female not being pregnant at time $(t + dt)$ is (the probability of a female not being pregnant at time t) $\times$ (the probability of a pod not being found in dt).

Hence

$$p_1(t + dt) = p_1(t) [1 - adt(N_2 p_2)]$$

And in the limit

$$\frac{dp_1}{dt} = -aN_2 p_1 p_2 \quad (1)$$

Similarly, by definition, the probability that a male is looking for a pod at time $(t + dt)$ is (the probability that a male is looking at time t) $\times$ (the probability that a male does not find a pod in dt) + (the probability that a male is with a pod at time t) $\times$ (the probability that a male leaves a pod in dt).

Hence

$$p_2(t + dt) = p_2(t) \{ 1 - adt [n_1 - N_2 (1 - p_2(t))] \} + [1 - p_2(t)] \lambda dt$$

And in the limit

$$\frac{dp_2}{dt} = -ap_2 [n_1 - N_2 (1 - p_2)] + \lambda (1 - p_2) \quad (2)$$

Define

$$\alpha = an_1 t, \quad r = \frac{N_2}{n_1} \quad \text{and} \quad \beta = \frac{t}{1/\lambda}$$

Then from (1)

$$\frac{dp_1}{dt} = -rp_1 p_2 \quad (3)$$

And from (2)

$$\begin{aligned} \frac{dp_2}{dt} &= rp_2^2 + \left(r - 1 - \frac{\beta}{\alpha} \right) p_2 + \frac{\beta}{\alpha} \\ &= -r(p_2 - A)(p_2 - B) \end{aligned} \quad (4)$$

where A and B are the roots of

$$rp_2^2 - \left(r - 1 - \frac{\beta}{\alpha}\right)p_2 - \frac{\beta}{\alpha} = 0$$

$$\text{i.e. } A, B = \frac{r - 1 - \frac{\beta}{\alpha} \pm \sqrt{\left(r - 1 - \frac{\beta}{\alpha}\right)^2 + 4r \frac{\beta}{\alpha}}}{2r} \quad (5)$$

From (4)

$$\frac{dp_2}{(p_2 - A)(p_2 - B)} = \frac{dp_2}{A - B} \left[\frac{1}{p_2 - A} - \frac{1}{p_2 - B} \right] = -r dt$$

Integrating

$$\ln \left[\frac{p_2 - A}{1 - A} \cdot \frac{1 - B}{p_2 - B} \right] = -r\alpha(A - B)$$

$$\therefore \frac{p_2 - A}{p_2 - B} = \frac{1 - A}{1 - B} \exp[-r\alpha(A - B)] \quad (6)$$

$$\therefore \frac{p_2 - A}{1 - A} = \frac{(A - B) \exp(r\alpha B)}{(1 - B) \exp(r\alpha B) - (1 - A) \exp(r\alpha B)} \quad (7)$$

From (3)

$$\frac{dp_1}{p_1} = -rp_2 dt$$

From (4)

$$\frac{dp_2}{(p_2 - A)(p_2 - B)} = -r dt$$

$$\therefore -rp_2 dt = \frac{p_2 dp_2}{(p_2 - A)(p_2 - B)} = \frac{dp_2}{A - B} \left[\frac{A}{p_2 - A} - \frac{B}{p_2 - B} \right]$$

$$\therefore \frac{dp_1}{p_1} = \frac{dp_2}{A - B} \left[\frac{A}{p_2 - A} - \frac{B}{p_2 - B} \right]$$

Integrating

$$\ln(p_1) = \frac{A}{A - B} \ln \left[\frac{p_2 - A}{1 - A} \right] - \frac{B}{A - B} \ln \left[\frac{p_2 - B}{1 - B} \right]$$

$$\therefore p_1 = \left[\frac{p_2 - A}{1 - A} \right]^{\frac{A}{A - B}} \left[\frac{p_2 - B}{1 - B} \right]^{\frac{-B}{A - B}}$$

$$\therefore p_1 = \left[\frac{p_2 - A}{1 - A} \right] \left[\frac{p_2 - A}{p_2 - B} \cdot \frac{1 - B}{1 - A} \right]^{\frac{B}{A - B}}$$

Substituting from (6) and (7)

$$p_1 = \frac{(A - B) \exp(r\alpha B) \cdot \exp[-r\alpha(A - B)] \frac{B}{A - B}}{(1 - B) \exp(r\alpha A) - (1 - A) \exp(r\alpha B)}$$

$$\therefore p_1 = \frac{A - B}{(1 - B) \exp(r\alpha A) - (1 - A) \exp(r\alpha B)} \quad (8)$$

Appendix II

SUBROUTINE BMPR2(PUNEX, PZERO, P, S, AJ, Z, AFPROP, AMPROP, F)
COMMON/C1/A2, BETA, W

PUNEX is the pregnancy rate of the unexploited population.

PZERO is the pregnancy rate at 'zero' population level.

P is the mean pod size.

S is the yearly survivorship.

AJ is the age of female sexual maturity.

AK is the age of male social maturity.

Z is the exponent of density dependence.

AFPROP is the proportion of females of the unexploited stock.

AMPROP is the proportion of males of the unexploited stock.

All these are called from the main program.

F is the newly calculated pregnancy rate.

This is returned to the main program.

BETA is the ratio between the length of the breeding season and the average time spent by a male with a pod and must be stated in this subroutine.

BETA = 100.0

A1 = PUNEX * S ** AK

A2 = P * S ** (AJ - AK)

W = 1.0 - 2.0 * (1.0 - S) / A1

A3 = 1.0 + A1 * (A2 - 1.0) / (A2 * (A1 - 2.0 * (1.0 - S)))

SUBROUTINE ROOT is called to determine ALPHA at equilibrium.

CALL ROOT (ALPHA)

ALPHA = ALPHA * AFPROP

R = A2 * AMPROP / AFPROP

GAMMA = BETA / ALPHA

DELTA = R - 1.0 - GAMMA

A = (DELTA - SQRT(DELTA ** 2.0 + 4.0 * R * GAMMA)) / (2.0 * R)

B = (DELTA + SQRT(DELTA ** 2.0 + 4.0 * R * GAMMA)) / (2.0 * R)

P1 = (A - B) / ((1.0 - B) * EXP(R * ALPHA * A) - (1.0 - A) * EXP(R * ALPHA * B))

Q = PZERO - PUNEX

F = (1.0 - P1) * (PUNEX + Q * (1.0 - AFPROP ** Z))

RETURN

END

SUBROUTINE ROOT determines the root, Y, of the function described in FUNCTION FUNC.

SUBROUTINE ROOT (Y)

L0 = 0

S1 = 0.0

S2 = 0.1

S3 = 0.0001

100 DO 200 I=1,20

X1 = S1 + FLOAT(I) * S2

X2 = X1 + S2

F1 = FUNC(X1)

F2 = FUNC(X2)

PROD = F1 * F2

IF (PROD .LT. 0.0) GOTO 300

200 CONTINUE

```
300 IF (L0. EQ.1) GOTO 400
    L0 = 1
    S2 = S2/20.0
    S1 = X1-S2
    GOTO 100
400 X2 = X1+S3
    F1 = FUNC(X1)
    F2 = FUNC(X2)
    Y = X1-F1*S3/(F2-F1)
    ABS = ABS(Y-XI)
    IF (ABS. LT. 0.00001) GOTO 500
    X1 = Y
    GOTO 400
500 RETURN
    END
```

```
FUNCTION FUNC evaluates the function used by SUB-
ROUTINE ROOT.

FUNCTION FUNC(X)
COMMON/C1/A2, BETA, W
D = (A2-1.0 -BETA/X)**2.0 +4.0
*A2*BETA/X
U = (A2-1.0 -BETA/X-SQRT(D))/(2.0 *A2)
V = (A2-1.0 -Beta/X+SQRT(D))/(2.0 *A2)
FUNC = (U/V)/((1.0 -V)*EXP(A2*X*U)-(1.0
-U)*EXP(A2*X*V))-W
RETURN
END
```


North Pacific Sperm Whale Stock Identity: Distributional Evidence from Maury and Townsend Charts¹

John Bannister

The Western Australian Museum, Perth, Western Australia.

Edward Mitchell

Arctic Biological Station, Ste. Anne de Bellevue, Quebec, Canada.

ABSTRACT

We extracted North Pacific sperm whale data by month and five degree squares from the whale charts compiled by M. F. Maury (1851 *et seq.*) from early 19th century American pelagic whalers' logbooks. Indices were extracted representing the ratio between number of days spent searching for whales, and the number of days on which sperm whales were seen. Sperm whale catch positions by month were replotted from charts compiled by Townsend (1935). Results show discontinuous distributions of sperm whales during the peak breeding season (April–May) in the latitudes between 20°–40°N, as follows: west of 145°E ('Bonin Grounds'), 145°E–179°E ('Japan Grounds'), 179°E–150°W ('Hawaiian Grounds'). We conclude on this evidence that at least three, possibly more, stocks of sperm whales may exist in the North Pacific.

INTRODUCTION

Early large catches of sperm whales, *Physeter macrocephalus*, in the North Pacific may have had a substantial effect on population levels. 19th century pelagic whalers sailed throughout the Pacific. Modern commercial whaling in the North Pacific dates back to around the beginning of the 20th century, but major catches of sperm whales have been taken mainly since the Second World War. There have been trends in the area of catch. Early emphasis was on large bulls in the Bering Sea, but during the last one or two decades, catches have been restricted to the more southerly waters, with mixed catches of males and females. Comparisons of catches through time are thus rather difficult, especially since the sperm whale segregates seasonally by sex and/or by size.

Some knowledge of stock identity is required to even begin analysis of the impact that post Second World War catches have had on North Pacific sperm whales. Recent analysis of stock identity by the Scientific Committee of the International Whaling Commission (IWC, 1979; 1980) has recognized only two North Pacific stocks (modified from Ohsumi and Masaki, 1977), an Eastern and a Western stock, divided first by the 'Cronulla Line', and then by the 'Cambridge Line' (of Fig. 1). However, other authors (Masaki, 1970; Tillman, 1977; Mitchell, 1977Ms) have suggested that there might be three or more North Pacific stocks.

Berzin (1972, pp. 161–3) summarized earlier work and the evidence for one, two or more stocks of North Pacific sperm whales, and on the basis of shipboard observations of whale movements (Berzin and Rovnin, 1966), concluded that there were many small local groupings organised into three major herds orientated along migration routes. Fujino (1963) used blood typing data to show that there were different breeding populations in waters adjacent to Japan and around the Aleutian Islands.

The International Whaling Commission's Scientific Committee initially established a separate North Pacific Working Group to deal with sperm whale and other problems in the Pacific. Three breeding stocks were recognised in the North Pacific by IWC Scientific Committee meetings from Seattle in 1963, and subsequently until 1970

(IWC, 1971, p. 41). Masaki (1970Ms) reviewed data from marking, blood typing (e.g. Fujino, 1963), catch distributions, sightings and size composition, and recognised three stocks centered as follows (as quoted by Tillman, 1977, p. 343; and see Best, 1974, p. 258):

West of 170°E – including coastal water of Japan, Kuril Islands and Kamchatka;

East of 150°W – including the Gulf of Alaska and North American coastal waters;

180° – 160°W – including the central North Pacific and Aleutian Islands.

However, the IWC sperm whale assessment meeting in 1972 at Parksville did not use these or any other separate stock units for the North Pacific (IWC, 1973). Tillman (1977) adapting Masaki's results and recognising three stock areas, modified them to accord with recent catch history and recent recoveries of sperm whales marked in North American coastal waters. Using the IWC terminology for 10° squares (Fig. 1), the stock areas used by Tillman (and Tillman and Breiwick, 1977), and adopted at the Sperm Whale Meeting in 1976 in La Jolla (IWC, 1977), were:

Asian	–	P21–23
		N20–22
		M19–21
		L19–20
Central	–	P24–26
		N23–28
		M22–29
		L21–31(?)
American	–	P27–30
		N29–30
		M30–31

Ohsumi and Masaki (1977) reviewed data on catch distribution, marking, catch per unit effort and pregnancy rates as bearing on the recognition of stock units. They concluded that females can be separated into two stocks:

Western	–	W of 160°W
Eastern	–	E of 160°W

but that males intermingle in the northern and central parts of the North Pacific. They regarded Masaki's (1970) central

¹ Revised and reviewed; based on IWC SC/SPC/20 (by Mitchell) from Cronulla meeting, November 1977, and IWC SC/SP78/16 (by Bannister and Mitchell) from La Jolla meeting, November–December 1978.

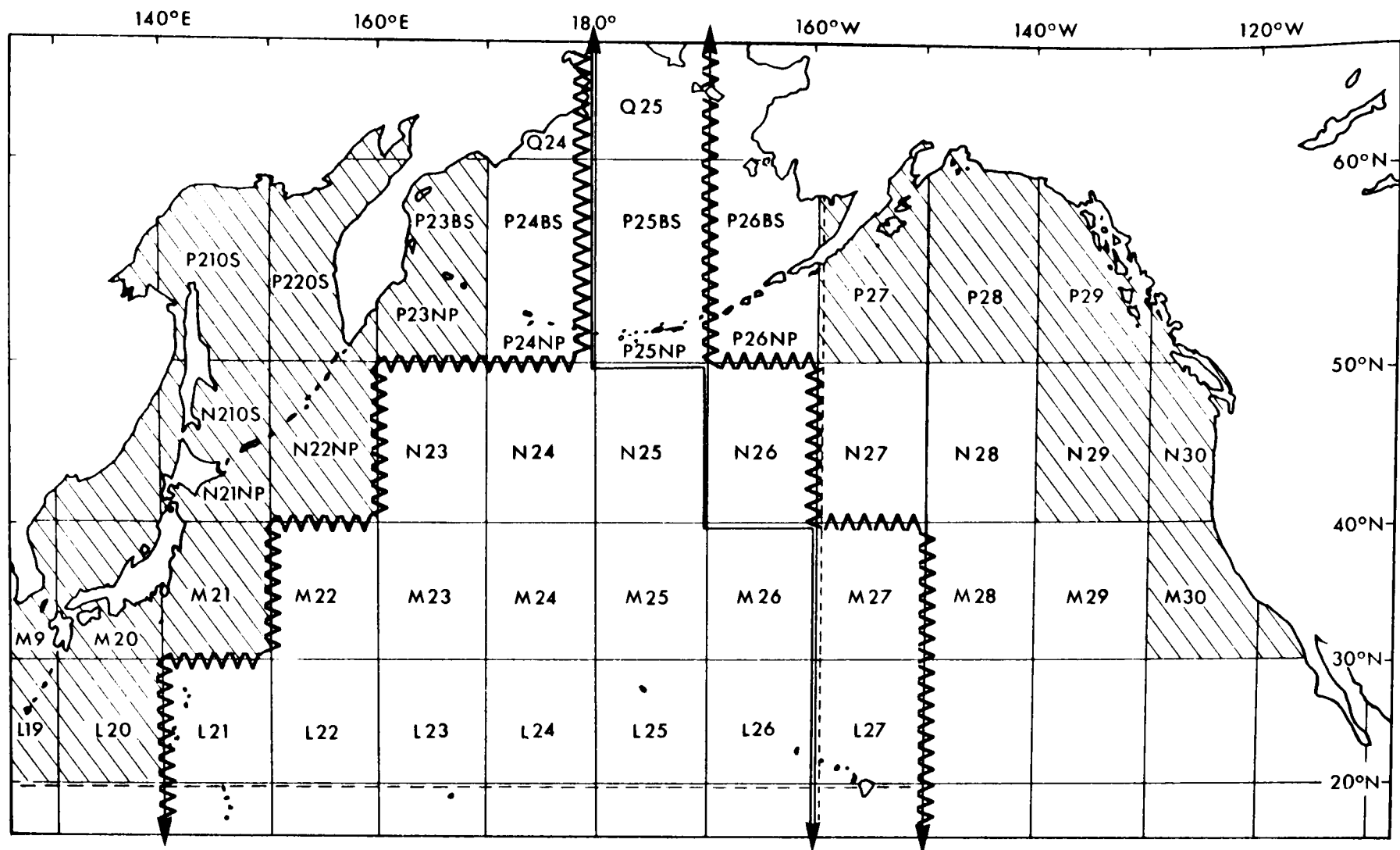


Fig. 1. Map of portion of North Pacific, showing IWC terminology for 10° squares. Key is as follows: Hatching stocks as recognised by Masaki (1970Ms), modified by Tillman (1977). Double line "Canberra Line." Vertical Dashed Line division of Ohsumi and Masaki (1977). Wavy Line biological stock units proposed by Mitchell in earlier draft of this paper (e.g. SC/SPC/Doc 20).

unit (180°–160°W) as the area of intermixing of males from eastern and western stocks.

The 1977 IWC Scientific Committee meeting in Canberra (IWC, 1978, pp. 60–1) reviewed "the data on female catch distribution in SC/28/Docs 21 and 25", and recognised at least two stocks with the following boundary (the "Canberra Line"):

"From the ice edge south along the 180°W meridian of longitude to 180°W, 50°N, then east along the 50°N parallel of latitude to 170°W, 50°N, then south along the 170°W meridian of longitude to 170°W, 40°N, then east along the 40°N parallel of latitude to 160°W, 40°N, then south along the 160°W meridian of longitude to the equator" (see Fig. 1).

The Scientific Committee concluded that, "because mark returns show a high degree of mixing of males in northern latitudes of the Pacific Ocean (see Ohsumi and Masaki, 1977, p. 171, Fig. 4) it is not possible to distinguish between males from these stocks for assessment purposes, particularly for the early years of the fishery" (IWC, 1978, pp. 60–1).

The Special Meeting on sperm whales held at Cronulla in November 1977 concluded that in spite of the uncertainty on stock identity, "a more conservative approach would be on the basis of divisions such as those proposed at the June 1977 meeting," and erected a "Cronulla Line" (IWC, 1980; and cf. Fig. 1).

The best evidence for identification of stocks would be the recognition of geographically separate entities during the breeding season, inferred to be reproductively isolated by means of direct tag-recapture data, or shown to be separate from direct evidence of genetic dissimilarity by means of protein chemistry data (e.g. electrophoresis), external pigmentation or other morphological features.

However, at present the distribution of tagging and catch effort have not been examined closely enough to give clear cut evidence for stock separation: blood typing or grouping studies (e.g. Fujino, 1963; Wada, 1980) have shown some differences, but either have sampled disparate areas through time, or are based on small samples; and pigmentation and other morphological evidence has not been collected widely enough, and analyzed, to be conclusive (see e.g. Yablokov, 1974; Veinger *et al.* 1975).

Many authors have previously suggested that the Townsend charts, representing approximately 37,000 sperm whale kills mainly by 19th century whalers, might be used to make a first approximation of possible geographic separation of putative stocks. These data (as adapted by Gilmore, 1959, to include modern whaling catches) were considered at the Parkville sperm whale meeting (IWC, 1973) and again in the La Jolla meeting (IWC, 1977) particularly for the Southern Hemisphere. More recently, some authors, particularly Kugler (1976) and Best (1977) have suggested that the charts of Matthew Fontaine Maury (1851 *et seq.*) would be even more useful since they contain data on effort expended in searching for whales, although the time span covered is short by comparison with Townsend (1935).

Materials and Methods

Charts and plots are available of areas where sperm whales have been caught in the historical past. These comprise 5° squares giving effort expended and whales seen (Maury, 1851, *et seq.*), whaling grounds (Clark, 1887), a summary chart of (seasonal?) distribution (Bolau, 1895), monthly plottings of positions of whale ships on days when one or more whales were taken (Townsend, 1935 and replottings by Anon., 1952), and maps compiled from both

Townsend's charts and "tabulation of the result of modern steam-whaling from 1865 to 1958" prepared by Gilmore (1959; reproduced in Mitchell and Kozicki, 1978). The Bolau (1895) chart is apparently based upon Maury and secondary sources, and accords with then-known distribution patterns.

The Maury and Townsend charts are based upon whalers' reports and logbooks and they represent different data which may overlap to some extent (e.g. pre-1851 reports and logbooks, versus 1761–1920 logbooks). Townsend (1935) and Gilmore (1959) summarized whalers' terms for whaling grounds. We limited our analysis to the series of whale charts published by M. F. Maury in the early 1850s, and by C. H. Townsend in 1935. The full bibliographic citations to the charts, and ancillary published materials bearing on these citations and/or method of plotting the data will be found in literature cited below. Bathymetric terminology follows Heezen and Tharp (1969).

Maury charts – The Maury whale charts represent a confusing bibliographical problem, in that they are rare and full citations to all of them are difficult to find (e.g. Williams, 1963, pp. 187–8, 533, 696, 697; and see Bertrand, 1971, pp. 214–18). The first whale chart (1851, 'Preliminary Sketch, Series F') bears small representations of two species, sperm whales and right whales, drawn in each 5° square, with indication by letter of the season of occurrence there. (This has been reprinted in Starbuck, 1878, repr. Argosy, 1964, as a small folding map in the

pocket of the leather bound, limited ed. version and on the endpapers of the cloth bound version – see References).

Plotting only sperm whales from the first Maury chart by season (Fig. 2), it is clear that some autumn and spring records exist between the equatorial (e.g. "On the Line") grounds and the more temperate (e.g. "Japan") grounds.

The Maury (1851) chart clearly shows North Pacific sperm distribution on the traditional tropical grounds: "On the Line", "Offshore", "Galapagos", "Panama Bay"; and traditional temperate to tropical grounds: "Bonin", "Japan", "Hawaiian", "West Mexico", and "Lower California". More broad traditional grounds are represented in the east ("Eureka" and apparently part of "British Columbia"), but in the west, whaling had not yet started on the "Coast of Japan" ground. Many other northerly grounds were not yet recognised or fully exploited. Thus, the Maury chart represents good coverage from the equator only to approximately 40°N.

The subsequent editions of the whale chart were amplified into 'Series F, No. 1', 1852, and 2, 3, and 4, all *n. d.* (Bertrand, 1971 p. 215). These are in fact four adjacent sheets, covering the world's oceans. These charts show for each five degree square, by means of histograms for each month, the number of days searching for whales and the number of days on which sperm whales and right whales were seen, distinguished by color (blue for right whales, red for sperm whales; but some of the charts may be otherwise coded – see Maury, 1858, p. 326). Coverage is for the

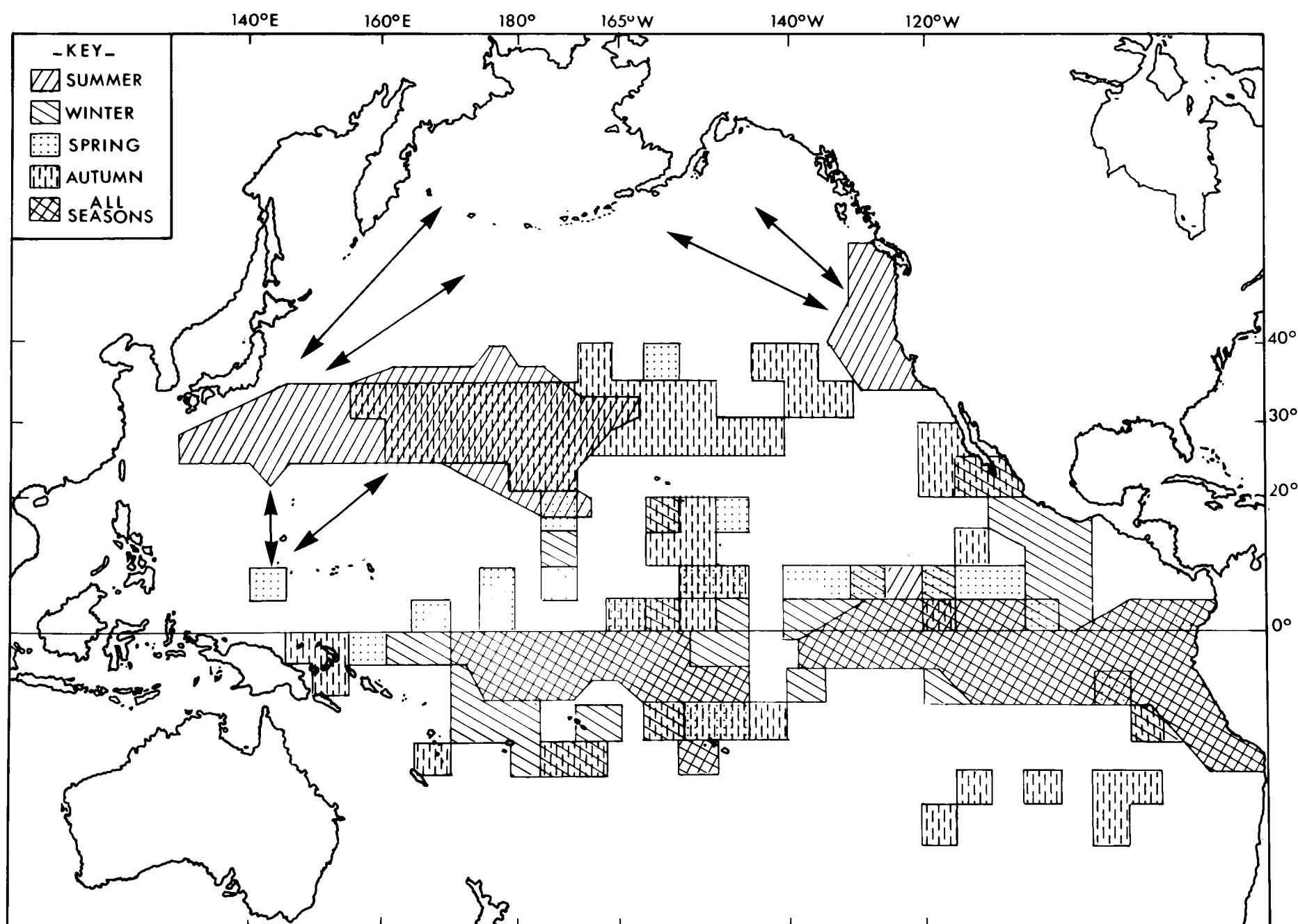


Fig. 2. Seasonal occurrence of North Pacific Sperm Whales, coded as indicated in Key, from symbols in 5° squares on Maury "Whale Chart" of 1851 (drafted from reprint in Starbuck, 1964). Arrows represent tagging trends, from data of Ohsumi and Masaki (1977).

world's oceans, except for the polar regions north and south of 60°, reflecting the pre-1850 American pelagic fishery for black right whales (*Eubalaena* sp.) and the sperm whale (*Physeter macrocephalus*).

Another chart, that showing favorite resorts of sperm and right whales, by R. H. Wyman (1853?, 2nd. ed., 1853, re-engraved, 1859— see Bertrand, 1971, p. 696) is a distribution map based on the 1851 chart.

Maury's descriptions of the data, and how he handled them, are found in an essay that itself has a complicated bibliographical history. The essay was apparently first published in the 'Explanations and Sailing Directions to accompany the Wind and Current Charts', (and earlier editions, considered to be 'Notice to Mariners', 1850— see Bertrand, 1971, p. 214, Note 9). We have not confirmed the various states or editions of this essay, but use here the version from the amplified eighth edition, two volumes, of the 'Explanations . . .', 1858–1859 (Maury, 1858, 'The Whale Charts', pp. 319–27).

'The log-books of whalers were collected in great numbers and patiently examined, co-ordinated, and discussed. . . .' The data from which Maury plotted his whale charts comprised 'log-books containing the records by different ships for hundreds of thousands of days . . . , (Maury, 1858, p. 321); or extracts or abstracts kept by whalers, see Sherman, 1965, p. 58, and Schmitt, 1971, pp. 106–7.

In our analysis of the Maury charts (Series F, nos. 1–4), we extracted data for the North Pacific, by five degree square and for each month, of the number of days spent searching for whales and the number of days on which sperm whales were seen. From these data, read directly off the histograms, indices representing the ratio between effort spent searching, and sightings, of sperm whales were obtained for each five degree square for each month (Figs 3–4).

Townsend charts — The Townsend charts comprise two folding colored charts (A and B, of four, A–D) with sperm whale data plotted by month, six months per sheet, coded with open or closed colored circles ('plats'). In carrying out the plotting, Townsend began with a single chart, (1931, p. 176; 'the chart presented herewith', representing a catch of 11,026 sperm whales), then, finding that the data chart 'became overloaded with data', he replotted it on two charts. Chart A comprises records for April through September and Chart B, October through March, inclusive. The data cover the period 1761–1920, each colored plat representing the position of an American whale ship on a day when one or more whales were taken, representing a total catch of 36,908 sperm whales.

H. Winn, R. Payne, and G. Utting have located some of the original data compiled by A. C. Watson and C. H. Townsend for Townsend's 1935 paper. These include in tabular form: vessel, year, month, day, ocean, latitude and longitude, number and species of whale taken, and sporadic remarks. No effort data are given, and we have therefore been unable to carry out a useful quantitative analysis.

The charts are rare, which may account in part for the little use made of them to date. A reprint of the 1935 article, containing black and white photo reductions of the four colored charts (Townsend, 1969) is virtually useless for analyses of the plotted data. A replotting of the data from all four charts (Townsend, 1935, charts A–D) done by month on twelve charts, but again color coded in red, blue, and green by species (Anon., 1952) is very much more useful. We drew arbitrary lines around the groupings of

solid red plats representing sperm whales on these twelve charts. The resulting groupings were then shaded for ease of comparison, month to month.

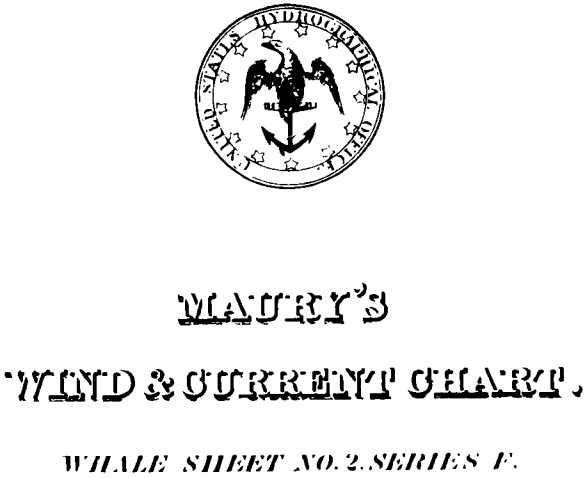
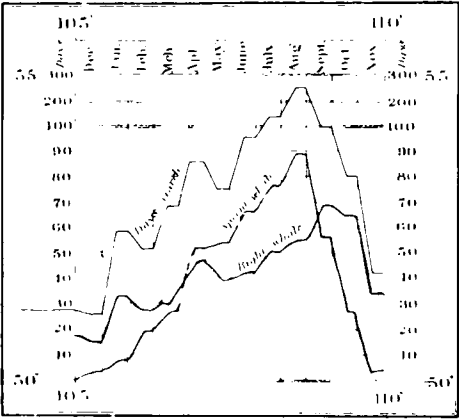


Diagram for Explanation



Explanation.

The horizontal lines between the parallels stand for days, counting by tens to 100, thence by hundreds to 300 commencing at the southern parallel.

The perpendicular lines between the meridians divide the space into 12 columns, representing the months, always beginning with December the first winter month at the left and ending with November at the right.

The black curve shows the number of days search for whales, recorded in each square for each month. The red curve shows in the same manner the number of days on which Sperm whales were seen, and the blue curve the number of days on which Right whales were seen for each month.

Thus, to tell how many days have been spent by different vessels searching for whales in the same month of different years in any district of 5° square, you have to follow the days of search curve, black, till you find a horizontal break in it, in the column for the required month, then counting by tens and hundreds from the southern parallel which bounds the district in question, you see the number of days of search, then following the red curve in the same manner you see on how many of those days sperm whales were seen, in like manner the blue curve shows the number of days on which Right whales were seen.

When the number of days of search for any one month exceeds 300, there is more than one break in the curve, in the column for such month, in which case each break must be counted at its own value, and the sum of all gives the number of days.

When the curve instead of crossing a monthly column terminates at the southern parallel, it denotes, if the search curve, that no vessel has fished in that district during such month, and if a whale curve, that no whales have been seen there during such month.

The reading of the diagrams above is explained by figures in the following table.

TABLE OF EXPLANATION.	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov
N° of days search for whales in each month.	25	58	53	68	80	75	66	130	215	100	80	12
N° of days on which Sperm whales were seen	4	7	18	26	51	51	67	77	88	56	26	4
N° of days on which Right whales were seen	15	33	27	30	47	39	12	50	85	69	65	31

Note:
When the whale curves are not colored red and blue, the Right whale curve may be known by the near striking of the two dotted lines, and the sperm whale curve by the other.

Fig. 3. Explanation of graphic data presented in Maury "Whale Chart of the World," 1852, as it appears on each of four sheets (here from Sheet No. 2). (Photocopy courtesy K. Nesheim and Yale University.)

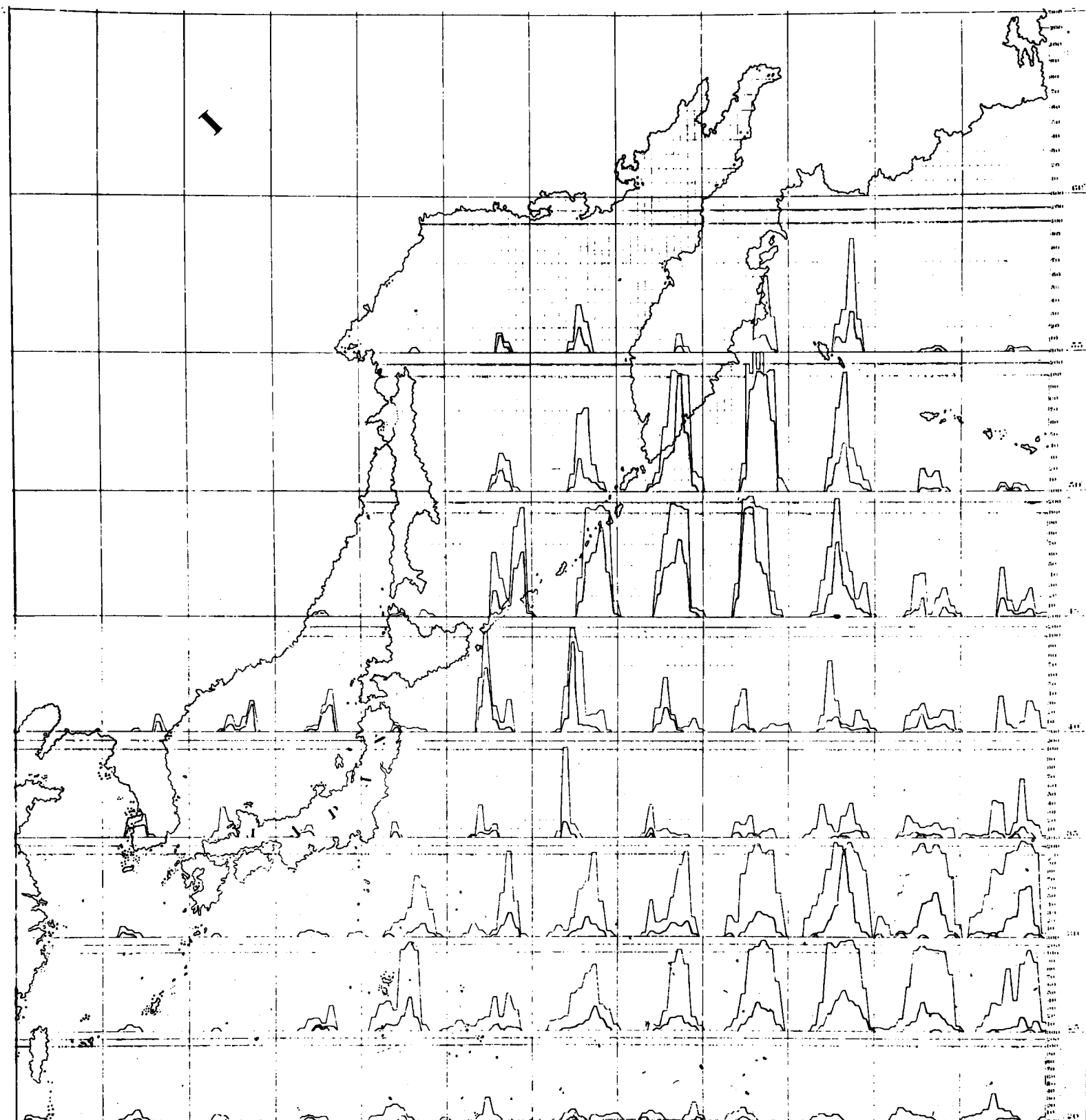


Fig. 4. Lower right corner portion only of Sheet No. 2, Maury, 1852, "Whale Chart of the World", showing example of searching and sighting data presented on all four sheets. Heavy border on right, light neat line on bottom, represented outside printed lines on chart as published. (Photocopy courtesy K. Nesheim and Yale University.)

RESULTS AND DISCUSSION

Maury charts — The results of the calculation of the indices (sightings per searching day) for the North Pacific for all months, combined, are given in Fig. 5. There the index for each five degree square is entered in a circle, the diameter of which is proportional to the size of the index. The bulk of the observations are for the months April through September.

The combined data from the Maury charts (Fig. 5) fall into two main belts, one between 20° – 40° N, and one 'On the Line', between 10° N and 10° S (approximately). In the absence of any information on the relationships of the 'On the Line Grounds' to those farther north, we have confined our analysis to the belt between 20° – 40° N. Fig. 5 also shows that there are very few density data east of the Hawaiian Group. The amount of effort expended there is relatively low; as an example, the effort data for April–May are given in Table 1.

Considering the combined data west of Hawaii for all months (Fig. 5), we can say that there is no obvious distinction into subgroups, but there are longitudinal changes in density. Density is highest west of 175° E, towards Japan, i.e., including the region described by Townsend (1935) as the 'Japan Ground' from 28° – 35° N and 150° – 179° E, and to include an area westwards towards what was known as the 'Bonin Ground'. Earlier, in 1931, Townsend himself had limited his definition of the 'Japan Ground' to 29° – 32° N and 160° – 175° E.

In seeking evidence for breeding stocks from such data, one would expect those for the breeding season to be more significant than those for other times of the year. A subset of the combined data was therefore obtained for the months of April and May (Fig. 6). These months were chosen since they represent the peak of the main breeding period in the North Pacific (e.g. Ohsumi, 1965; Ohsumi and Satake, 1977; Mitchell and Kozicki, 1978) as agreed at the

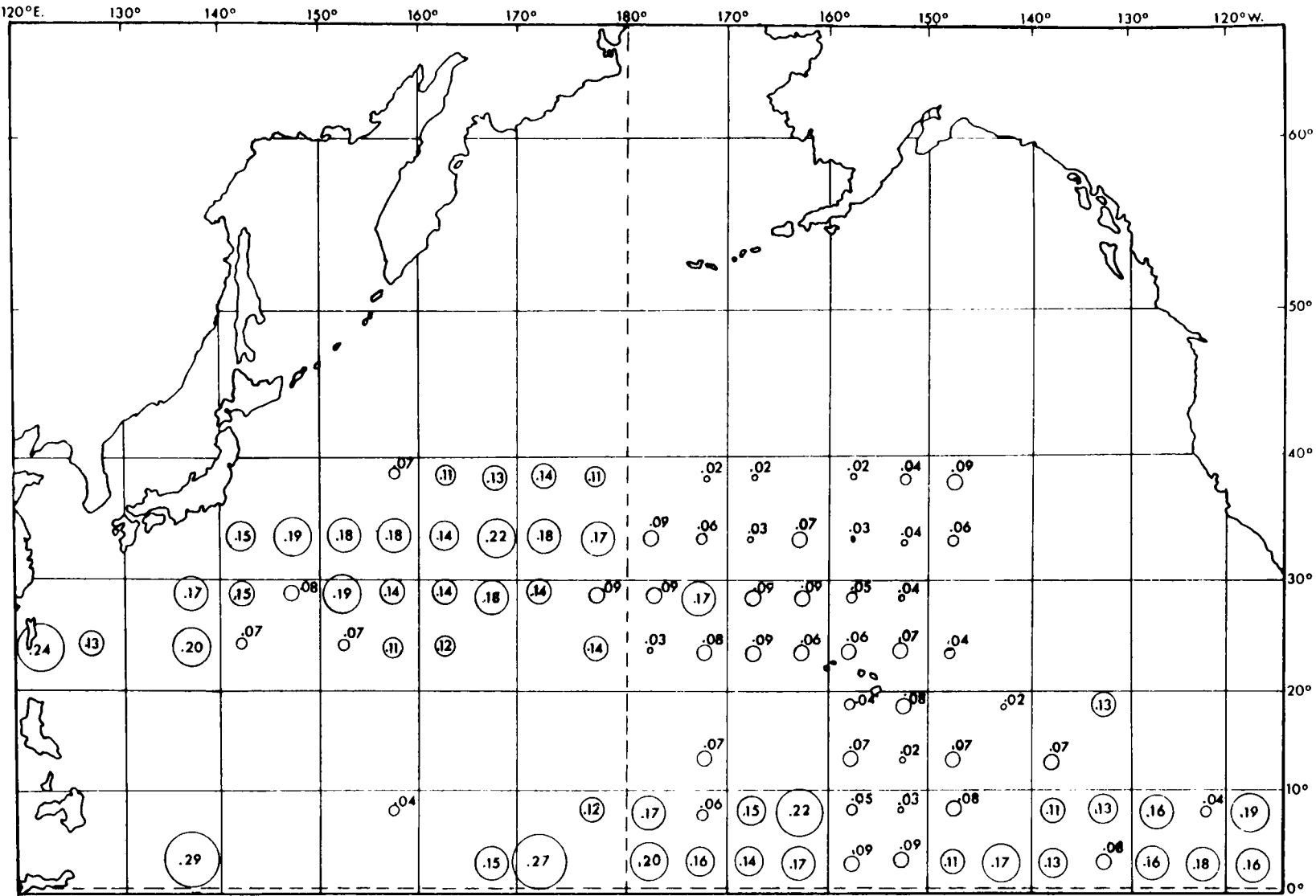


Fig. 5. Index of days sighted sperms/total days effort, by 5° square for the North Pacific, from Maury “Whale Chart of the World” (1852, Sheet Nos. 1–4).

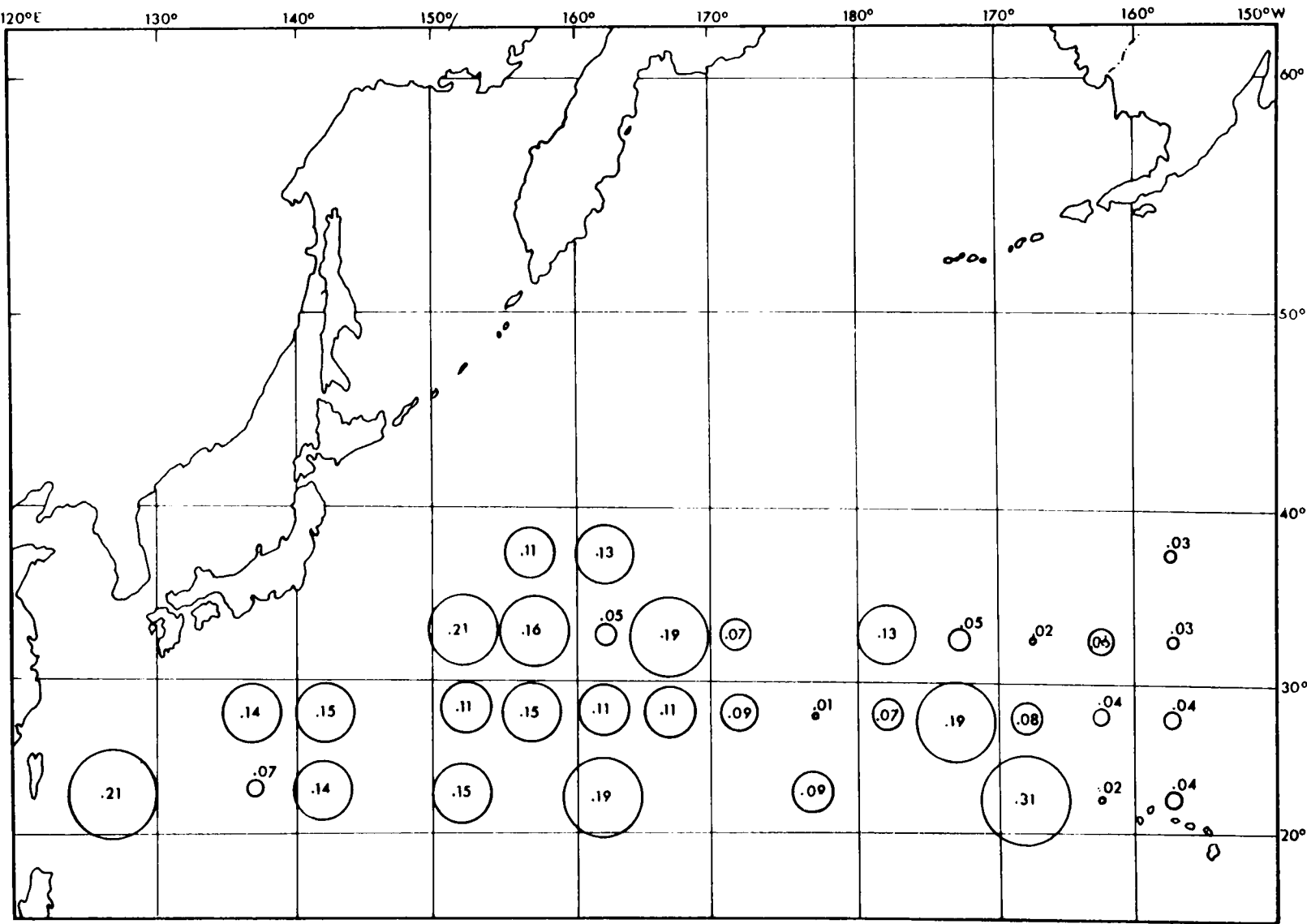


Fig. 6. Index of days sighted sperms/all days for effort for 20–40°N., west of Hawaiian Islands, April-May, only, by 5° square, from Maury “Whale Chart of the World” (1852, Sheet Nos. 1–2).

Table 1

Effort data (days searching for whales) for months April-May, extracted from Maury's whale chart Series F, Nos. 1 and 2 (1852).

April	40°N	35	12	17	38	120	38	17	39	25	43	8	8	9	73	78	49	8	5	9	0	0	0		
		0	7	16	7	6	44	17	52	76	82	28	13	83	130	130	23	7	0	7	3	14	6	2	
	30°N	4	13	26	13	18	8	14	37	57	36	34	4	32	120	160	47	0	8	6	5	3	3	4	0
		7	6	20	7	8	10	7	8	11	38	49	10	18	66	280	70	15	6	13	11	3	6	0	0
May	20°N																								
	40°N	18	0	0	8	16	8	14	13	17	40	4	42	60	45	160	46	6	8	5	0	2	0		
		0	5	20	2	21	17	76	81	140	77	83	50	85	140	95	36	5	0	3	0	16	13	0	
	30°N	0	15	140	16	48	5	47	220	130	34	77	38	29	55	100	10	7	4	4	0	0	0	0	0
		0	3	15	30	12	16	10	5	7	15	35	13	6	25	140	14	7	3	2	2	2	0	0	0
	20°N																								

130°E 140° 150° 160° 170°E 180° 170°W 160° 150° 140° 130° 120° 110°W

Canberra meeting (IWC, 1978, p. 70) and Cronulla sperm whale meeting (IWC, 1980, para. 12).

In this subset discontinuities occur, particularly at 175°E and at 145°E. That these may reflect real whale distribution is indicated by trends in the indices from the middle of the grouping to the edges, particularly in the grouping westwards from 175°E to the Hawaiian Group. Further, this discontinuity at 145°–150°E may represent a division between stock units on this evidence, but the indices do not fall off in the same way as they do for the eastern end of the Japan Grounds, even though the division between the western end of the Japan Ground and the Bonin Ground occurs at that longitude.

Townsend charts – The points representing positions of a ship on a day when a sperm whale was taken, as redrafted by Anon. (1952) from Townsend (1935, charts A–B) were arbitrarily outlined by grouping for visual comparisons, and are here presented in Figs 7A–7L (months January through December, inclusive).

The winter plots (December–March) show few records north of 10°–15°N. The April-May plots show three separate areas of concentration in the belt between 20°–40°N, identical with, from west to east, the Bonin Ground, the Japan Ground and the Hawaiian Ground (Townsend, 1935; Gilmore, 1959, Fig. 1). By May, the Coast of Japan Ground is occupied, but there are progressively fewer records on the Hawaiian Grounds through the summer months. However, the distinction between the Coast of Japan, and the Japan Grounds, appears to become blurred during June–August. From September through October, with progressively fewer records, the discontinuity between the Japan Ground and the Hawaiian Ground appears to widen.

The records intermediate in position between the series of groups in the band between 20°–40°N and the ‘On the Line Grounds’, may represent direct evidence of the northward migration of Northern Hemisphere whales from the ‘On the Line Grounds’ in March-April. These plots appear to support Gilmore’s (1959, Fig. 1, arrows and legend) interpretation of migration between “On the Line Grounds” and grounds of higher latitudes. In the data for the months April–May, the peak of the North Pacific breeding season (see above; and Figs 7D–7E), three clear cut groups appear in the band between 20°–40°N. The discontinuity between the Bonin Ground and the Japan Ground is well defined between 145°–155°E. That one between the Japan Ground

and the Hawaiian Ground is less well defined, but could be somewhat arbitrarily placed about 180°.

Biases in the data – The indices given in Table 1 indicate that areas where there are few records were not searched by whalers as much as areas where there are many. However, we note that the habit of ‘gamming’ by whalers often involved the exchange of information on the occurrence of whales and rumours about the positions of large catches by competing captains. Some captains kept detailed records of catches, and plotted these on their own charts, but considered these data commercial intelligence and did not advertise them widely.

As an example, we note that in the 20°–40°N band, the Maury data show some effort but few catches east of the Hawaiian Grounds, while the Townsend data show few records between the Hawaiian Grounds and the North American continental shelf. We think that the 19th century American whaler believed that this area was sparsely inhabited by sperm whales, and took his ship to areas of greatest known concentration. Subsequently, modern commercial whaling throughout the North Pacific has shown catches in this band, east of the Hawaiian Grounds, to be in the tens to low hundreds for the period 1954–1975, as compared with thousands elsewhere in the North Pacific (Ohsumi and Masaki, 1977, p. 169, Figs 1–2). An apparently independent chart of whaling grounds shows a restricted band east of the Hawaiian Grounds representing a sperm whaling ground abandoned by 1880 (Clark, 1887, vol. 2, p. xvii, 7–24; plates, p. xiii, pl. 183).

The Townsend plots show the traditional tropical and temperate grounds more fully. (The “Eureka” and “British Columbia” grounds do not show up – see Gilmore, 1959, p. 13.) However, the Townsend charts probably cover a relatively much later period (mainly post-1851) than the Maury charts, or a bias in the sample of logbooks (e.g. the total catch represented, or the total number of logbooks sampled) may account for some disparities between the Maury and the Townsend data. Conversely, the Townsend charts clearly show the later, heavy exploitation of the “Coast of Japan” ground.

Other Evidence:

A. Catch composition

Ohsumi and Masaki (1977, Figs 6–7) present data showing a lower pregnancy rate and lower CPUE in Sector III

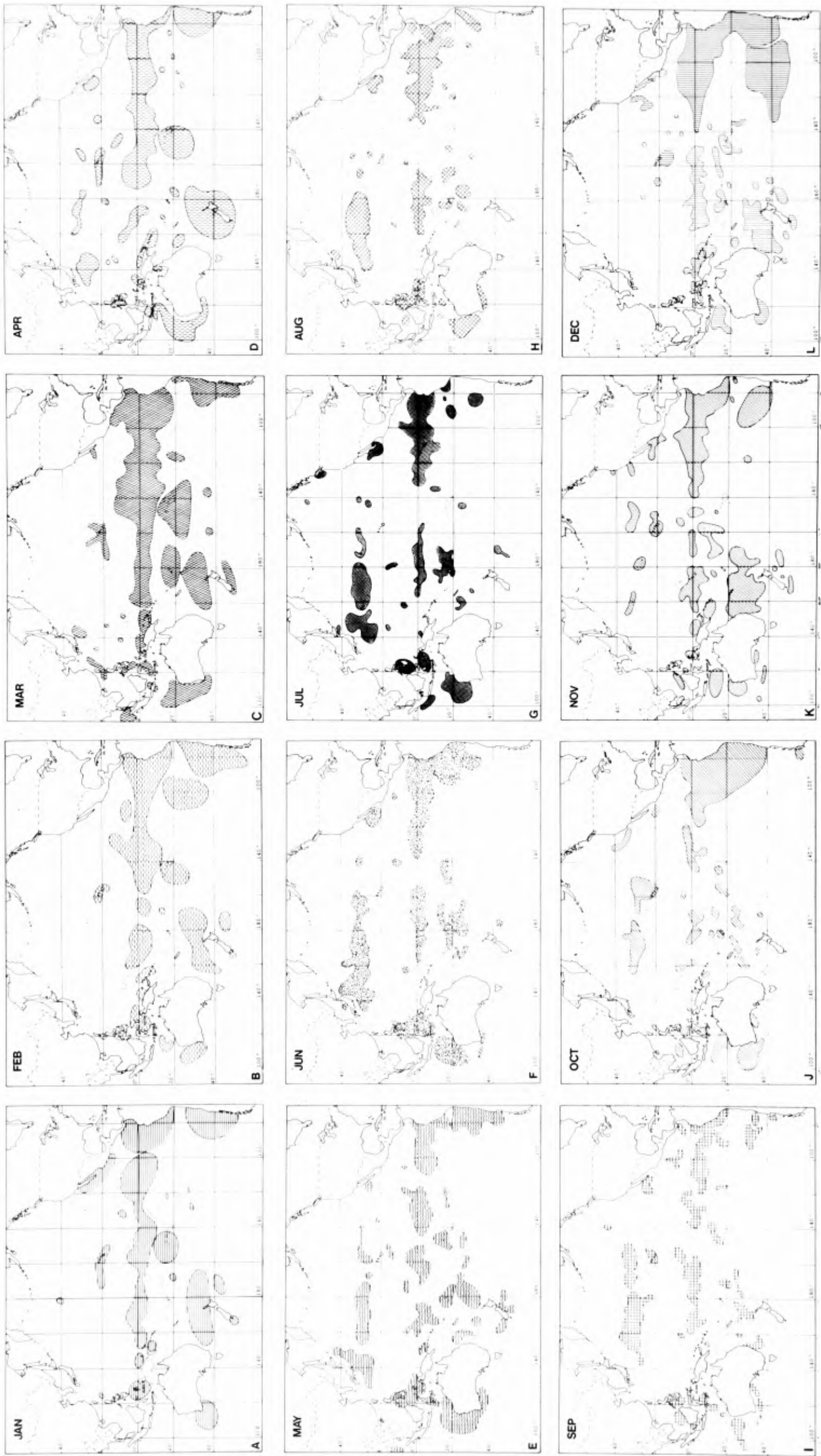


Fig. 7. Pacific sperm whale distribution, from data of Townsend (1935, Charts A–B), by month, January (A) through December (L). Arbitrary lines around plots of Townsend (as redrafted by month in Anon., 1952) do not reflect actual density.

(140°W–160°W) compared with adjacent Sectors. This corresponds precisely with a hiatus in distribution observed in the Townsend charts (Anon., 1952, May–October) and in part with a similar hiatus in distribution in the Maury chart (Fig. 6). We interpret this evidence as indicative of the edge of distribution of two or more stocks, one defined as including the “Hawaiian” ground and the central “On the Line” ground from 150°W and westward, and one (or two) including the “Offshore” ground and “Lower California” ground eastward of 150°W.

The high percentage of males (Ohsumi and Masaki, 1977, Fig. 3) and the number of large males, e.g. over 45ft. (Allen, 1980) in Series M and N, especially in the central area, has been interpreted variously. The Canberra meeting (IWC, 1978) defined a “Canberra Line” (see Fig. 1) that runs through this concentration of males, but divides the female distribution given by Ohsumi and Masaki (1977, Fig. 9).

B. Tagging

Ohsumi and Masaki (1975; see our Fig. 8) summarized Japanese tagging results, 1949–1972. Ohsumi and Masaki (1977, Figs 4–5) give a breakdown of the results by sex. Some American data were taken into account by Tillman (1977); USSR recovery data on two American tags were given by Rice (1977a). Other recent USSR tagging data appear in Ivashin (1977). Rice (1974, Table 6–3) reported three recoveries out of 176 sperm whales tagged in the northeast Pacific, and as of 1979 had a total of seven recoveries from this programme, all “showing movement between central-southern California winter grounds and northern California to western Gulf of Alaska summer grounds” (D. W. Rice, pers. comm., 11 Oct. 1979).

The plots of Ohsumi and Masaki (1975; 1977) show clearly that females in the Asian stock area are discrete, and that females in the “Kodiak” or “Northwest” ground

(Gilmore, 1959, Fig. 1) move within the limits of the grounds from around the Aleutians to British Columbia and the “Eureka” grounds. For males, however, Ohsumi and Masaki (1977) interpret the data as indicating intermingling of a great degree. However, the degree of interchange is a small percentage of the total marked and recaptured whales east to west (Ohsumi and Masaki, 1977, Fig. 4); few recoveries are available from the central area, and an alternative interpretation of marking and recovery in the eastern area and the western areas could indicate that these are likely discrete stock units.

CONCLUSIONS

Definition of an Asian stock can be based on the evidence summarized by Masaki (1970 Ms.), the high percentage of tags returned in the same area, and the migration trends along the Asian continental shelf and slope as reflected in the Maury and Townsend charts. Some evidence indicates that square P24 should be included (Fujino, 1963). This Asian stock can be separated from a central stock but the separation may not be as complete as that between central and American.

An American stock can be recognized on the basis of the distinct distributions of both sexes and tagging and other data. There may be a separate stock in the equatorial Pacific (Rice, 1977b), south of the “West Mexico” ground.

A central stock probably occurs with a distinct eastern margin. It may intergrade somewhat with the Asian stock. Occurrence of high percentages of males in the north central Pacific, south of the Aleutians (Ohsumi and Masaki, 1977, Fig. 3), could be interpreted as the male component of a Central stock that does not migrate to the Bering Sea. However, tagging data are insufficient to address this point.

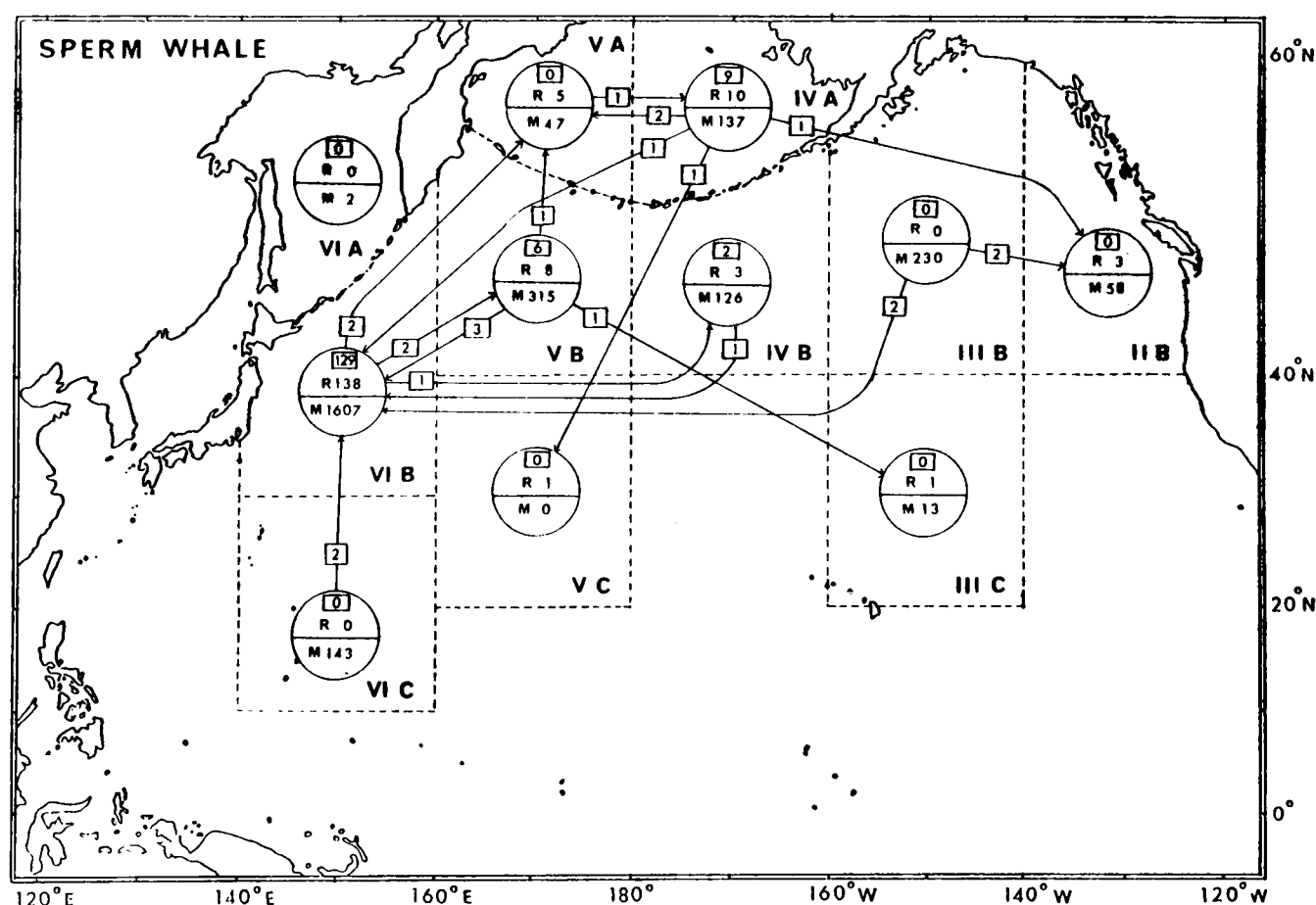


Fig. 8. Summarized results of Japanese marking and recovery for sperm whales in the North Pacific during years, 1919–1972. Key: M: number of whales marked, R: total number of whales recaptured in each area, Numeral in square: number of whales recaptured within the marked area, Numeral in square with arrow: number of whales recaptured in different area. (From Ohsumi and Masaki, 1975, Fig. 2.)

However, limiting our consideration of evidence from the North Pacific to the band between 20°–40°N, and west of Hawaii (corresponding largely to the Western Division used by the IWC Scientific Committee in recent assessments), we conclude that the Maury data show a distinct discontinuity between the Japan Grounds and the Hawaiian Grounds, while the Townsend data show a distinct discontinuity between the Japan Grounds and the Bonin Ground, all during the peak period of breeding in April and May. The Maury data also show the discontinuity between the Japan Grounds and the Bonin Ground, but less convincingly than the Townsend data. Since the Maury data include information on effort, we take these groupings to represent real, geographically separate, units of sperm whales during the breeding season. We therefore believe that, on the basis of these data, consideration should be given in further assessment work to a subdivision of the western region into two and possibly three divisions. We conclude that there are at least three, possibly more, separate stocks of sperm whales in the North Pacific.

ACKNOWLEDGMENTS

We thank Richard Kugler, Director, The Whaling Museum, Old Dartmouth Historical Society; Kenneth Nesheim, Associate Librarian, Beinecke Rare Book and Manuscript Library, Yale University; and George Utting, Archivist, and Roger Payne, The New York Zoological Society, for access to and/or copies of the Maury and Townsend charts, and some of the original Townsend data. Sue Patterson, Helen Sutherland, and Sandra Taylor made the extractions and undertook most of the basic analysis of the Maury data. Richard W. Stephenson, Head of Reference and Bibliography, Geography and Map Division, U.S. Library of Congress, was especially helpful with information and measurements of Maury charts. We thank V. M. Kozicki, D. W. Rice and P. B. Best for critical comments on earlier drafts of the manuscript. Mrs Ginette Ferrand drafted the illustrations.

REFERENCES

- Allen, K. R. 1980. Size distribution of male sperm whales in the pelagic catches. Paper SC/SPC/9 (published in this volume).
- Anon. 1952. Whale Intelligence [January, 1952; Prepared by CinCPacFlt Intelligence.] [Previously published in issues of the *Pacific Command Weekly Intelligence Digest*.] U.S. Navy, CinCPacFlt, Pearl Harbor, Territory of Hawaii; Paper covers + pp. i–ii + 1–10 + 12 folding colour-coded plates (January–December).
- Anon. 1978. Alaska whales and whaling. *Alaska Geogr.* 5(4): 1–144 + 1 unnumb. folding plate.
- Beneden, P. J. van. 1868. Les baleines et leur distribution géographique. *Bull. de l'Académie royale de Belgique*, Ser. 2, 25(1) 9–21 + 1 folding, lith. coloured map. [See similar map, with format and data differences, second unnumb. pl. following p. 630, van Beneden and Gervais, 1880, text.]
- Beneden, P. J. van and Gervais, P. 1880. *Ostéographie des Cétacés Vivants et Fossiles, Comprenant la Description et l'Iconographie des Squelette et du Système Dentaire de ces Animaux; ainsi que des Documents Relatifs à leur Histoire Naturelle*. Paris, A. Bertrand, [i–iv] + i–viii + 643pp. (text) + 64 pls. (atlas).
- Bertrand, K. J. 1971. *Americans in Antarctica 1775–1948*. American Geogr. Soc., New York, Spec. Publ. No. 37, i–xvi + 554pp. + 22 pls.
- Berzin, A. A. 1971. *Kashalot*. Tikhookeanskii Nauchno – Issledovatel' skii Institut Rybnogo Khozyaistva i Okeanografii Izdatel' stvo "Pishchevaya Promyshlennost'", Moskva, 367pp.
- Berzin, A. A. 1972. *The Sperm Whale (Kashalot)*. Israel Program for Scientific Translations, Jerusalem, i–vi + 394pp.
- Berzin, A. A., Gordievskaiya, W. S., Kun, M.S. and Novikov, U. V. (Eds) 1975. *Biologicheskie Resursy Morei Dal'nego Vostoka*. Vladivostok, Ministerstvo Rybnogo Khozyaistva SSSR. Ikhtiologicheskaya Komissiya Ministerstvo Rybnogo Khozyaistva. Tikhookeanski Nauchno-issledovatel'ski Institut Rybnogo Khozyaistva i Okeanografii (TNIRO). 150pp. + [i–vii].
- Berzin, A. A. and Rovnin, A. A. 1966. Raspredelenie i migratsii kitov v severo-vostochnoi chasti Tikhogo okeana, v Beringovom i Chukotskom Moriiakh. *Izv. Tikhookean. Nauchno- Issled. Inst. Rybn. Khoz. Okeanogr.* 58: 179–208. (In: K.I. Panin, (Ed) 1966, cited below).
- Berzin, A. A. and Rovnin, A. A. 1966 (Transl.). The Distribution and migrations of whales in the Northeastern part of the Pacific, Chukchee and Bering Seas. In: Panin, K. I. (Ed.) *Soviet Research on Marine Mammals in the Far East. (Collected Articles)*. Transl. U.S. Joint Publ. Research Service for Bur. Comm. Fish., Seattle, Washington. [i] + a – b + 148pp. (From K. J. Panin, (Ed.) 1966, cited below).
- Best, P. B. 1974. The biology of the sperm whale as it relates to stock management. pp. 257–93. In: W. E. Schevill (Ed.), *The Whale Problem. A Status Report*. Harvard University Press, Cambridge, Mass., i–x + 419pp. + 7 pls.
- Best, P. B. 1977Ms. Sperm whale stock assessments and the relevance of historical whaling records. Intl. Workshop on Historical Whaling Records, Sharon, Mass., Sept. 1977, Doc. No. 1.
- Bolau, H. 1895. Die Geographische Verbreitung der wichtigsten Wale des Stillen Ozeans. *Abh. Gebiete Naturw.* 13: 1–22 + map.
- Clark, A. H. 1887. (Part XV. The Whale Fishery.) 1. – History and present condition of the fishery. pp. 3–218, (in Sect. V, Vol. 2) + pl. 183 (folding chart) (In Sect. V, Plates) In: G. B. Goode (Ed.) *The Fisheries and Fishery Industries of the United States*. Washington, Govt. Print. Off., 5 Sections in 7 vols. [Description of "Sperm-Whale Grounds," pp. 8–15, based on literature summary, correspondence with whalers, kill and other data; chart completed in 1880, covers sperm, right, bowhead, gray, humpback and finback whales, all oceans, coded by species, extent of grounds and whether abandoned or then being fished.]
- Dodimead, A. J., Favorite, F. and Hirano, T. 1963. Review of Oceanography of the Subarctic Pacific Region. *Bull. INPFC* No. 13: i–iv + 1–195.
- Fujino, K. 1963. Identification of breeding subpopulations of the sperm whales in the waters adjacent to Japan and around Aleutian Islands by means of blood typing investigations. *Bull. Japan Soc. Sci. Fish.*, 29(12): 1057–63.
- Gilmore, R. M. 1959. On the mass strandings of sperm whales. *Pacific Nat.* 1 (10): 9–16.
- Heezen, B. C. and Tharp, M. 1969. Pacific Ocean Floor. *Nat. Geogr. Mag.* October, 1969. Map.
- International Whaling Commission. 1971. Report of the Special Meeting on Sperm Whale Biology and Stock Assessments, Honolulu, Hawaii, 13th–24th March 1970. *Rep. int. Whal. Commn* 21: 40–50.
- International Whaling Commission. 1973. Sperm Whale Assessment Meeting, Parksville, Vancouver Island, B. C., 3–10 May 1972. *Rep. int. Whal. Commn* 23: 55–88.
- International Whaling Commission. 1977. Report of the Sperm Whale Meeting, La Jolla, California, 16–25 March 1976. *Rep. int. Whal. Commn* 27: 240–52.
- International Whaling Commission. 1978. Report of the Scientific Committee. *Rep. int. Whal. Commn* 28: 38–92.
- International Whaling Commission. 1979. Report of the Scientific Committee. *Rep. int. Whal. Commn* 29: 38–105.
- International Whaling Commission. 1980. Report of Special Meeting on North Pacific Sperm Whale Assessments. [Cronulla, November 1977] (published in this volume).
- Ivashin, M. V. 1977. Soviet investigations of Cetacea – seasons 1975 and 1975–76. *Rep. int. Whal. Commn* 27: 94–7.
- Kugler, R. 1976Ms. The historical records of American sperm whaling: what they tell us and what they don't. Paper ACMRR/MM/SC/105 FAO Scientific Consultation on Marine Mammals, Bergen. pp. [i] + 5.
- Masaki, Y. 1970Ms. Study on the stock units of sperm whales in the North Pacific. Paper SP/9 presented to the IWC Special Meeting on Sperm Whale Biology and Stock Assessments, Honolulu, March 1970. [Not seen].
- Maury, M. F. 1851. *Whale Chart. (Preliminary sketch)*. Series F. Constructed by Lts. Leigh, Herndon and Fleming and Pd. Midn. Jackson. Published at the National Observatory by Authority of Commo. L. Warrington, Chief of Bureau of Ordnance and Hydrography. Washington, 1 sheet, 23.75 in. x 36.75in. "Lith. of Wm Endicott and Co. N. York." in margin of bottom right corner; "78" in margin of left corner at top.

- [VARIANTS SEEN: 1851, coded by four whale and blow symbols, plain, no label on Antarctica (COPY EXAMINED: photocopy of chart in U.S. Library of Congress); coded by four whale and blow symbols, overlay of hand coloured red, blue, light green and dark green fields delimiting coded areas of occurrence, labeled "Antarctic Continent, as seen by Wilkes". (COPY SEEN: reproduction of pp. 70-71 of Whipple, *et al.* 1979, which also shows part of hand written inscription "Colonel Force with Lt. Maury's Compliments" in top middle margin (photo credit, U.S. Library of Congress [original map = L.C. call no. G9096s.C7 var. M3 Series F]; both L.C. variants same size).) REPRINTED: "1851" n.d. [1954 or earlier], Washington, U.S. Hydrographic Office Miscellaneous No. 8514, 1 sheet, 23.50in. x 36.75in., with seal "Hydrographic Office, U.S. Navy" in top margin at left, and "Price 20 cents, H.O. Miscel. No. 8514" in bottom margin at right; "1851" n.d. [subsequent to above], Washington, U.S. Hydrographic Office Miscellaneous No. 8514, same as above except seal contains "United States Hydrographic Office," "Price 50 cents", and in top margin in right upper corner "Catalogue: Introduction Part 1" [publication dates uncertain: U.S. Nat. Archives, Cent. Cartographic and Architectural Arch. has "Ref. Rept." on one dated 1954, *fide* R. Grim, pers. comm., 28 II 80; U.S. Lib. Congr. copy of one accessioned June 1968, *fide* R. W. Stephenson, pers. comm., 28 II 80.]; 1964, in Starbuck, 1964, on end papers of cloth bound version, and as folding chart, 13.34in. x 21.80in., in pocket of vol. 2, leather bound version in 50 copies (with "Courtesy of U.S. Naval Oceanographic Office" in margin of bottom right corner and seal "Hydrographic Office, U.S. Navy" in margin of upper left corner - hence reprinted from "1851" n.d. reprint?); 1975, Picton Press, Great Britain, folded and included in Schmitt, 1975 by publishers, separate folding chart, 11.75in. x 18.05in. - reprinted from the "1851" n.d. reprint?]
- Maury, M. F. 1852 *et seq.* *Whale Chart of the World*. [The Wind and Current Charts], Series F. Washington, 4 sheets, two (Nos. 1, 4) 24.25in. x 35.75in., two (Nos 2, 3) 23.75in. x 35.75in. No. 1 [North Atlantic, N. E. Pacific], 1852. Whale Sheet No. 2 [N.W. Pacific], n.d. Whale Sheet No. 3 [S. Atlantic, S.E. Pacific], n.d. Whale Sheet No. 4 [S.W. Pacific, Indian Ocean], n.d. Each Sheet bears number outside heavy outer border, in left margin at top, as follows: No. 1 ("79"), 2 ("80"), 3 ("81"), 4 ("82"). [VARIANTS SEEN: 1852 *et seq.* four sheets, probably one printing, in plain and in colored versions (*cf.* Maury, 1858, p. 326, pl. 10). Legends state: "Note. When the whale curves are not colored red [sperm] and blue [right], the right whale curve may be known by the more striking of the two dotted lines, and the sperm whale curve by the other." (COPY SEEN: plain, photocopy, of sheets in U.S. Library of Congress, L.C. call no. G9096. C8 var. M3; color, Xerox copy, of sheets in Yale University Library.)]
- Maury, M. F. n.d. *A Chart Showing the Favourite Resort of the Sperm and Right Whale by M. F. Maury, L.L.D. Lieut. U.S. Navy*. Constructed from Maury's Whale Chart of the World, by Robt. H. Wyman, Lieut. U.S.N. by Authority of Commo: Charles Morris U.S.N. Chief of Bureau of Ordnance and Hydrography. Washington, 1 sheet, all editions 24.0in. x 37.0in. [VARIANTS: Editions cited as "1853 (?)", 2nd ed., 1853; re-engraved 1859" by Williams, 1963; confirmed as n.d.; 2nd Ed. 1853; 3rd Ed. 1859, *fide* R. Stephenson, pers. comm. 28.2.80. (COPY EXAMINED: 1853, "78" on left margin in upper corner, lithographed, colour overlays in red (sperm), blue (right) and purple (both) showing whale distribution, labeled "Antarctic Continent, as seen by Wilkes," and "Lith. of Endicott and Co N.Y." on bottom in margin of right corner, omits typeset sentence "it is supposed that the Right Whales resort to these grounds in considerable numbers and that good fishing may be had in these latitudes during winter (w) i.e. the Southern Summer" across bottom above Antarctica as occurs on 1851 chart "78", has typeset sentences as follows: obliquely in N. Atlantic to Norwegian Sea, "Investigations have not extended to this Sea," and obliquely in Davis Strait, "This Sea has been partially investigated," size 24.0in. x 37.0in., original, in EDM Library.) [The distribution limits do not correspond precisely with those of the engraved, folding world map, "Sea Drift and Whales, on which the movements of the sea, as indicated by the Thermometer are shewn," in various eds. of *The Physical Geography of the Sea* (e.g. Maury, 1856, pl. 9) - and although "commandant Maury" is mentioned, van Beneden's (1868, p. 11n, pl. oppos. p.12) coloured chart of balaenid distribution owes little to any Maury chart.]]
- Maury, M. F. 1856. *The Physical Geography of the Sea*. Sixth Ed., London; Sampson Low, Son, and Co., pp. i-xxiv + 25-348 + pls. 5-13 + pp. [1] - 16.
- Maury, M. F. 1858. *Maury's Sailing Directions*. Eighth Edition - Enlarged and Improved. Vol. 1. Washington, William A. Harris. i-xxxvi + 383pp. + 39 pls. + 24 unnumbered charts. [*cf.* "The Whale Charts," pp. 319-27 + pls. 9-10, 14.]
- Mitchell, E. and Kozicki, V. M. 1978. Sperm whale regional closed seasons: proposed protection during mating and calving. *Rep. int. Whal. Commn* 28: 195-8.
- Ohsumi, S. 1965. Reproduction of the sperm whale in the North-West Pacific, *Sci. Rep. Whales Res. Inst., Tokyo* 19: 1-35.
- Ohsumi, S. and Masaki, Y. 1975. Japanese whale marking in the North Pacific, 1963-1972. *Bull. Far Seas Fish. Res. Lab., Shimizu* 12: 171-219.
- Ohsumi, S. and Masaki, Y. 1977. Stocks and trends of abundance of the sperm whale in the North Pacific. *Rep. int. Whal. Commn* 27: 167-75.
- Ohsumi, S. and Sataki, Y. 1977. Provisional report on investigation of sperm whales off the coast of Japan under a Special Permit. *Rep. int. Whal. Commn* 27: 324-32.
- Panin, K. I. (Ed.) 1966. *Nastoiashchii Tom Izvestiya TNIRO Posviashchen Rezultatum Issledovani Morskikh Mlekopitaiushchikh. Izv. Tikhookean. Nauchno-issled. Inst. Rybn. Khoz. Okeanogr.* 58: 1-251.
- Panin, K. I. (Ed.). 1966. *Soviet Research on Marine Mammals in the Far East*. (Collected articles). Translated by U.S. Joint Publications Research Service for Bureau of Commercial Fisheries, Seattle, Washington. pp. [i] + a-b + 1-148. (From K. I. Panin, (Ed.) 1966. (cited above), pp. 15-21, 41-48, 97-207, 233-241 only.)
- Rice, D. W. 1974. Whales and whale research in the eastern North Pacific. pp. 170-195. In: W. E. Schevill (ed.) *The Whale Problem. A Status Report*, Harvard Univ. Press, Cambridge, 419pp + 7 pls.
- Rice, D. W. 1977a. United States Progress report on whale research - June 1975 to June 1976. *Rep. int. Whal. Commn* 27: 98-9.
- Rice, D. W. 1977b. Sperm whales in the equatorial eastern Pacific: population size and social organisation. *Rep. int. Whal. Commn* 27: 333-6.
- Schmitt, F. P. 1971. *Mark well the whale! Long Island ships to distant seas*. Ira J. Friedman Division, Kennikat Press, Port Washington, N.Y., [i-xii] + 151pp. + 12 unnumb. pls.
- Schmitt, F. P. 1975. *The Whale's Tale as Told with Postage Stamps*. Picton Publishing, Great Britain, i-xii + 69pp. + 1 folding map.
- Sherman, S. C. 1965. *The Voice of the Whaleman*. Providence Public Library, Providence, R.I., 219pp.
- Starbuck, A. 1878. *History of the American Whale Fishery from its Earliest Inception to the year 1876*. Rept. U.S. Commissioner Fish and Fisheries, pt. 4, 1875-1876, 768pp. + 6 pls. [Reprinted: 1964, Argosy-Antiquarian Ltd., New York, N.Y., 2 vols. Vol. 1 [i-viii] + i-x + 407pp.; Vol. 2, [i-v] + 408-779 + 1 folding plate (pocket) [= Chart: Maury, 1851.].
- Tillman, M. F. 1977. Trends in abundance of sperm whales in three areas of the North Pacific. *Rep. int. Whal. Commn* 27: 343-50.
- Tillman, M. F. and Breiwick, J. M. 1977. Estimates of stock size for exploitable North Pacific male sperm whales. *Rep. int. Whal. Commn* 27: 180-5.
- Townsend, C. H. 1931. Where the Nineteenth Century whaler made his catch. *Bull. New York Zool. Soc.*, 34 (6) 173-9 + 1 folding, colour map. [= Chart: "Sperm Whaling Grounds of the Nineteenth Century."]
- Townsend, C. H. 1935. The distribution of certain whales as shown by logbook records of American whaleships. *Sci. Contr. New York Zool. Soc., Zoologica*, 19, (1): 1-50 + [colour, folding] plates 1-4 (= Charts A-d). [Reprinted: 1969 (or 1970?), Kraus Reprint Co., Millwood, N.Y., text +4 folding, half-tone (uncoloured reduced) maps; 1978, Charts C-D only, reproduced approximately half size, without original legends, on pp. 50-53 of Anon., 1978, cited above.]
- Veinger, G. M., Lagerev, S. I. and Mel'nikov, V. V. 1975. Dannye po morfo-populiatsionnoi izmenchivosti kashalotov Severnoi pat-sifiki. pp. 117-18. In: Berzin, A. A. *et al.* (eds.), *Biologicheskije Resursy Morei Dal'nego Vostoka*, Vladivostok (Cited above).
- Veinger, G. M., Lagerev, S. I. and Mel'nikov, V. V. 1975. Data on the morpho-population variability of sperm whales in the North Pacific. Translation by Language Services Division, F 43, Office of International Fisheries, Nat. Mar. Fish. Serv., NOAA, U.S. Dept. Commerce, Washington. 2pp. typescript. (From Berzin, A. A. *et al.* (eds.) *Biological Resources of the Far-East Seas*, Vladivostok (Cited above).)

- Wada, S. 1980. On the genetic uniformity in the North Pacific sperm whale. Paper SC/SP78/12 (published in this volume).
- Whipple, A. B. C. 1979. *The Whalers. The Seafarers*. Time-Life Books, Alexandria, Virginia, 176pp.
- Williams F. L. 1963. *Matthew Fontaine Maury Scientist of the Sea*. Rutgers Univ. Press. New Brunswick, N.J., i-xxii + 720pp.
- Wyman, R. H. 1853. [See Maury, M. F., 1853.]
- Yablokov, A. V. 1974Ms. Proposal for agenda item 6.8.3 [new areas of research]. Report prepared for IWC Scientific Committee, Special Meeting, La Jolla 3-13 December 1974, unpubl. doc., pp. 1-3 + figs.

Notes added in proof

- (1) Maury indicated that Capt. Daniel McKenzie and George Manning obtained information from whalers and that by implication the resulting abstracts were the "logbooks: used in Washington by Lieuts. Herdon, Leigh and Fleming (Maury, M. F., 1851, "Important Notice to Whalemens." *Hunts Merchants' Magazine*, Vol 24, No. 6, June 1851, pp. 773-7 and see Harrison, J. P., 1954, An 1849 Statement on the Habits of Right Whales by Captain Daniel McKenzie of New Bedford, America. *Neptune*, Vol. 14, pp. 139-41 (N.V.)).
- (2) Criticism of Maury's system of research and opinions (e.g. by C. Wyville Thomson see S. R. van Campen, 1878, *The Dutch in the Arctic Seas*. Truebner and Co., London, Vol. 1, pp. 25N-26N "Thompson, C. W. 1873, *The Depths of the Sea*." MacMillan and Co., London, 527 pp. and others, e.g. Williams, 1963, p. 562, footnote 13) were defended by Martin H. Jansen (1873, *The Gulf Stream*. Ocean highways: *The Geographical Review*, New Ser., Vol. 1, No. 3, pp. 98-101) and apparently do not reflect on the accuracy or interpretation of Maury's whale data.

Two Concerns About the Sperm Whale Model

S. J. Holt

(*UNEP and FAO*)

A consensus appears to have been reached that a curve of sustainable yield against stock size for whales will if anything be skewed to the right, so that the MSY stock level is somewhat greater than 50% of the initial stock. The Scientific Committee has applied a generalised logistic model to baleen whales, using alternatively a symmetrical logistic with a maximum sustainable yield level (MSYL) = 50% of initial level, and a modified model, with a density-dependence exponent for a reproductive rate of 1.4, giving MSYL = 60%. The Commission, on the Committee's advice, had adopted the 60% version as the basis for classification, and also for setting quotas for Sustained and Initial Management Stocks. This choice was made essentially on the grounds that the 60% assumption is more 'conservative', since under it stocks become protected when in a state of lesser depletion than they would under the 50% assumption. Which of the two assumptions is the more conservative with respect to the size of quotas for stocks which are not protected depends on exactly how observed and assumed pregnancy and recruitment rates are applied to fix the parameters of the model. This is a general question calling for examination by the Committee, but my purpose here is to show that the 60% assumption is very far from being conservative as it has been applied to sperm whales.

In the sperm whale model used by the Committee, it is assumed that the sustainable yield of females, as a function of their numbers, may be represented by the modified logistic with MSYL = 60%. This particular assumption is not however relevant to the classification of female sperm whales which is based on the estimation from the model, of the *combined* MSYL; this turns out to be virtually the same, for either the 60% or the 50% assumptions regarding female MSY, and of course much higher than 60%. However, the chosen assumption makes a very great difference to the calculated sustainable yields of females, and especially in the range of female stock sizes near to the combined MSY level. This is a consequence of the procedure used for fixing the curve of density dependent recruitment, which is to assume a lowest pregnancy rate value, corresponding with initial stock size, and a highest possible value corresponding with a very small stock size. At the June 1978 meeting of the Committee the values adopted were 0.20 and 0.25 respectively. However, for any given stock size the ratio of quota on the 60% assumption to the quota on the 50% assumption is independent of the parameter values; it is given by:

$$\frac{1 - p^{2.4}}{1 - p}$$

where p is the stock size as a fraction of the initial size.

For $p = 0.8$ this ratio is 2.1; that is the quotas that have hitherto been set are double what they would have been under the 50% assumption. Thus, if the present model is used and it is assumed that the female yield curve is skewed

to the right, but to an unknown extent, the reasonably cautious procedure would be to adopt the 50% MSYL assumption.

In recent assessments it has been assumed that the natural mortality is constant (at 0.05) for all ages greater than 2 years, independent of density, and the same for males as for females. The origin of the value adopted, at the Parkville meeting, is somewhat obscure, but I understand that it came from the slopes of the right-hand tails of an age distribution of catches of males. Trials at La Jolla (IWC, 1977) established that the output of the model did not depend greatly on the precise value adopted for the 'non-juvenile' M .

The assumption that M is the same for males and for females has a substantial effect on the output, and particularly on the classifications of 'stocks' of males. Until such time as the natural mortality of both male and female sperm whales has been investigated it may be surmised that M for females is likely to be somewhat lower than for males. This would be consistent with many observations of vertebrate animals, ranging from fishes to humans, that where there is marked sexual dimorphism whichever sex attains the larger maximum size has the higher natural mortality rate, and that this is particularly so when the male is the bigger sex (Ralls *et al.*, 1980).

To see the consequence of such an alternative assumption to that of equal M , we can take the case where male $M = 0.05$ but female $M = 0.04$. Working step by step through the model application it is evident, firstly, that the estimates of exploitable (20+ year old) male stock size are unaffected. The initial numbers of mature (10+ year old) females are calculated by dividing the initial numbers of exploitable males by:

$$e^{-M\delta(20-10)} = 0.61$$

This estimate is therefore also unchanged.

The pregnancy rate of females in the initial stock (0.19 in previous estimates, 0.20 in the June 1978 Report) must then be related to an initial recruitment rate equal to the female natural mortality (primarily through adjustment of the calculated juvenile mortality rate); this recruitment is assumed to increase by 25% (i.e. in the ratio 0.25/0.20) as the female stock is reduced towards zero. The sustainable yields of females, which are proportional to the difference between the recruitment rate and the natural mortality rate, are therefore, for any given population size, only 80% $\left(\frac{0.04}{0.05}\right)$ of those calculated assuming the natural mortality of the females is the same as that of the males. We cannot reason directly from this conclusion to the level of quotas because that depends on what is the stock level for females giving the combined MSY.

The sustainable yields of males are proportional to the number of male recruits; these, too if M_q is assumed to be

0.04, will be only 80% of the values obtained under the assumption that $M\phi = 0.05$.

Thus, if it is assumed that the natural mortality rates of the two sexes are equal, when in fact that of females is lower than that of males, the sustainable yields of both sexes will be over-estimated, and to the same degree. However, the assumption as to whether the natural mortalities are equal or not has another, and greater, effect on the assessments with respect to the classification of males. According to the model and procedure used, MSY level for males is that below which the pregnancy rate falls as result of the reduction of the mature male to mature female ratio below a threshold determined by the constant mean school size and the assumed 'male reserve'. The threshold adopted has been 1.3 socially mature males (25+ years) to 10 mature females. The ratio calculated in the initial stock is about 4.7:10. That is, if the number of socially mature males is reduced to less than 28% of the initial number the pregnancy rate will fall. For this to be achieved the number of recruited males needs to be reduced to only 41% of the initial number, by the operation of $F = 0.073$. If the females are, for combined MSY, reduced to 80% of their initial number, then the recruited males can be reduced to $41 \times 0.80 = 33\%$ of their initial number before the sex ratio falls below the critical level; this is essentially the MSY level used today by the Committee in classifying male sperm whale stocks.

However, if the natural mortality rates are assumed to differ, the calculated initial ratio is also changed. Assuming the juvenile natural mortalities are equal, but that two different M values apply from age 2 onwards, then the initial mature male: female ratio becomes 3.5:10. If it is assumed, for example, that the different rates apply only from, say, 10 years (the age of female maturity) then the ratio becomes 3.8:1. These values would imply that the critical level for reproduction was reached when the number of mature males reached 37 or 34% respectively of their initial numbers (instead of 28%). This would result, if the recruited males were reduced to 49 or 46% of *their* initial numbers, by the application of $F = 0.053$ or 0.059 (instead of to 41%). If the combined MSY level for females remained at 80%, then the male combined MSY levels become 38 or 36% respectively. However, it is not clear that the combined MSY level for females would

remain virtually unchanged; a computer-run of the model is necessary to determine this.

It should finally be noted that the sustainable yields of males, and therefore the quotas for those classified as Sustained or Initial Management stocks, would be reduced as a result of their not being exploited so intensively as the current assumption of equal mortality rates permits. The sustainable yields vary as the ratio F/Z . For the comparable cases of the females being unexploited, the male MSY becomes $\frac{0.053}{0.073} = 73\%$ or $\frac{0.059}{0.073} = 81\%$ of that based on equal natural mortality rates. This is in addition to the reduction of 80% by the scale effect on the recruitment rate of both males and females examined earlier. The two effects are multiplicative so the male quotas would be 58% or 65% of the values based on the assumption of equal rates.

I realise this is an incomplete analysis of this problem, but I hope it has revealed sufficient to justify:

- (i) re-examination of natural mortality rates by sex;
- (ii) minor modification of the sperm whale model to take into account any difference found, or to explore the consequences of likely differences even if the available data are not good enough to reveal them, and
- (iii) a comparative review of sex differences in mortality rates, especially in mammals and including other cetaceans, to supplement studies of the limited sperm whale data (see Ohsumi, 1979; Ralls *et al.*, 1980). (It may be noted that at the recent symposium and workshop on odontocete ageing techniques, information was provided which indicated differences in average age – and hence in mortality rate – by sex in samples of different species, including those in which males are larger than females, and vice versa).

REFERENCES

- International Whaling Commission, 1977. Report of the sperm whale meeting. *Rep. int. Whal. Commn* 27: 240–52.
- Ohsumi S. 1979. Interspecies relationships among some biological parameters in cetaceans and estimation of the natural mortality coefficient of the Southern Hemisphere minke whale. *Rep. int. Whal. Commn* 29:397–406.
- Ralls, K., Brownell, R. L. and Ballou, J. 1980. Differential mortality by age and sex in mammals with specific reference to the sperm whale. Paper SC/SP78/18 (published in this volume).

Differential Mortality by Sex and Age in Mammals, with Specific Reference to the Sperm Whale

by Katherine Ralls,¹ Robert L. Brownell, Jr.,² and Jonathan Ballou¹

ABSTRACT

Natural mortality rates of males exceed those of females in many mammalian species; possible reasons for this trend are discussed. Although most female mortality curves conform to the classic 'U-shaped' curve, males in some species have mortality patterns of other shapes.

Theory predicts that male mortality rates in unexploited populations should be particularly high in extremely polygynous species and this prediction appears to be confined in several mammalian taxa, including pinnipeds. The limited evidence on natural mortality rates in odontocetes suggests that the genera *Stenella*, *Globicephala*, and *Physeter* may form a series showing increasing degrees of both sexual dimorphism, and presumably polygyny, and higher male mortality. All actual estimates, of natural mortality rates for male sperm whales are higher than both the comparable estimates for females and the natural mortality rate of 0.05 used in recent years for both sexes in the sperm whale model.

Thus, comparative, theoretical, and empirical evidence all suggest that the current assumption of equal natural mortality rates for male and female sperm whales is unlikely to be true. We recommend that the natural mortality rates used for males and females be based upon actual available estimates for each sex.

INTRODUCTION

Natural mortality rates of males exceed those of females in many mammalian species (Dittus, in press; Dubost, 1978; Stirling, 1975; Trivers, 1972). Rates may also vary dramatically from one age class to another. Mammalian life tables have been reviewed by Caughley (1966), who concluded that the typical mortality pattern is a 'U-shape' consisting of a juvenile phase when the rate of mortality is initially high but rapidly decreases, followed by a post-juvenile phase characterized by an initially low but steadily increasing rate of mortality.

Ohsumi (1979) summarized the available data on natural mortality rates (M) in cetaceans. He assumed M was the same for both sexes in all species, although noting that sex differences probably exist in some species. Holt (1979) expressed concern over the current assumption in the sperm whale model that natural mortality is equal in males and females. He called for a comparative review of sex differences in mortality rates since it was his general impression that where there is marked sexual dimorphism whichever sex attains the larger maximum size has the higher natural mortality rate. If this is true, we should expect natural mortality rates for male sperm whales to be greater than those for females.

This report attempts to provide such a review for mammalian species. We have summarized the information available to us on differential mortality by sex and age. Because of the limited time available to us for the preparation of this review, we make no claim for its comprehensiveness. Our coverage of the small mammal literature is somewhat sketchy because we concentrated our efforts on large, long-lived taxa which seemed most relevant to the sperm whale. These taxa are the primates, proboscideans, and artiodactyls among the terrestrial mammals and the pinnipeds and odontocetes among the marine mammals. The only group of large mammals not reviewed were the baleen whales.

MATERIALS AND METHODS

Several types of data are pertinent to our questions. The most useful is a complete life table for each sex. However, complete, accurate life tables for both sexes exist for very few species of mammals. In a review of mortality patterns in mammals, Caughley (1966) found such tables for only three species: humans, the Orkney vole, *Microtus orcadensis*, and the Dall sheep, *Ovis dalli*. In his review, Caughley (1966) rejected many proposed life tables for one or more of the following reasons: inadequate data (i.e., less than 50 ages at death or 150 ages of living animals); age structure analyzed as a kd_x series; mortality and emigration confounded; sample taken between breeding seasons; form of life table, or a significant portion of it, based largely on assumption; and inadequate aging. We have rejected several subsequent papers, as well as the Dall sheep data accepted by Caughley, for the same reasons. [The aging technique used for the Dall sheep has been shown to underestimate the age of females, but not males, to an unknown degree (Geist, 1971).] In 1977, Caughley stated that only a few adequate life tables had been developed in the period since his last review but did not specify them (Caughley, 1977).

Although the data in many papers are insufficient for the calculations of a life table, they may still suffice to indicate whether or not differential mortality by sex or age occurs, and we have utilized such information. For many species, the available data consist only of sex ratio counts at various ages. It is difficult to determine accurately the sex ratio for a species. The most serious source of bias is that males and females often make themselves differentially available to the observer or hunter. For example, in many small mammals, males are more easily captured than females (Beer, Frenzel, and MacLeod, 1958; Myers and Krebs, 1971). This effect has been well investigated in weasels, *Mustela nivalis*, where the heavy spring mechanisms and wide spacing of conventional spring traps select for males;

¹ Office of Zoological Research, National Zoological Park, Smithsonian Institution, Washington D.C. 20008.

² National Fish and Wildlife Laboratory, U.S. Fish and Wildlife Service, National Museum of Natural History, Smithsonian Institution, Washington D.C. 20560.

in addition, females may be more ‘trap-shy’ than males (King, 1975). In other species, males and females may tend to use different habitats at some ages or seasons. In spite of such difficulties, we have accepted sex ratio data in situations where the author felt the counts were relatively unbiased and reflected natural mortality.

Many authors give mortality rates only for immature and adult animals. Others divide the immature portion of the life span into juvenile and subadult phases. We have indicated this in Table 1 by a diagonal division of the ‘immature’ column. Juvenile mortality rates are then indicated in the space above the diagonal line and subadult mortality rates in the space below the diagonal line. When authors only gave mortality rates for the entire life span of each sex, we have indicated their findings as ‘adult mortality’. Species in which females are larger than males are noted by an asterisk preceding the scientific name. Scientific names given in Tables 1 and 2 are not repeated in the text.

RESULTS

It should be kept in mind that the extent of a sex difference in mortality can vary within a species. If the difference between the sexes is fairly small, it may disappear, or even reverse under varying conditions. Geographic location (Tryon and Snyder, 1973; Beer, 1955; Goehring, 1972), population density (Mech, 1975; Smuts, 1970), birth season (Tryon and Snyder, 1973), and food abundance (Dittus, 1977, in press; Geist 1971) are among the variables known to affect sex differences in mortality rates.

Data on non-marine mammals are summarized in Table 1; a general trend towards higher mortality rates in adult males is apparent in the marsupials, primates, rodents, proboscideans and artiodactyls but not in the chiroptera, lagomorphs and carnivores. We will comment here only on the data for primates and artiodactyls.

Abundant data on human populations indicate that male mortality rates are almost always higher than those of females although both the actual rates and the degree of

Table 1.

Summary of data on mortality rates in non-marine mammals by sex and age. Male mortality rates exceeding those of females are indicated by asterisks in the left column, male mortality rates equal to those of females by asterisks in the centre column, and male mortality rates less than those of females by asterisks in the right column. Each column is divided by age into ‘immature’ and ‘adult’ categories. When possible, the ‘immature’ category is subdivided into a ‘juvenile’ category above a diagonal line and a ‘subadult’ category below a diagonal line. Species for which mortality rates were available only for the entire life span are scored under ‘adult’ mortality. Species in which females are larger than males are identified by an asterisk preceding the scientific name (Ralls, 1976).

Taxon	Common name	Mortality rate						Source
		♂ > ♀		♂ = ♀		♂ < ♀		
		Imm	Ad	Imm	Ad	Imm	Ad	
Marsupialia								
<i>Antechinus stuartii</i>	Marsupial mouse	*	*					Wood, 1970.
<i>A. flavipes</i>	Marsupial mouse		*					Lee <i>et al.</i> , 1976.
<i>A. bellus</i>	Marsupial mouse		*					Lee <i>et al.</i> , 1976.
<i>A. swainsoni</i>	Marsupial mouse		*					Lee <i>et al.</i> , 1976.
<i>A. minimus</i>	Marsupial mouse		*					Lee <i>et al.</i> , 1976.
<i>A. bilarni</i>	Marsupial mouse		*					Lee <i>et al.</i> , 1976.
<i>Trichosurus vulpecula</i>	Brush-tail phalanger	*/						Tyndale-Biscoe, 1973.
<i>Pseudocheirus peregrinus</i>	Ring-tail phalanger			*	*			Thomson and Owen, 1964.
<i>Schoinobates volans</i>	Greater flying phalanger	/	*	*/	*			Tyndale-Biscoe and Smith, 1969.
<i>Macropus rufus</i>	Red kangaroo	/	*	*/				Newsome, 1977.
Chiroptera								
<i>Rhinolophus hipposideros</i>	Lesser horseshoe bat				*			Bezem <i>et al.</i> , 1960.
* <i>Myotis lucifugus</i>	Little brown bat	*	*					Humphrey and Cope, 1976.
* <i>M. mystacinus</i>	Whiskered bat				*			Bezem <i>et al.</i> , 1960.
* <i>M. emarginatus</i>	Geoffroy's bat				*			Bezem <i>et al.</i> , 1960.
* <i>M. dasycheme</i>	Pond bat				*			Bezem <i>et al.</i> , 1960.
* <i>M. daubentonii</i>	Daubenton's bat				*			Bezem <i>et al.</i> , 1960.
* <i>M. myotis</i>	Large mouse-eared bat				*			Bezem <i>et al.</i> , 1960.
* <i>M. sodalis</i>	Indiana myotis		*					Humphrey and Cope, 1977.
* <i>Pipistrellus subflavus</i>	Pipistrelle bat						*	Davis, 1966.
* <i>Eptesicus fuscus</i>	Big brown bat				*1		*2	1 Beer, 1955; 2 Goehring, 1972.
Primates								
<i>Perodictus potto</i>	Potto		*					Charles-Dominique, 1977.
<i>Galago alleni</i>	Allen's bushbaby		*					Charles-Dominique, 1977.
<i>Alouatta caraya</i>	Black howler monkey		*			*		Pope, 1968.
<i>Macaca sinica</i>	Toque monkey	/	*			*/		Dittus, 1977.
<i>Macaca mulatta</i>	Rhesus monkey	/	*			*/		Koford, 1966; Drickhamer, 1974.
<i>Papio cynocephalus</i>	Yellow baboon		*					Altmann and Altmann, 1970.
<i>Homo sapiens</i>	Human	*	*					Caughley, 1966; Keyfitz and Flieger, 1968.
Lagomorpha								
* <i>Lepus americanus</i>	Snowshoe hare				*			Meslow and Keith, 1968.
* <i>Oryctolagus cuniculus</i>	European rabbit	/	*		*			Stephens, 1952.

Table 1 (cont.)

Taxon	Common name	Mortality rates						Source
		$\delta > \varphi$		$\delta = \varphi$		$\delta < \varphi$		
		Imm	Ad	Imm	Ad	Imm	Ad	
Rodentia								
<i>Tamiasciurus hudsonicus</i>	Red squirrel				*			Kemp and Keith, 1970.
<i>Spermophilus richardsonii</i>	Richardson ground squirrel		*					Michener and Michener, 1977.
<i>Citellus tridecemlineatus</i>	Thirteen-lined ground squirrel	*	*					Rongstad, 165.
<i>Thomomys bottae mewa</i>	Pocket gopher	*/	*					Howard and Childs, 1959.
<i>Peromyscus leucopus</i>	White-footed mouse			*	*			Snyder, 1956.
<i>Ondatra zibethicus</i>	Muskrat					*/		Sather, 1958; Beer and Truax, 1950.
<i>Microtus orcadensis</i>	Orkney vole		*	*				Leslie <i>et al.</i> , 1955.
<i>Rattus exulans</i>	Polynesian rat		*					Jackson and Barbehenn, 1962.
<i>Rattus diardii</i>	House rat		*					Harrison, 1956; Jackson and Barbehenn, 1962.
<i>Rattus norvegicus</i>	Norway rat		*					Davis, 1953; Schein, 1950.
<i>R. r. argentiventer</i> , <i>R. r. jarak</i> , <i>R. r. jalorensis</i>	House rat, various subspecies				*			Harrison, 1956.
<i>Dasyprocta punctata</i>	Agouti	*	*					Smythe, 1978.
<i>Psammomys obesus</i>	Saharan gerbil		*					Daly, 1974.
<i>Cynomys ludovicianus</i>	Black-tailed prairie dog	*	*					King, 1955.
Carnivora								
<i>Canis familiaris</i>	Domestic dog (stray)		*					Beck, 1973.
<i>Canis latrans</i>	Coyote				*			Nellis and Keith, 1976.
<i>Canis lupus</i>	Wolf	*1				*2		Mech, 1975; 1 high density; 2 low density.
<i>Vulpes vulpes</i>	Red fox	*/						Storm <i>et al.</i> , 1976.
<i>Urocyon cinereoargenteus</i>	Gray fox				*			Wood, 1958.
<i>Lycaon pictus</i>	African wild dog						*	Frame <i>et al.</i> , in press.
<i>Ursus arctos</i>	Grizzly bear		*					Craighead <i>et al.</i> , 1974.
<i>Ursus maritimus</i>	Polar bear			*	*			Stirling <i>et al.</i> , 1976; Lentfer <i>et al.</i> , in press.
<i>Ursus americanus</i>	Black bear		*					Rogers, 1977.
<i>Enhydra lutris</i>	Sea otter	*	*					Kenyon, 1969.
* <i>Crocota crocuta</i>	Spotted hyena						*	Kruuk, 1972.
<i>Lynx rufus</i>	Bobcat		*			*		Fritts and Sealander, 1978.
<i>Panthera leo krugeri</i>	Lion	*	*					Smuts, 1976.
Proboscidea								
<i>Loxodonta africana</i>	African elephant		*					Laws, Parker and Johnstone, 1975.
<i>Elephas maximus</i>	Indian elephant		*					McCay, 1973; Kurt, 1974.
Perissodactyla								
<i>Equus burchelli boehmi</i>	Zebra			*	*			Spinage, 1972.
Artiodactyla								
* <i>Hyemoschus aquaticus</i>	Water chevrotain	*	*					Dubost, 1978.
<i>Cervus elephus</i>	Red deer	*1	*1		*2			Darling, 1937 – 1; Guinness <i>et al.</i> , 1978.
<i>C. elephus canadensis</i>	Wapiti (elk)	*	*1		*2			Peek <i>et al.</i> , 1967; Flook, 1970; Knight, 1970 – 1 limited exploitation, 2 heavy exploitation.
<i>Odocoileus hemionus</i>	Mule deer	/	*			*/		Robinette <i>et al.</i> , 1957.
<i>O. h. columbianus</i> , <i>O. h. sitkensis</i>	Black-tailed deer	*/	*					Taber and Dasmann, 1954, 1957; Klein and Olson, 1960.
<i>Rangifer tarandus</i>	Caribou	*	*					Bergerud, 1971.
<i>Giraffa camelopardalis</i>	Giraffe	/	*					Leuthold and Leuthold, 1978.
<i>Syncerus caffer</i>	African buffalo			*/	*			Sinclair, 1977.
<i>Connochaetus taurinus</i>	Wildebeest	*						Talbot and Talbot, 1963.
<i>Aepyeros melampus</i>	Impala	*	*					Jarman and Jarman, 1973.
<i>Antidorcas marsupialia</i>	Springbok	*	*					Crowe and Liverside, 1972.
<i>Saiga tatarica</i>	Saiga	*	*					Bannikov <i>et al.</i> , 1967.
<i>Oreamnos americanus</i>	Rocky Mountain goat	*						Cowan, 1943.
<i>Ovibus moschatus</i>	Musk ox	*						Tener, 1965.
<i>Ovis aries</i>	Feral sheep	/	*					Grubb, 1974.
<i>Ovis canadensis</i>	Big horn sheep			*1	*	*2		Geist, 1971 – 1 good conditions, 2 poor conditions.

difference between the sexes varies somewhat with time (Bourgeois-Pichat, 1965) and place (Keyfitz and Flieger, 1968). One of the best studies of natural mortality rates in a wild primate is on the toque monkey, *Macaca sinica* (Dittus, 1977). Males had slightly lower mortality rates than females as juveniles but higher rates as adults and far higher rates as subadults. Dittus (in press) reviewed the literature on the genera *Macaca*, *Papio*, and *Alouatta* and reported a pattern similar to that of the toque monkey in all species for which data exist. Slightly lower mortality rates for young males seem to occur when food is scarce. If food is abundant, juvenile mortality rates are similar in males and females. The higher mortality rates of subadult and adult males, however, are not dependent upon food abundance.

Although male artiodactyls are often subjected to higher hunting pressures than females, there is sufficient evidence from unexploited populations to indicate that natural mortality rates of males are higher than those of females in many, perhaps the majority of species. However, a few instances of equal mortality rates in males and females, such as the bighorn sheep (Geist, 1971) and the African buffalo (Sinclair, 1977) have been reported. High subadult male mortality was reported in mule deer, black-tailed deer, giraffe, and feral sheep. Occasional findings of lower male mortality rates in juvenile artiodactyls (Robinette, Gashwiller, Low and Jones, 1957; Geist, 1971) may be analogous to the situation in primates.

In all seven species of pinnipeds, adult female survivorship exceeds that of males (Table 2). Juvenile mortality rates appear to be similar for both sexes in the two species for which data are available.

Ohsumi (1979) summarized available information on biological parameters in cetaceans. He noted that the natural mortality coefficient (M) is estimated from the slope of the right half of the age-composition curve of whales caught from an unexploited population. In populations with a long history of exploitation, the age-composition curve includes the fishing mortality coefficient (F). The total mortality coefficient, Z, equals M + F. The value of F can be neglected if the population has had a relatively short history of exploitation (Ohsumi 1964). With regard to changes in M values by age, Ohsumi (1979) noted the following: (1) M is estimated as constant at least after the age of sexual maturity, (2) M for juveniles is almost impossible to estimate directly from age distribution, and (3) the values of juvenile mortality rates may differ

between toothed and baleen whales because of the great difference in the length of the period of maternal care. With regard to possible sex differences in the value of M, he notes that although there may be such differences, it is presently technically difficult to detect them, and he therefore treats them as being equal. He comments that further study of this problem is needed.

Ohsumi (1979) reported estimates of natural mortality coefficients in five species of odontocetes representing four genera: *Stenella*, *Delphinapterus*, *Globicephala*, and *Physeter*. We will review the evidence for differential mortality by sex and age in these genera in order of increasing degrees of sexual dimorphism. Male/female size ratios for these genera, based on average body lengths of full-grown individuals, given in Ohsumi, are as follows: *Stenella*, 1.06 (*S. coeruleoalba*) to 1.07 (*S. attenuata*); *Delphinapterus*, 1.18; *Globicephala*, 1.26; and *Physeter*, 1.44.

Kasuya, Miyazaki and Dawbin (1974) calculated the Z value of both sexes of spotted dolphins, *Stenella attenuata*, from the western North Pacific to be 0.355 from the age distribution based on dentine layers. They also estimated Z to be 0.077 in females from the corpora composition and annual ovulation rate. However, they believe the former value was too high, because the ages of physically mature animals were often underestimated by dentine layer counts. Kasuya (1976) re-examined Z values from age compositions based on cemental layers and obtained 0.078 and 0.114 for females and males, respectively. The Z value was regarded as almost the same as M, because the stock has been only lightly exploited.

Data on sex ratios in a large sample of *S. attenuata* from an exploited population in the eastern tropical Pacific have been presented by Perrin, Coe and Zweifel (1976). The percentage of males in a series of ontogenetic color pattern stages is shown on Fig. 1, together with the approximate length, weight, and number of tooth-layers spanned by each color pattern stage. The percent of males decreases as the color pattern of the animals changes with age. The largest decrease occurs between the speckled and the mottled stages, at approximately seven to eight tooth-layers. There is probably about a five-layer period during which the onset of puberty may take place (about 7 to 12 layers) and about two to four layers are probably required to attain adult testis size. This period of high male mortality thus appears to be equivalent to the high subadult male mortality seen in some other species of mammals. Perrin, Holts and Miller (1977) found slightly more females than males in samples

Table 2.
Summary of data on mortality rates in pinnipeds by sex and age. Conventions are the same as in Table 1.

Taxon	Common name	Mortality rate						Source
		♂ > ♀		♂ = ♀		♂ < ♀		
		Imm	Ad	Imm	Ad	Imm	Ad	
Pinnipeds								Chapman, 1964; Johnson, 1968.
<i>Callorhinus ursinus</i>	Northern fur seal		*					Bigg, 1969.
<i>Phoca vitulina</i>	Harbor seal		*	*				Smith, 1973, 1975.
<i>Pusa hispida</i>	Ringed seal		*	*				Hewer, 1964, 1974; Mansfield
<i>Halichoerus grypus</i>	Grey seal		*					and Beck, 1977; Mansfield and Prime, 1978.
<i>Leptonychotes weddelli</i>	Weddell seal		*					Siniff <i>et al.</i> , 1977.
<i>Cystophora cristata</i>	Hooded seal		*					Oritsland and Benjaminsen, 1975.
<i>Mirounga leonina</i>	Southern elephant seal	/ *	*					Carrick and Ingham, 1962; Laws, 1960.

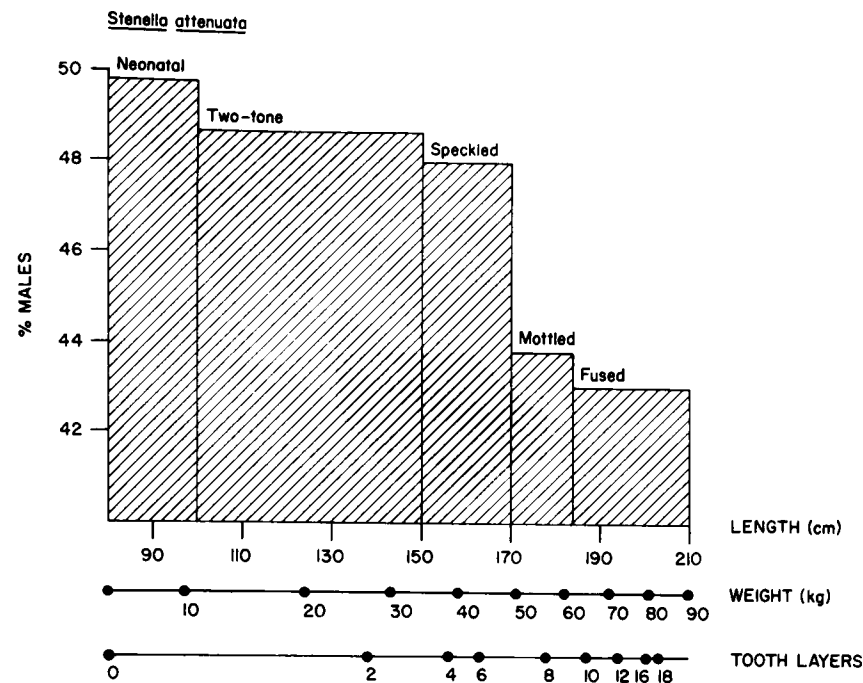


Fig. 1. Percentage of males in the catch of spotted dolphin, *stenella attenuata*, in relation to colour, patterns, length, weight and tooth layer. The percentage of males decreases as the animals mature. Data from Perrin *et al.* (1976).

than a year old. We will not discuss them further as they are not comparable to estimates for other species of odontocetes.

Differential natural mortality rates by sex in the pilot whale, *Globicephala melaena*, have been described by Sergeant (1962). Mortality rates were calculated by plotting logarithms and calculating a least squares fit. These were 0.0445 for females and 0.0580 for males. The considerably higher value for male mortality is in accordance with the known sex ratio favoring females and the considerably lower proportion of old males versus old females, as indicated by animals with completely filled teeth in the age frequency distribution.

Sergeant comments as follows: ‘attempts to construct a life table showed that the divergence between male and female mortality rates should be even greater than is estimated above in order to obtain sex ratios throughout life agreeing with those observed in the population. A difference of the necessary magnitude may quite easily exist, considering the fairly large sampling error inherent in the survival estimates. Among other possibilities, a balanced population model can be obtained by applying a mortality rate of 0.30 for both sexes in the first year, a mortality of 0.035 for females and 0.058 for males aged one to eight, and increasing rates at ages older than eight. However, larger samples are needed in order to determine mortality rates with greater accuracy before a definitive life table can be constructed’.

Ohsumi (1979) doubted that the age distribution reported by Sergeant (1962) reflected the true age distribution of the entire population, because tooth layers were not counted for older animals. Ohsumi estimated the Z value for females to be 0.090 to 0.136, based on the gradient of the corpora distribution shown in Sergeant (1962). He then assumed that the Z value for males was equal to that of females. Although Sergeant (1962) and Ohsumi (1979) both assumed that this stock was lightly exploited and that Z was therefore approximately equal to M, this assumption was false because Mitchell (1974) and Mercer (1975) demonstrated that the stock was severely depleted in the mid 1960’s by a local fishery.

Adult natural mortality rates for North Pacific sperm whales are reviewed by sex in Table 3. The Z values for both sexes were derived from stocks considered to be only lightly exploited and have therefore been equated with the

Table 3.

Estimates of natural mortality coefficients (M) for North Pacific sperm whales.

Location	Female estimates and age	Male estimates and age	Data period	Method	Reference
Japanese Coastal		0.069	1946–50	Age length key (= Z)	Chapman, 1979
Pelagic Areas III, IV, V		0.064	1967	Age length key	Shimadzu, 1970
Pelagic Areas III, IV, V		0.060	1968	Age length key	Shimadzu, 1970
Pelagic	0.058 (20–48)		1967–68	Age sample	Shimadzu, 1970
Japanese Coastal	0.053 (13–50)		1968	Age sample	Shimadzu, 1970
Japanese Coastal		0.081 (26–50)	1960–64	Age length key (= Z)	Ohsumi, 1966
Aleutian		0.071 (24–66)	1961–62	Age length key (= Z)	Ohsumi, 1966
Japanese Coastal	0.073 (12–52)		1960–64	Age sample	Ohsumi, 1966
Japanese Coastal	0.053 (13–47)		1960–61	Age sample	Ohsumi, <i>et al.</i> , 1963

M value. Ohsumi, Kasuya and Nishiwaki (1963) examined the age distribution of 1,226 female sperm whales caught in the Japanese coastal waters in 1960 and 1961. They estimated that the mortality coefficient was 0.053, assuming that one growth layer is laid down per year. Ohsumi (1966) examined the age composition of 1,035 male and 2,237 female sperm whales taken from the coastal waters of Japan between 1960 and 1969, and 1,975 males from the Aleutian waters in 1961 and 1962. Based on this sample, he calculated the following total mortality coefficients: coast of Japan males (from age 26 to 50) – 0.081; and females (from age 12 to 50) – 0.073; and Aleutian males (from age 24 to 66) – 0.071. Shimadzu (1970) examined the age composition of two female samples and two male age-length key samples. Based on these samples, he calculated the following values for M: (1) coastal Japan females in 1968 (from age 13 to 50) – 0.05; (2) pelagic females between 1967 and 1968 (from age 20 to 48) – 0.058; and (3) pelagic males (Areas III, IV, V) in 1967 and 1968 – 0.064 and 0.060, respectively. Chapman (1979) examined the age-length key data for male sperm whales caught in Japanese coastal waters between 1946 and 1950. From these data he calculated the following values for M: (1) 1946 (from age 20 to 34) – 0.073; (2) 1947 (from age 20 to 34) – 0.064; (3) 1948 (from age 20 to 34) – 0.068; (4) 1949 (from age 20 to 34) – 0.073; (5) 1950 (from age 25 to 34) – 0.070. The mean M value for this period was 0.069.

DISCUSSION

Differential Mortality by Sex

The general tendency for the males of mammalian species to suffer higher mortality rates has been observed by many previous authors, including Trivers (1972) and Case (1978). Most current theoreticians agree that a high male mortality rate after the age at which young are independent cannot affect the neonatal sex ratio, which will remain close to equality (Hamilton, 1967; Leigh, 1970; Trivers, 1972; Maynard-Smith, 1978). At least five possible explanations have been offered for the tendency of males to suffer higher mortality rates: unfavorable alleles on the single X chromosome of males, higher metabolic rates in males, greater susceptibility of males to nutritional stress, greater tendencies for males to emigrate, and male-male competition for mates. We will discuss each of these in turn, although they are not mutually exclusive and more than one may apply to a single species.

Single X chromosome

It has often been assumed, particularly in the older literature, that the fact that males may often possess unguarded deleterious alleles on their single X chromosome provides an adequate explanation for the general tendency towards higher mortality rates in males. However Trivers (1972) argued rather effectively that this hypothesis cannot provide a complete explanation, as follows: (1) the distribution of differential mortality by sex is not predicted by a knowledge of which sex is heterogametic, e.g., female birds are heterogametic but suffer a lower mortality rate than males in polygynous species; (2) theoretical predictions of the degree of differential mortality expected by males due to their unguarded X chromosomes are far lower than those observed in many mammals; and (3) castrated domestic cats and human males outlive normal individuals.

Higher Metabolic Rates in Males

Taber and Dasmann (1954) suggested that the higher male mortality rate of black-tailed deer fawns is caused by a higher metabolic rate than females: 'the higher metabolic rate of the male, reflected in its greater activity, curiosity, independence, etc. results in an increased male mortality due to starvation, disease and accidents'. Factors such as increased activity and earlier independence may indeed often predispose young males to a higher mortality rate. However, it seems likely that such qualities are related to social systems in which males rather than females tend to emigrate (see below), rather than to a high metabolic rate *per se*. Moen (1973) states that the few existing data on metabolic rates in wild ruminants do not indicate any sex differences for males and females under similar conditions.

Greater Susceptibility to Nutritional Stress

In all well-studied species (humans, rats, pigs, mink, chickens), females are better able than males to withstand a shortage of food (Widdowson, 1976). For example, in a study involving the undernourishment of young pigs, 87 per cent of the females but only 22 per cent of the males were alive at the end of a year. When young rats were undernourished and then given unlimited food, both sexes responded by gaining weight rapidly, but only females 'caught up' with littermates who had not been starved. Males were permanently reduced in weight. Subadult males undergoing a rapid 'adolescent growth spurt' seem particularly affected by inadequate nutrition. This greater susceptibility of males to nutritional stress appears to be due to the effect of androgens in causing an increased utilization of protein (Widdowson, 1976).

However, the effects of food shortages on wild populations may depend on other variables as well as susceptibility to nutritional stress. If males are larger than females they may be able to dominate them in social encounters and thus obtain a larger share of the available food, as in juvenile toque monkeys (Dittus 1977), or if they have larger fat reserves they may be able to fast for longer periods than females, as in California sea lions, *Zalophus californianus*, (Schusterman and Gentry, 1971).

Greater Tendency for Males to Emigrate

Sex differences in dispersal are common in vertebrates; in mammals the most common pattern is greater male than female dispersal (Greenwood, in press). This differential dispersal may have evolved because of the selective advantages of avoiding inbreeding (Maynard-Smith, 1978).

As the results of long-term studies of the social organization of group-living mammals accumulate, it is becoming increasingly clear that in the majority of species, stable groups are composed of genetically related females. In these species, males normally leave the group in which they were born, while a proportion of the females remain permanently with their mother and other female relatives. Female kin groups have been documented in many species such as baboons (*Papio* spp.), elephants, lions and coatis, *Nasua nasua*, (Wilson, 1975). Emigration exposes young males to nutritional stress and high risks of predation and accident not suffered by females. They are then subjected to further stress from strange conspecifics when they attempt to establish themselves in a new social group.

Only a few mammalian species are known in which the usual pattern is reversed and females rather than males transfer to new groups: some rodents (Lidicker, 1975) and, among larger mammals, zebras, chimpanzees, *Pan troglo-*

dytes, gorillas, *Gorilla gorilla*, and African wild dogs (Greenwood, in press). In the African wild dog, mortality rates of females are considerably higher than those of males (Frame, Malcolm, Frame and Van Lawick, in press).

Male-Male Competition

In species having promiscuous or polygynous mating systems, the number of matings a male may attain is potentially large and there is an increased selective premium on morphological, behavioral and physiological characteristics that function in epigamic and intrasexual interactions directly related to mating. With increased competition among males for mating, characteristics promoting survival of the male have a relatively reduced influence on the total fitness of the individual, and Darwin's theory predicts (Huxley, 1938) that characteristics such as large size and aggressiveness may develop to a point in which mortality rates are much higher in males than in females.

Thus the extent of sex differences in adult mortality rates may often be related to the social system of a species. It is instructive to consider the carnivore data in Table 1 in this light. Two of the three species (coyote, gray fox) in which adult mortality rates are equal are monogamous (Kleiman, 1977) and the two species in which adult female mortality rates are higher than those of males have very unusual social systems in which competition among females may be more severe than among males. The hyena lives in matriarchal clans (Kruuk, 1972) and wild dogs live in packs which typically consist of one female and several unrelated males (Frame *et al.*, in press).

Many authors have commented that male-male competition appears to contribute to high adult male mortality rates in polygynous species. A thorough discussion of this point is given by Trivers (1972); we will provide only a few examples here. Flook (1970) points out that male wapiti enter the winter with lower fat reserves than females due to their strenuous activity and lack of time for feeding during the fall rut. They are thus less well prepared for the food shortages and cold temperatures of winter than are the females. The same probably applies to many other seasonally breeding cervids. Johnson (1968) commented as follows on fur seals: 'Apparently, the competition for territories, and other rigors associated with the breeding season, increases the mortality of adult males. Many of the males found dead had wounds from fighting so it is likely that the competition among males to obtain and hold breeding territories is an important cause of natural mortality'. According to Stirling (1975) the situation in the pinnipeds conforms to the theoretical expectation that the extent of the difference between adult male and female mortality rates should be related to the degree of polygyny. 'In general, highly polygynous species have disparate adult sex ratios and the annual mortality rate of adult males greatly exceeds that of adult females . . . this is generally assumed to be the result of intense competition between males for eventual reproductive status, a goal which only a small proportion of each cohort can achieve. In promiscuous species, where more males are required for reproduction, the difference in adult sex ratio is much less marked . . . indicating that the difference between adult male and female mortality rates is not as great'.

Holt (1979) suggested that in sexually dimorphic vertebrate species, the larger sex should have the higher mortality rate. In mammals in which males are considerably larger than females, this is a reasonable prediction. There are no

known instances of a extremely dimorphic monogamous species (Kleiman, 1977) although a few cases of polygynous species in which males do not exceed females in size have been reported (Ralls, 1976, 1977). Thus extreme dimorphism favoring males in mammals does generally seem to be related to the advantages of large size on male-male competition in these species. However, female mammals rarely, if ever, compete among themselves in order to mate with as many males as possible (Ralls, 1976). Large size in females often appears to be related to other factors, such as the selective advantages of producing a large baby in many bats (Ralls, 1976; Myers, 1978) or of having greater energy reserves available during gestation in baleen whales (Downhower, 1979). Thus, one would predict on theoretical grounds that a larger size in the female sex would not necessarily be associated with a higher mortality rate in this sex. This appears to be true. Females average larger than males in several species listed in Table 1: nine bats belonging to the family Vespertilionidae, two lagomorphs, the spotted hyena and the African water chevrotain; and in one species listed in Table 2: the Weddell seal (Ralls, 1976; Myers, 1978). Male mortality rates exceed those of females in two of the bats, the chevrotain, and the seal.

Case (1978) argued that, in vertebrates as a whole, there is an association between a high juvenile mortality rate and rapid growth. He proposed that this is also true within a species; the faster-growing sex having the higher juvenile mortality rate. The faster growing sex is usually the one attaining the greatest adult size, thus he predicted that the larger sex should have the higher juvenile mortality rate. This does not appear to be true in mammals as there are several species in Table 1 in which males are larger than females yet have lower mortality rates as juveniles, at least under some conditions, such as the toque monkey, muskrat, lynx, wolf, mule, deer and bighorn sheep. Case (1978) listed four species in support of the idea that species in which females are the larger sex also tend to have higher mortality rates: rabbits (Stephens, 1952), jack-rabbits (Brand, Vowles and Keith, 1975), spotted hyenas (Kruuk, 1972), and blue whales, *Balaenoptera musculus*, (Ichihara, 1966). However, the spotted hyena is the only valid example of the four. Stephens (1952) indicated that male mortality exceeds that of females in subadult rabbits, Brand *et al.* (1975) gave no data on sex-specific mortality rates in jack-rabbits, and Ichihara (1966) indicates that male mortality rates slightly exceed those of females in blue whales. However, it would be useful to review mortality rates by sex in baleen whales. Rice (1977) estimated that in the eastern North Pacific sei whales, *Balaenoptera borealis*, the annual mortality rates after sexual maturity were 0.088 and 0.103 for females and males, respectively. In Southern Hemisphere sei whales, Ohsumi (1978) estimated that the natural mortality coefficients were 0.080 and 0.065 for females and males, respectively.

Differential Mortality by Age

Caughley (1966, 1977) suggested that the typical mammalian mortality pattern is 'U-shaped', consisting of a juvenile phase in which the rate of mortality is initially high but rapidly decreases, followed by a post-juvenile phase characterized by a initially low but steadily increasing rate of mortality. The available evidence suggests that most female mortality patterns do conform to this shape. This is true for the Orkney vole (Leslie, Tener, Vizoso and Chitty, 1955), the toque monkey (Dittus, 1977), humans (Dublin

and Lotka, 1936), buffalo (Sinclair, 1977), the Himalayan tahr, *Hemitragus Jemlahicus*, and the domestic sheep (Caughley, 1966).

The mortality patterns of some male mammals, however, do not seem to be 'U-shaped'. Three examples are shown in Fig. 2; toque monkey, *Macaca sinica*, impala, *Aepyceros melampus*, human, *Homo sapiens*. Both male toque monkeys and impala have a high mortality rate as subadults; a similar but much less dramatic peak is apparent in the human data when it is plotted on a semi-log scale. In the toque monkey, this high subadult mortality occurs during the period when sexually maturing young males leave the troop in which they are born and emigrate to another group. During this period, they suffer from sub-optimal nutrition and are exposed to a high risk of predation. As they attempt to become accepted in a foreign social group, they undergo frequent threats, attacks, and other forms of social stress and many do not survive. However, the individuals who do survive and succeed in establishing themselves in a new group then have a considerably reduced mortality rate (Dittus, 1977).

The impala shows a similar picture. Jarman and Jarman (1973) comment as follows: 'the weaned juvenile male is driven out of the female herd by a territorial male. He waits near the herd, hoping for a chance to rejoin it, which he may do for a time. But after repeated evictions he starts to associate with bachelor groups where, being the youngest and smallest, he is at the bottom of the age-based hierarchy and spends much of his time avoiding the others. He gradually integrates with bachelor society, establishes an individual hierarchical rank, and remains in male company either until a dry season when territoriality collapses and he can mingle with females or until he holds a territory himself. . . . This process exposes the male to risks over and above those experienced by females. Firstly, he is physically harassed, frightened and possibly exhausted when being evicted by the territorial male. Secondly, he spends some time alone waiting on the fringes of female herds, eating rather little and alert to the aggression of the territorial male rather than to the possibility of predation. At this stage he must change from herd-reliance to self-reliance for anti-predator watchfulness. Thirdly, he becomes subordinate within the bachelor society, where he is at first found peripherally within the herds, somewhat deprived of undisturbed feeding time and alert to aggression. Fourthly, in the bachelor herd he is in a herd that is smaller, more dispersed and at times less co-ordinated than that of the females. Any of these factors might be detrimental, either through increasing the male's energy expenditure or reducing his food consumption or exposing him to the risk of attack from predators. Whichever of these is effective in any situation is unknown, but the net result is that, between weaning and three years of age, males die faster than females'.

Impala in southern and eastern Africa differ in the proportion of the year during which adult males are effectively territorial, and consequently in the age at which young males are driven from female herds. A comparable difference in the age at which male mortality accelerates relative to female's is strong evidence that the sex difference in subadult mortality is ultimately due to the social organization imposed by adult males (Jarman and Jarman, 1973). If a male impala survives the subadult stage, he has a considerably reduced chance of mortality, like the toque monkey, for the next several years. Male impala show another mortality peak at eight years, the age when most

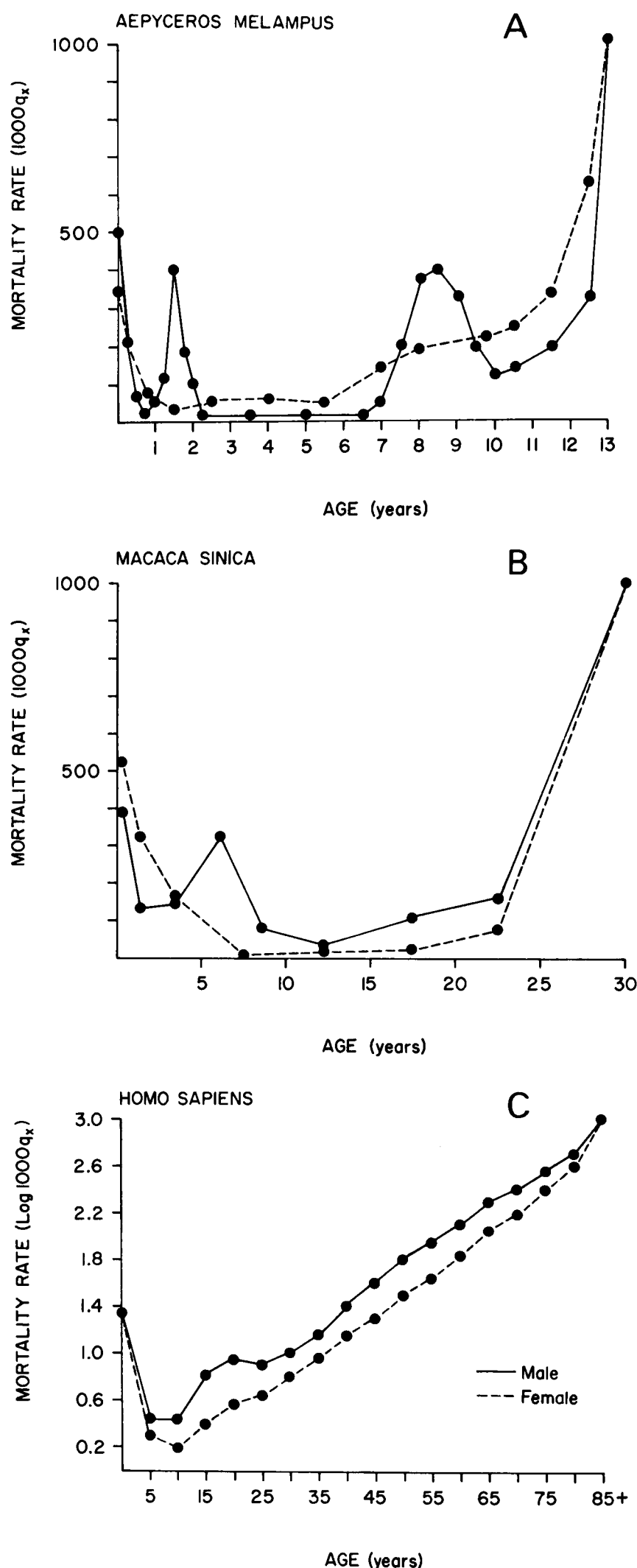


Fig. 2. Mortality curves for three mammalian species in which the pattern of male mortality is not 'u-shaped'. (a) Impala, *Aepyceros melampus*, based on data at Jarman and Jarman (1973); (b) toque monkey, *Macaca sinica*, based on data at Dittus (1977); (c) Human, *Homo sapiens*, based on data on Keyfitz and Flieger (1968).

males can no longer successfully maintain territories against younger, more vigorous males (Jarman and Jarman, 1973). The impala data also show that the relationship between male and female mortality rates can change with age even in adulthood and that it is probably an oversimplification to

assume, as we and many others have done, that it remains constant.

The general pattern of male emigration in mammals and the frequency of intense competition between males in polygynous species suggest that it may be rather common for male mammals to have mortality patterns which are not 'U-shaped'.

Probable Mortality Patterns in Sperm Whales

Although present calculations of mortality rates in the genera *Stenella*, *Globicephala*, and *Physeter* suffer from a number of probable biases, reports of higher male mortality in these genera are consistent with a general mammalian pattern. The high subadult male mortality found by Perrin *et al.* (1976) in *S. attenuata* represents a common mammalian pattern and is likely to be a real phenomenon. The three genera from a series showing an increasing degree of sexual dimorphism, and presumably polygyny, *Physeter* being the most extreme. According to theoretical predictions these genera should also form a series showing increasing degrees of higher mortality rates in males.

Sperm whales are polygynous and are more dimorphic than any other mammalian species except for a few of the pinnipeds. (Best, 1979; Ralls, unpublished data). Large sperm whale males have many scars, apparently caused by wounds from teeth, on their heads and backs. It seems probable that these are the result of fights with other males as females and young males do not have them (Ohsumi, 1971; Best, 1979), and that male-male competition contributes to high male mortality rates in sperm whales as in many other polygynous mammalian species.

The current assumption of equal mortality rates for males and females in this species thus appears extremely unlikely on both theoretical and comparative grounds. Furthermore, all actual estimates of natural mortality rates for male sperm whales are higher than both the comparable estimates for females (see Table 3) and the natural mortality rate of 0.05 currently used for both sexes. We therefore recommend that actual estimates of the natural mortality rate for each sex be used in the sperm whale model.

It also seems unlikely that the current assumption that the mortality rates of both sexes remain constant after the age of two years is true. Males in particular may have high subadult mortality rates, and both sexes undoubtedly have higher mortality rates in old age. However, we feel that it would be premature to introduce age-specific mortality rates for animals older than two years into the model without additional data.

ACKNOWLEDGEMENTS

We thank Glenn Hausfater, Robert S. Hoffmann, Steven R. Humphrey, Edward Mitchell, William F. Perrin, Tim D. Smith, Ian Stirling, Richard W. Thorington Jr. and Christen Wemmer for suggesting references; Douglas P. DeMaster, John F. Eisenberg, James A. Estes, Ancel M. Johnson, Toshio Kasuya, Devra G. Kleiman and James Mead for references and comments on an early draft of the manuscript; Sigurd James for graphics, and Trish Roberts, Paul Schmelzer and William Poe for typing the manuscript.

REFERENCES

Altmann, S. A. and Altmann, J. 1970. *Baboon Ecology*. Univ. Chicago Press. 220pp.

- Bannikov, A. G., Zhirnov, L. V., Lebedeva, L. S. and Fandeev, A. A. 1967. *Biology of the Saiga* (English translation). U.S. Dept. of Commerce, Clearinghouse for Federal Scientific and Technical Information, Springfield, VA 22151 USA. 252pp.
- Beck, A. M. 1973. *The Ecology of Stray Dogs: a study of free-ranging urban animals*. York Press, Baltimore, Maryland. 98pp.
- Beer, J. R. 1955. Survival and movements of banded big brown bats. *J. Mammal.* 36: 242-8.
- Beer, J. R. and Truax, W. 1950. Sex and age ratios in Wisconsin muskrats. *J. Wildl. Mgmt.* 14: 323-31.
- Beer, J. R., Frenzel, L. D. and MacLeod, C. F. 1958. Sex ratios of some Minnesota rodents. *Amer. Midl. Nat.* 59: 518-24.
- Bergerud, A. T. 1971. The population dynamics of Newfoundland caribou. *Wildl. Monogr.* 25: 1-55.
- Best, P. B. 1979. Social organization in sperm whales, *Physeter macrocephalus*. pp. 227-85. In: H. E. Winn and B. L. Olla (eds.) *Behaviour of Marine Animals*. Vol. 3. Cetaceans. Plenum Press, New York and London.
- Bezern, J. J., Sluiter, J. W. and van Heerdt, P. F. 1960. Population statistics of five species of the bat genus *Myotis* and one of the genus *Rhinolophus*, hibernating in the caves of S. Limburg. *Arch. Néerlandaises Zool.* 13: 512-39.
- Bigg, M. A. 1969. The harbour seal in British Columbia. *Bull. Fish. Res. Board Can.* 172: 1-33.
- Bourgeois-Pichat, J. 1965. The general development of the population of France since the eighteenth century. pp. 474-506. In: D. V. Glass and D. E. C. Eversley (eds.) *Population in History, Essays in Historical Demography*. Aldine Pub. Co. Chicago. 692pp.
- Brand, C. J., Vowles, R. H. and Keith, L. B. 1975. Snowshoe hare mortality monitored by telemetry. *J. Wildl. Mgmt.* 39: 741-7.
- Carrick, R. and Ingham, S. E. 1962. Studies on the southern elephant seal, *Mirounga leonina* (L.), V. Population dynamics and utilization. *C.S.I.R.O. Wildl. Res.* 7: 198-206.
- Case, T. J. 1978. On the evolution and adaptive significance of postnatal growth rates in the terrestrial vertebrates. *Quart. Rev. Biol.* 53: 243-82.
- Caughley, G. 1966. Mortality patterns in mammals. *Ecology* 47: 906-18.
- Caughley, G. 1977. *Analysis of Vertebrate Populations*. Wiley & Sons, London, 234pp.
- Chapman, D. G. 1964. A critical study of Pribilof fur seal population estimates. *Fish. Bull.* 63: 657-69.
- Chapman, D. G. 1979. Natural mortality rate - males. Paper SC/SPC/18 (published in this volume).
- Charles-Dominique, P. 1977. *Ecology and Behaviour of Nocturnal Primates*. Columbia Univ. Press, New York. 277pp.
- Cowan, I. McT. 1943. Report on some conditions in Banff, Jasper and Kootenay National Parks. *Can. Wildl. Serv., Rep.* C313, Ottawa.
- Craighead, J. J., Varney, J. R. and Craighead, F. C. Jr. 1974. A population analysis of the Yellowstone grizzly bears. *Bull. Mont. Forest Cons. Expt. Station.* 40: 1-20.
- Crowe, T. M. and Liverside, R. 1977. Disproportionate mortality of males in population of springbok (*Artiodactyla: Bovidae*) *Zool. Afr.* 12: 469-74.
- Daly, M. and Daly, S. 1974. Spatial distribution of a leaf-eating Saharan gerbil (*Psammomys obesus*) in relation to its food. *Mammalia* 38: 591-603.
- Darling, F. 1937. *A Herd of Red Deer*. Oxford Univ. Press, Oxford. 226pp.
- Davies, D. E. 1953. The characteristics of rat populations. *Quart. Rev. Biol.* 28: 373-401.
- Davis, W. E. 1966. Population dynamics of the bat *Pipistrellus subflavus*. *J. Mammal.* 47: 383-396.
- Dittus, W. P. J. 1977. The social regulation of population density and age-sex distribution in the toque monkey. *Behavior* 63: 281-322.
- Dittus, W. P. J. (in press). The social regulation of primate populations: a synthesis. In: D. Lindburg (ed.) *The Macaques: studies in ecology, behaviour and evolution*. Van Nostrand Reinhold Co., New York.
- Downhower, J. F. 1976. Darwin's finches and the evolution of sexual dimorphism in body size. *Nature* 263: 558-63.
- Drickhamer, L. C. 1974. A ten-year summary of reproductive data for free-ranging *Macaca mulatta*. *Folia primat.* 21: 61-80.
- Dubost, G. 1978. Un aperçu sur l'écologie du chevrotain africain *Hyemoshus aquaticus* Ogilby, Artiodactyle Tragulide. *Mammalia* 42: 1-62.
- Dublin, L. I. and Lotka, A. J. 1936. *Length of Life: a study of the life table*. Ronald Press, New York. 400pp.

- Flook, D. R. 1970. Causes and implications of an observed sex differential in the survival of wapiti. *Can. Wildl. Serv. Rep. Ser.* 11: 1-71.
- Frame, L. H., Malcolm, J. R., Frame, G. W. and van Lawick, H. (in press). Social organization of African wild dogs (*Lycaon pictus*) on the Serengeti Plains. *Z. Tierpsychol.*
- Fritts, S. H. and Sealander, J. A. 1978. Reproductive biology and population characteristics of bobcats (*Lynx refus*) in Arkansas. *J. Mammal.* 59: 347-53.
- Geist, V. 1971. *Mountain Sheep: a study in behaviour and evolution* Univ. Chicago Press. 383pp.
- Goehring, H. H. 1972. Twenty year study of *Eptesicus fuscus* in Minnesota. *J. Mammal.* 53: 201-7.
- Greenwood, P. J. (in press). Mating systems, philopatry and dispersal in birds and mammals. *Anim. Behav.*
- Grubb, P. 1974. Population dynamics of the Soay sheep. pp 242-72. In: P. Jewell, C. Milner, and J. M. Boyd, (eds.) *Island Survivors*. Athlone Press, London, 386pp.
- Guinness, F. E. Clutton-Brock, T. H. and Albon, S. D. 1978. Factors affecting calf mortality in red deer (*Cervus elaphus*). *J. A. Anim. Ecol.* 47: 817-32.
- Hamilton, W. D. 1967. Extraordinary sex ratios. *Science* 156: 477-88.
- Harrison, J. L. 1956. Survival rates of Malayan rats. *Bull. Raffles Mus.* 27: 5-26.
- Harwood, J. and Prime, J. H. 1978. Some factors affecting the size of British gray seal populations. *J. Appl. Ecol.* 15: 401-11.
- Hewer, H. R. 1964. The determination of age, sexual maturity, longevity, and a life table in the gray seal (*Halichoerus grypus*). *Proc. Zool. Soc. Lond.* 142: 593-623.
- Hewer, H. R. 1974. *British Seals*. Collins, London. 256pp.
- Holt, S. J. 1979. Two concerns about the sperm whale model. Paper SC/SP78/17 (published in this volume).
- Howard, W. E. and Childs, Jr., H. E. 1959. Ecology of pocket gophers with emphasis on *Thomomys bottae mewa*. *Hilgardia* 29: 277-358.
- Humphrey, S. R. and Cope, J. B. 1976. Population ecology of the little brown bat, *Myotis lucifugus*, in Indiana and North-Central Kentucky. *Amer. Soc. Mammal. Spec. Publ.* 4: 1-81.
- Humphrey, S. R. and Cope, J. B. 1977. Survival rates of the endangered Indiana bat, *Myotis sodalis*. *J. Mammal.* 58: 32-6.
- Huxley, J. S. 1938. The present standing of the theory of sexual selection. pp. 11-42. In: G. R. de Beer (ed.) *Evolution*. Clarendon Press, Oxford.
- Ichihara, T. 1966. The pygmy blue whale, *Balaenoptera musculus brevicauda*, a new subspecies from the Antarctic. pp. 79-103. In: K. S. Norris (ed.) *Whales, Dolphins and Porpoises*. Univ. California Press, Berkeley.
- Jackson, W. B. and Barbehenn, K. R. 1962. Longevity and mortality. pp. 107-113. In: T. I. Storer (ed.) *Pacific Island Rat Ecology*. Bull. Bernice P. Bishop Museum. 225.
- Jarman, P. J. and Jarman, M. V. 1973. Social behavior, population structure and reproduction potential in impala. *E. Afr. Wildl. J.* 11: 329-38.
- Johnson, A. M. 1968. Annual mortality of territorial male fur seals and its management significance. *J. Wildl. Mgmt.* 32: 94-9.
- Kasuya, T. 1976. Reconsideration of life history parameters of the spotted and striped dolphins based on cemental layers. *Sci. Rep. Whales Res. Inst., Tokyo.* 28: 73-106.
- Kasuya, T. and Miyazaki, N. 1976. The stock of *Stenella coeruleoalba* off the Pacific coast of Japan. Paper ACMRR/MM/SC 25, FAO Scientific Consultation on Marine Mammals, Bergen.
- Kasuya, T., Miyazaki, N. and Dawbin, W. H. 1974. Growth and reproduction of *Stenella attenuata* in the Pacific coast of Japan. *Sci. Rep. Whales Res. Inst., Tokyo.* 26: 157-226.
- Kemp, G. A. and Keith, L. B. 1970. Dynamics and regulation of red squirrel (*Tamiasciurus hudsonicus*) populations. *Ecology* 51: 763-79.
- Kenyon, K. W. 1969. The sea otter in the eastern Pacific Ocean. *North Amer. Fauna.* 68: 1-352.
- Keyfitz, N. and Flieger, W. 1968. *World Population: and analysis of vital data*. Univ. Chicago Press. 672pp.
- King, C. M. 1975. The sex-ratio of trapped weasels (*Mustela nivalis*). *Mammal Rev.* 5: 1-8.
- King, J. A. 1955. Social behaviour, social organization, and population dynamics in a black-tailed prairie dog town in the Black Hills, of South Dakota. *Contr. Lab. Vert. Biol. Mich.* 67: 1-123.
- Kleiman, D. G. 1977. Monogamy in mammals. *Quart. Rev. Biol.* 52: 39-69.
- Klein, D. R. and Olson, S. T. 1960. Natural mortality patterns of deer in Southeast Alaska. *J. Wildl. Mgmt.* 24: 80-8.
- Knight, R. R. 1970. The Sun River elk herd. *Wildl. Monogr.* 23: 1-66.
- Koford, C. B. 1966. Population changes in rhesus monkeys at Cayo Santiago, 1960-64. *Tulane Stud. Zool.* 13: 1-7.
- Kruuk, H. 1972. *The Spotted Hyena: a study of predation and social behavior*. Univ. Chicago Press. 335pp.
- Kurt, F. 1974. Remarks on the social structure and ecology of the Ceylon elephant in the Yala National Park. pp. 618-34. In: V. Geist and F. Walther (eds.) *The Behavior of Ungulates and its relation to Management*. IUCN Publ. (new series) 2: 618-34.
- Laws, R. M. 1960. The southern elephant seal (*Mirounga leonina* Linn.) at South Georgia. *Norsk Hvalfangsttid.* 49: 466-76 and 520-4.
- Laws, R. M., Parker, I. S. C. and Johnstone, R. C. B. 1975. *Elephants and their Habitats: the ecology of elephants in North Bunyoro, Uganda*. Clarendon Press, Oxford. 376pp.
- Lee, A. K., Bradley, A. J. and Braithwaite, R. W. 1976. Corticosteroid levels and male mortality in *Antechinus stuartii*. pp. 209-220. In: B. Stonehouse and D. Gilmore (eds.) *The Biology of Marsupials*. Univ. Park Press, Baltimore/London/Tokyo.
- Leigh, E. G., Jr. 1970. Sex ratio and differential mortality between the sexes. *Amer. Nat.* 104: 205-10.
- Lentfer, J. W., Hensel, R. J., Gilbert, J. R. and Sorensen, F. F. (in press). Population characteristics of Alaskan polar bears. In: *Bears, Their Biology and Management*. IUCN Publ. (new series) vol. 4.
- Leslie, P. H., Tener, J. S., Vizoso, M. and Chitty, H. 1955. The longevity and fertility of the Orkney vole, *Microtus orcadensis*, as observed in the laboratory. *Proc. Zool. Soc. Lond.* 125: 115-25.
- Leuthold, B. M. and Leuthold, W. 1978. Ecology of the giraffe in Tsavo East National Park, Kenya. *E. Afr. Wildl. J.* 16: 1-20.
- Lidicker, W. Z., Jr. 1975. The role of dispersal in the demography of small mammals. pp 103-128. In: Petruszewicz, E. B. Golley and L. Ryszkowski (eds.) *Small Mammal Productivity and Dynamics of Populations*. Cambridge Univ. Press, London.
- Mansfield, A. W. and Beck, B. 1977. The grey seal in eastern Canada. *Fish. Mar. Serv. Tech. Rep.* 704: 1-81.
- Maynard-Smith, J. 1978. *The Evolution of Sex*. Cambridge Univ. Press. 222pp.
- McKay, G. M. 1973. Behavior and ecology of the Asiatic elephant in South-eastern Ceylon. *Smith. Contrib. Zool.* 125: 1-113.
- Mech, L. D. 1975. Disproportionate sex ratios in wolf pups. *J. Wildl. Mgmt.* 39: 737-40.
- Mercer, M. C. 1975. Modified Leslie-Delury population models of the long-finned pilot whale (*Globicephala melaena*) and annual production of the short-finned squid (*Illex illecebrosus*) based upon their interaction at Newfoundland. *J. Fish. Res. Bd Can.* 32: 1145-54.
- Meslow, E. C. and Keith, L. B. 1968. Demographic parameters of a snowshoe hare population. *J. Wildl. Mgmt.* 32: 812-34.
- Mitchell, E. 1974. Present status of northwest Atlantic fin and other whale stocks. pp. 108-169. In: W. E. Schevill (ed.) *The Whale Problem: a status report*. Harvard Univ. Press, Cambridge, Massachusetts, 419pp.
- Michener, G. R. and Michener, D. R. 1977. Population structure and dispersal in Richardson's ground squirrels. *Ecology* 58: 325-68.
- Moen, A. N. 1973. *Wildlife Ecology*. W. H. Freeman, San Francisco. 458pp.
- Myers, J. and Krebs, C. 1971. Sex ratios in open and closed vole populations: demographic implications. *Amer. Nat.* 105: 325-44.
- Myers, P. 1978. Sexual dimorphism in size of vespertilionid bats. *Amer. Nat.* 112: 701-11.
- Nellis, C. H. and Keith, L. B. 1976. Population dynamics of coyotes in central Alberta, 1964-68. *J. Wildl. Mgmt.* 40: 389-99.
- Newsome, A. E. 1977. Imbalance in the sex ratio and age structure of the red Kangaroo, *Macropus rufus*, in central Australia pp. 221-36. In: B. Stonehouse and D. Gilmore (eds.) *The Biology of Marsupials*. Univ. Park Press, Baltimore, Maryland.
- Ohsumi, S. 1964. Examination on age determination of the fin whale. *Sci. Rep. Whales Res. Inst., Tokyo.* 18: 123-48.
- Ohsumi, S. 1966. Sexual segregation of the sperm whale in the North Pacific. *Sci. Rep. Whales Res. Inst., Tokyo.* 20: 1-16.

- Ohsumi, S. 1971. Some investigations on school structure of sperm whale. *Sci. Rep. Whales Res. Inst., Tokyo*. 23: 1-25.
- Ohsumi, S. 1978. Estimation of natural mortality rate, recruitment rate and age at recruitment of Southern Hemisphere sei whales. *Rep. int. Whal. Commn* 28: 437-48.
- Ohsumi, S. 1979. Interspecies relationships among some biological parameters in cetaceans and estimation of natural mortality coefficient of the Southern Hemisphere minke whale. *Rep. int. Whal. Commn* 29: 397-406.
- Ohsumi, S., Kasuya, T. and Nishiwaki, M. 1963. Accumulation rate of dentinal growth layers in the maxillary tooth of the sperm whale. *Sci. Rep. Whales Res. Inst., Tokyo* 17: 15-35.
- Øritsland, T. and Benjaminsen, T. 1975. Sex ratio, age composition and mortality of hooded seals at Newfoundland. *Intnl. Comm. Northwest Atl. Fish. Res. Bull.* 11: 135-43.
- Peek, J. M., Lovaas, A. L. and Rouse, R. A. 1967. Population changes within the Gallatin elk herd, 1932-65. *J. Wildl. Mgmt.* 31: 304-16.
- Perrin, W. F., Coe, J. M. and Zweifel, J. R. 1976. Growth and reproduction of the spotted porpoise, *Stenella attenuata*, in the offshore eastern tropical Pacific. *Fish. Bull.* 74: 229-69.
- Perrin, W. F., Holts, D. B. and Miller, R. B. 1977. Growth and reproduction of the eastern spinner dolphin, a geographical form of *Stenella longirostris*, in the eastern tropical Pacific. *Fish. Bull.* 75: 725-50.
- Pope, B. L. 1968. II. Population characteristics. pp. 13-20. In: M. R. Malinow (ed.) *Biology of the howler monkey (Alouatta caraya)*. *Bibliotheca Primatologica*, No. 7.
- Ralls, K. 1976. Mammals in which females are larger than males. *Quart. Rev. Biol.* 51: 245-76.
- Ralls, K. 1977. Sexual dimorphism in mammals: avian models and unanswered questions. *Am. Nat.* 111: 917-38.
- Rice, D. W. 1977. Synopsis of biological data on the sei whale and Bryde's whale in the eastern North Pacific. *Rep. int. Whal. Commn* (special issue 1): 92-7.
- Robinette, W. L., Gashwiller, J. S., Low, J. B. and Jones, D. A. 1957. Differential mortality by sex and age among mule deer. *J. Wildl. Mgmt.* 21: 1-16.
- Rogers, L. 1977. Social relationships, movements, and population dynamics of black bears in northeastern Minnesota. Unpublished doctoral dissertation, Univ. Mich., 194 pp.
- Rongstad, O. J. 1965. A life history study on the thirteen-lined ground squirrel in southern Wisconsin. *J. Mammal.* 46: 76-87.
- Sather, J. H. 1958. Biology of the muskrat. *Wildl. Monogr.* 2: 1-35.
- Schein, M. W. 1950. The relation of sex ratio to physiological age in the wild Brown Rat. *Amer. Nat.* 84: 489-96.
- Schusterman, R. J. and Gentry, R. L. 1971. Development of a fattened male phenomenon in California sea lions. *Devel. Psychobiol.* 4: 333-9.
- Sergeant, D. E. 1962. The biology of the pilot or pothead whale *Globicephala melaena* (Traill) in Newfoundland waters. *Bull. Fish. Res. Bd Can.* 132: 1-84.
- Sergeant, D. E. 1973. Biology of white whales (*Delphinapterus leucas*) in western Hudson Bay. *J. Fish. Res. Bd Can.* 30: 1065-90.
- Shimadzu, Y. 1970. Natural mortality coefficient and rate of exploitation for sperm whales in the North Pacific Paper Sp/11, presented at the IWC Scientific Committee Sperm Whale Biology and Stock Assessments Meeting, Honolulu, March 1970.
- Sinclair, A. R. E. 1977. *The African Buffalo: a study of resource limitation of populations*. Univ. Chicago Press. 355 pp.
- Siniff, D. B., DeMaster, D. P. and Hofman, R. J. 1977. An analysis of the dynamics of a Weddell seal population. *Ecol. Monogr.* 47: 319-35.
- Smith, T. G. 1973. Population dynamics of the ringed seal in the Canadian eastern Arctic. *Bull. Fish. Res. Bd Can.*, 18: 1-55.
- Smith, T. G. 1975. Parameters and dynamics of ringed seal populations in the Canadian Eastern Arctic. *Rapp. P.-V. Réun. CIEM* 169: 281-95.
- Smuts, G. L. 1976. Population characteristics and recent history of lions in two parts of the Kruger National Park. *Koedoe* 19: 153-64.
- Smythe, N. 1978. The natural history of the Central American agouti (*Dasyprocta punctata*). *Smith. Contrib. Zool.* 257: 1-52.
- Snyder, D. P. 1956. Survival rates and population fluctuations of the white-footed mouse. *Misc. Publ. Mus. Zool. Univ. Michigan* 95: 1-33.
- Spinage, C. A. 1972. African ungulate life tables. *Ecology* 53: 645-52.
- Stephens, M. N. 1952. Seasonal observations on the wild rabbit (*Oryctolagus cuniculus cuniculus* L.) in West Wales. *Proc. Zool. Soc. Lond.* 122: 412-34.
- Stirling, I., Pearson, A. M. and Bunnell, F. L. 1976. Population ecology studies of polar and grizzly bears in northern Canada. *Trans. North. Amer. Wildl. Conf.* 41: 421-30.
- Storm, G. L., Andrews, R. D., Philips, R. L., Bishop, R. A., Siniff, D. B. and Tester, J. R. 1976. Morphology, reproduction, dispersal, and mortality of Midwestern red fox populations. *Wild. Monogr.* 49: 1-82.
- Taber, R. D. and Dasmann, R. F. 1954. A sex difference in mortality in young Columbian black-tailed deer. *J. Wildl. Mgmt.* 18: 309-15.
- Taber, R. D. and Dasmann, R. F. 1957. The dynamics of three natural populations of the deer *Odocoileus hemionus columbianus*. *Ecology* 38: 233-46.
- Talbot, L. M. and Talbot, M. H. 1963. The wildebeest in western Masailand, Eastern Africa. *Wildl. Monogr.* 12: 1-88.
- Tener, J. S. 1965. Muskoxen in Canada: a biological and taxonomic review. *Can. Wildl. Serv. Monog. Ser.*, No. 2. 166 pp.
- Thomson, J. A. and Owen, W. H. 1964. A field study of the Australian ringtail possum *Pseudocheirus peregrinus* (Marsupialia: Phalangeridae). *Ecol. Monogr.* 34: 27-52.
- Trivers, R. L. 1972. Parental investment and sexual selection. pp. 136-79. In: B. Campbell (ed.) *Sexual Selection and the Descent of Man, 1871-1971*. Aldine Pub. Co., Chicago.
- Tryon, C. A. and Snyder, D. P. 1973. Biology of the eastern chipmunk, *Tamias striatus*: life tables, age distributions, and trends in population numbers. *J. Mammal.* 54: 145-68.
- Tyndale-Biscoe, C. H. and Smith, R. F. C. 1969. Studies on the marsupial glider, *Schoinobates volans* (Kerr). II. Population structure and regulatory mechanisms. *J. Anim. Ecol.* 38: 637-50.
- Widdowson, E. 1976. The response of the sexes to nutritional stress. *Proc. Nutr. Soc.* 35: 175-80.
- Wilson, E. O. 1975. *Sociobiology*. Harvard Univ. Press, Cambridge, Massachusetts. 695 pp.
- Wood, D. H. 1970. An ecological study of *Antechinus stuartii* (Marsupialia) in a south-east Queensland rain forest. *Aust. J. Zool.* 18: 185-207.
- Wood, J. E. 1958. Age structure and productivity of a gray fox population. *J. Mammal.* 39: 74-86.

Comparative Efficiency of Catcher Boats With and Without Asdic in Japanese Pelagic Whaling Fleets*

J. W. Horwood

M.A.F.F., Fisheries Laboratory, Lowestoft, UK.

ABSTRACT

Data are presented on the time spent on various operations by catcher boats in two Japanese expeditions over seven seasons in the Southern Hemisphere. They allow a comparison to be made between boats equipped with Asdic and those without Asdic. It is found that chasing time per whale caught by boats with Asdic is one hour and 50% more for boats without Asdic. This is explained by: (a) the boats with Asdic lost a proportion of 20% of those caught whereas those without lost 30%; (b) boats with Asdic expended less time on chasing whales that were subsequently lost.

The data show that boats without Asdic did proportionately more towing and handling per whale caught and there is a suggestion that these boats may have given whales they sighted to boats with Asdic. This explains why the previous erroneous figure of a 4.5 hr improvement in chasing time was obtained since all differences were assumed to be in chasing operations.

Chasing times for Soviet operations are given in an Appendix.

INTRODUCTION

The basic effort information which is available for stock assessment is the 'catcher days worked' (CDW) from which an index of abundance may be obtained as catch per catcher day worked (C/CDW). However, much of the CDW are taken up with operations other than searching for whales, and catch per effort expended in searching is a less biased index of abundance. Searching time has not been recorded and to obtain it from CDW the other components of the day's operations have to be subtracted. These include such elements as towing time, handling time, chasing time and time wasted. These time budgets have been documented for the Japanese industry by Ohsumi (1980b) and Tillman (1980) has summarised Soviet data.

Throughout the history of exploitation the efficiency of the catcher boats has altered and this has to be corrected for. One improvement was the introduction of Asdic into the Japanese fleets. It is considered that Asdic is only used in the capture of a whale once it has been sighted (Ohsumi, 1980a) and hence it affects only the chasing time. Values of C/CDW for boats with and without Asdic are available and if values of the other time components are known then the improvement in efficiency attributable to Asdic can be deduced (IWC, 1980). Using this approach the reduction in the time spent chasing an individual whale for the Japanese coastal industry was 1.57 hr, for the North Pacific pelagic fleets it was 0.26 hr and for the Southern Hemisphere fleets it was 4.54 hr. No explanation of this particularly large latter figure has been made.

Ohsumi (1980b) provided a detailed description of the time spent on different operations in the North Pacific and Southern Hemisphere pelagic fleets. The Southern Hemisphere data are from two fleets — pelagic fleets *Kyokuyomaru 2*, (K2) and *Kyokuyomaru 3*, (K3) — and span the seasons 1956/57 to 1962/63 and the time budgets are presented for the entire fleet. However, the original data come from the individual catcher boats and therefore allow an assessment to be made of the operational procedures of those boats equipped with Asdic compared with those without Asdic. In particular, the effect on chasing time can be calculated directly and the accessory information can be used to explain the change. Further, it can be seen whether

boats without Asdic were used in the same way as those with Asdic during the period in which the fleets had both sets of boats. Finally, this study is based on the same data as those used by Ohsumi (1980b) and should be regarded as a complement to that study.

DATA AND METHODS

The basic data have been grouped into times and catches from boats with and without Asdic by expedition and season. They are summarised in Tables 1 and 2 which are largely self-explanatory. In addition to the time components certain ratios are calculated. These involve, amongst others, the ration of lost to caught whales, chasing time per whale caught, searching time per whales encountered (considered as the sum of those caught plus those lost), the time spent chasing whales which were eventually lost per whale lost and the time spent chasing whales which were caught per whale caught. This information has not been previously available and allows a better explanation of the previously noted gross changes. Based on the assumption that Asdic affects only chasing time, the analysis will be first directed at that component, then to those elements which may explain the change and finally to other differences not associated with chasing time.

In the original document presented at the meeting, a preliminary analysis was undertaken. This analysis considered only changes in chasing time per whale caught with values of 1.38 hr for boats without Asdic and 0.98 hr for boats with Asdic. It was assumed that the differences within the fleets in each year should be taken as the basic measure and then weighted by catches in order to obtain one final figure for chasing time before and after the introduction of Asdic. Further, since the division of a time by a small number of catches (say <6) is likely to introduce a large bias, individual catcher boats that caught only a few whales were neglected in the analysis. This is not so here. The effect of weighting times by the catches of individual boats in a fleet is the same as summing all times and all catches. Consequently, times and catches have been summed for all boats with and without Asdic in each expedition. These are the basic data presented in Tables 1 and 2. There still remains the choice of whether it is more correct to assume that operations were essentially similar over all the seasons and two fleets and hence to sum all the

Table 1
Data from *Kyokuyomaru 2*

Season	Catcher boats				W _L	S	C	H	T	C _L	C - C _L	W _L /W _C	S/W _C + W _L	C/W _C	H/W _C	T/W _C	C _L /W _L	C - C _L	
	Used	Not used	W _C	Ratio														W _C	W _L
Asdic No Asdic Ratio	1	0	20		1	811	13.6	4.3	29.3	0.3	13.3	0.050	38.6	0.680	0.215	1.47	0.30	0.665	
	10	1	147		24	7,646	114.0	44.0	278.0	29.3	84.7	0.163	44.7	0.776	0.299	1.89	1.22	0.576	
Asdic No Asdic Ratio	5	0	216		36	4,726	182.0	39.0	129.0	56.2	126.0	0.167	18.8	0.841	0.182	0.60	1.56	0.581	
	7	0	134		37	4,808	160.0	37.0	322.0	81.4	78.8	0.276	28.1	1.196	0.273	2.40	2.20	0.588	
Asdic No Asdic Ratio	8	0	198		37	4,190	194.0	33.0	107.0	68.4	126.0	1.65	1.50	1.42	1.50	4.03	1.41	1.01	
	4	0	52		22	2,088	80.5	11.0	158.0	43.1	37.4	0.423	28.2	1.548	0.206	3.04	1.96	0.719	
Asdic No Asdic Ratio	9	1	182		38	4,807	181.0	33.0	244.0	65.7	115.0	0.209	21.9	0.995	0.181	1.34	1.73	0.634	
	0	2	0		0	70	0	0	0	0	0	-	-	-	-	-	-	-	
Asdic No Asdic Ratio	10	1	219		50	4,293	232.0	40.0	310.0	72.3	160.0	0.228	16.0	1.061	0.183	1.41	1.45	0.731	
	2	1	5		5	565	15.4	1.1	17.7	8.2	7.2	1.000	56.5	3.080	0.220	3.54	1.64	1.440	
Asdic No Asdic Ratio	11	1	212		59	4,035	252.0	40.0	203.0	119.0	134.0	4.39	3.54	2.90	1.20	2.51	1.13	1.97	
	1	0	0		1	130	2.3	0	1.5	2.3	0	0.278	14.9	1.190	0.190	0.96	2.01	0.631	
Asdic No Asdic Ratio													130.1	-	-	-	2.30	-	
													8.74	-	-	-	1.15	-	

Catcher boats not used are those which expended no time on the listed operations.
W_C = whales caught; W_L = whales lost; S = searching time; C = chasing time; H = handling time; T = towing time; C_L = time spent chasing whales that were not eventually caught.
All times are in hours.

Table 2
Data from *Kyokuyomaru 3*

Season	Catcher boats				W _L	S	C	H	T	C _L	C - C _L	W _L /W _C	S/W _C + W _L	C/W _C	H/W _C	T/W _C	C _L /W _L	C - C _L	
	Used	Not used	W _C	Ratio														W _C	W _L
Asdic No Asdic Ratio	5	1	31		11	1,208	56.6	5.8	25.0	35.7	20.9	0.355	28.8	1.826	0.187	0.81	3.25	0.674	
	5	0	10		12	1,195	32.8	3.0	38.7	24.9	7.9	1.200	54.3	3.280	0.300	3.87	2.08	0.791	
Asdic No Asdic Ratio	9	0	39		10	1,123	32.9	9.0	15.1	9.1	23.8	3.38	1.89	1.80	1.60	4.80	0.64	1.17	
	3	5	3		8	996	12.3	0.8	71.8	9.6	2.7	2.667	90.5	4.100	0.267	23.90	1.20	0.900	
Asdic No Asdic Ratio	2	3	40		1	733	22.7	6.8	14.4	2.8	19.9	10.40	3.95	4.86	1.16	61.80	1.32	1.48	
	5	1	77		10	1,300	51.4	17.0	134.0	18.8	32.6	0.130	15.0	0.668	0.217	1.74	1.88	0.423	
Asdic No Asdic Ratio													0.84	1.18	1.28	4.83	0.67	0.85	

Catcher boats not used are those which expended no time on the listed operations.
W_C = whales caught; W_L = whales lost; S = searching time; C = chasing time; H = handling time; T = towing time; C_L = time spent chasing whales that were not eventually caught.
All times are in hours.

data, or to assume that the differences between boats in a particular fleet in a particular year provide a more valid figure and hence to obtain a final answer by weighting the individual differences to test this. I have rejected the use of a chi-squared test since the times per whale may easily follow an overdispersed distribution. Consequently, the analysis has been done both ways. From Tables 1 and 2 it can be seen that catches, or losses, are usually high but in a few instances are low (<6). Since the major comparisons are of ratios these differences, or ratios where appropriate, have been weighted by the lower catch or loss. For example from Table 1 in 1956/57 the ratio of the handling time per whale caught of boats with and without Asdic (215/299) will have a weighting of 20, whereas that from 1957/58 (182/273) will have a weighting of 134. Finally, expedition K3 operated between 30–40°S, whereas all the others operated near to the pack ice and the analyses have been performed including and excluding this expedition.

RESULTS

1. Chasing time

Chasing time includes that expended on both whales caught and those chased but subsequently lost. Tables 3 and 4 show the summed times and ratios for all expeditions, including and excluding K3 in 1962–63. These show that average chasing time per whale caught without Asdic was about 1.1–1.2 hr, and with Asdic was about 1.01–1.02 hr. It took about 9–17% longer without Asdic. However, the ratios of chasing time per whale caught without and with Asdic within each fleet is never lower than 14% and even exceeds 400%. A weighted average of these ratios, weighted by the lower of the two catches, gives about 50% including or excluding the one K3 expedition. The difference may be explained by the large fleet and seasonal variability in chasing times per whale caught and the different numbers caught in each season hiding the true difference between the boats. This suggests (as used in the earlier document) that if a suitable weighting can be found, the data from the individual fleets should be treated as the basic comparison rather than the simple grouped data of Tables 3 and 4. Nevertheless, this leaves a problem of how these data can be incorporated into the present assessments. They suggest that chasing time per whale caught takes 48–53% (including and excluding the K3 fleet) longer without Asdic. The question is – longer than what?

If this factor of 1.5 is applied to the time per whale of 1.01 (from Table 3) then the value of 1.09, the time per whale caught without Asdic, is not achieved and vice versa with a factor of 1/1.5 applied to 1.09. Since the value of 1.01 is obtained from three times as many catches it is recommended that this be taken as the basic time and the nominal time without Asdic be calculated as 1.01 × 1.5 = 1.52 hr. This compares with figures of 0.98 hr and 1.38 hr from the original analysis.

Consequently, figures have been provided for the improvement in chasing times due to the introduction of Asdic into the Japanese fleet, but the differences have not been explained. There are three elements that may be associated in this change. Firstly there may be a difference in the proportion of whales which are caught after being sighted, secondly, there may be a change in the time to capture a whale which is caught and, thirdly, there may be a change in the time expended on whales chased but which are not subsequently caught. These three are now considered.

Table 3
Accumulated total times

	Catcher boats			Total	WC	WL	S	C	H	T	CL	C - CL	WL/WC	S/WC + WL	C/WC	H/WC	T/WC	CL/WL	$\frac{C - CL}{WC}$
	Used	Not used																	
Asdic	60	7	1,157	243	25,926	1,167	211	1,077	429	738	0.210	18.5	1.01	0.183	0.93	1.77	0.638		
No Asdic	37	10	428	119	18,797	469	113	1,021	218	251	0.278	34.4	1.10	0.264	2.39	1.83	0.587		
Ratio											1.320	1.86	1.09	1.44	2.56	1.03	0.92		

Catcher boats not used are those which expended no time on the listed operations.
WC = whales caught; WL = whales lost; S = searching time; C = chasing time; H = handling time; T = towing time; CL = time spent chasing whales that were not eventually caught.
All times are in hours.

Table 4
Total times excluding K3, 1962-63

	Catcher boats		Total	S	C	H	T	C _L	C - C _L	W _L /W _C	S/W _C + W _L	C/W _C	H/W _C	T/W _C	C _L /W _L	$\frac{C - C_L}{W_C}$
	Used	Not used														
Asdic	58	4		25,193	1,145	204	1,062	426	718	0.217	18.5	1.02	0.183	0.95	1.76	0.643
No Asdic	32	9		17,496	418	96	887	199	219	0.311	38.0	1.19	0.274	2.53	1.82	0.623
Ratio										1.43	-	1.17	1.50	2.66	1.04	0.97

Catcher boats not used are those which expended no time on the listed operations.
W_C = whales caught; W_L = whales lost; S = searching time; C = chasing time; T = towing time; C_L = time spent chasing whales that were not eventually caught.
All times are in hours.

2. Ratio of lost to caught whales

Tables 3 and 4 show the summed results and indicate that boats without Asdic have a lost to caught ratio 32-43% worse than boats with Asdic. Typically boats with Asdic lose 20% of the whales caught and boats without Asdic 30%. As with the chasing time however a substantial difference is seen from results from the individual fleets, Tables 1 and 2, where the minimum comparison of lost to caught ratios is 65% and the weighted average, weighted by the minimum of the four caught or lost figures, is 2.6 or 160%. So boats without Asdic will lose many more whales, which will help to account for the differences detected in the chasing time per whale caught, since less total time will be expended chasing whales which are then lost. This is to be expected as Asdic allows contact to be kept with the whale when it has dived out of sight.

3. Time chasing 'lost' whales

Tables 3 and 4 show the summed time expended chasing whales which are not eventually caught and the time per whale. These figures indicate that 3-4% more time is expended per 'lost' whale for boats without Asdic. Again the individual fleet comparisons show a much greater difference, the lowest difference being 14% with a weighted average of 22%. This finding will also aid in explaining the decreased chasing time per whale caught since boats with Asdic abandon the chase for 'lost' whales earlier, presumably because they know at an earlier time that the whale has evaded them.

4. Time chasing 'caught' whales

Since the time expended chasing whales which are not caught is documented, subtracting yields the time expended on capturing the whales which are caught (C-C_L/W_C). Tables 3 and 4 show that boats with Asdic actually take between 3-9% longer to capture a whale. This is surprising. Data from the individual fleets show that in 2 of the 7 fleets in which comparisons can be made, this occurred. However, the weighted average ratio is 1.03 (including K3) and 1.06 (excluding K3). It is thus seen that for a whale caught Asdic does not help a great deal. It must be remembered, however, that there are now fewer whales lost and the boats with Asdic will probably spend longer pursuing whales which might otherwise have been abandoned.

This concludes the analyses of the results pertinent to the chasing time, but data have also been supplied on towing, handling and searching times. These are recorded below.

5. Towing time

Large differences can be seen in Tables 1-4 in the towing time per whale for boats with and without Asdic. The grouped data show that boats without Asdic spend 2.7 times as much towing time per whales caught. Inspection of the original data shows that some boats with Asdic spent no time towing and other non-Asdic equipped boats spent much time towing with none caught. Clearly during the period when the fleets were changing over to Asdic, boats were used differentially and this will have confounded the earlier analyses that attributed all efficiency changes to Asdic influencing chasing time. This is probably because the better boats were given Asdic first rather than to an active decision being made to liberate the boats with Asdic for chasing, since boats with Asdic were frequently used for large periods for scouting and were not used for capturing whales. A similar effect is seen in handling time and with searching time per whale encountered.

6. Handling time

Comparisons of handling times per whale caught for boats with and without Asdic shows that boats without Asdic expend about 40–50% more handling time per whale. This is true for the summed or weighted data.

7. Searching time

If the sum of whales caught plus whales lost is regarded as whales encountered, then the data show that boats with Asdic were about twice as successful in encountering whales. For the individual fleets this ratio varied between 1.16–8.74. The difference is very large and suggests that during these seasons a boat without Asdic, which should have encountered the same number of whales as a boat with Asdic, may have allowed boats with Asdic to take a whale which they had sighted first.

CONCLUSIONS

The detailed data provided from the Japanese fleets over the period 1956–63 show how Asdic improved efficiency and how the boats with and without Asdic behaved. Chasing time per whale caught of boats without Asdic is about 50% greater. This is explained by proportionately many more whales escaping boats that do not have Asdic and to a lesser degree by the reduction in time wasted chasing a whale which was subsequently lost. Values obtained in the original analysis presented and used for the stock assessments were 0.98 hr for boats with Asdic and 1.38 hr for boats without Asdic. There is no improvement

in the average chasing time of a whale which is killed, presumably because a longer time is spent chasing difficult whales but which are subsequently caught.

During the transition period when Asdic was being introduced, boats without Asdic were utilised in towing and handling whales and also probably allowed boats with Asdic to take whales which they had sighted. These factors would have confounded the previous analysis wherein all the changes were attributed to chasing time and led to the erroneous figure of a 4.5 hr improvement in chasing time for boats with Asdic.

ACKNOWLEDGEMENTS

The data were made available by Dr Y. Fukuda and Dr S. Ohsumi of the Far Seas Fisheries Research Laboratory, Ordo, Japan. I am grateful to them for allowing me to present them.

REFERENCES

- International whaling Commission. 1980. Report of the sub-committee on sperm whales. Annex E (published in this volume).
- Ohsumi, S. 1980a. A critical review of Japanese fishing effort of sperm whales in the North Pacific. Paper SC/SPC/2 (published in this volume).
- Ohsumi, S. 1980b. Time budgets of sperm whaling operations by Japanese whaling. Paper SC/SP78/9 (published in this volume).
- Tillman, M. 1980. Soviet time budget data. Report of the Special Meeting on Sperm Whale Assessments, 1978. Annex K (published in this volume).

APPENDIX

CALCULATION OF CORRECTED CHASING TIME FOR THE SOVIET NORTH PACIFIC AND SOUTHERN HEMISPHERE FLEETS

Data from Soviet catcher boats (Tillman, 1980) give 'taking times' which apparently do not include time expended on whales which are subsequently lost. This component needs to be included to obtain a value for 'chasing time per whale caught' for use in the assessments. This value (t') can be obtained from,

$$t' = (T \times C + p \times C \times q \times T) / C \\ = (1 + pq)T \quad \dots (1)$$

T is the taking time of whales caught per whale caught
C is the catch

p is the proportion of whales caught which are lost

q is the ratio of (chasing time of whales lost per whale lost) to (chasing time of whales caught per whale caught).

Dr Zemsky informed the meeting that he considered p to be approximately 0.4 preliminary analysis of Japanese data indicated $p \approx 0.28$. Using a value of $q = 0.57$ gave average values (from $p = 0.4$ and 0.28) of $t' = 2.34$ hr for the North Pacific operations and 1.38 hr for the Southern Hemisphere operations. It can be seen from Tables 3 and 4 that q was underestimated and a more complete review of the Soviet time budget is given in Appendix of the report of the sub-committee on sperm whales, July 1979.

Relation Between Catch Per CDW and Indices of Abundance Allowing for Non-Searching Time and Operation on Schools

K. Radway Allen

A previous paper at this meeting (Allen, 1980) examined some of the effects on population assessments of assuming that boats search for and find schools of whales which they then attack, sometimes in cooperation with other boats, and that the proportion of the school captured depends upon the number of whales in the school and the number of vessels cooperating. On these assumptions, it is the number of schools found and not the number of whales caught which is proportional to searching time.

The present paper examines further the effect of these assumptions on the relations between population size and catch per CDW. Additional data are also presented on the relation between catch, school size and number of catchers employed in the attack, for the Japanese coastal and North Pacific pelagic fisheries.

The symbols used in this paper largely follow those used in previous studies (e.g. Allen, 1980; Beddington, 1979).

- P = size of population.
- n = number of schools in population.
- S = average number of whales in school (= P/n).
- C(sv) = number of whales caught from a school of size S by V catchers in cooperation.
- k = number of catchers in expedition.
- q = chance of a standard catcher finding one (solitary) whale in 1 day when whales are distributed with unit density.
- A(s) = chance of finding a school of size S relative to that of finding a single whale.
- E = relative efficiency of catcher in finding schools.
- T_{si} = searching time by catcher i in 1 day, assumed the same for all days and catchers.
- T_w = time wasted by 1 catcher in 1 day.
- h = chasing and handling time for 1 whale of target species.
- g = time taken for other catchers to reach school and start the attack after it is found by the first catcher.
- b_j = number of whales of other species or sex (j) taken by 1 catcher in 1 day.
- h'_j = handling and chasing time for whale of species or sex (j).

Total number of encounters with schools made by catcher i in a day

$$= qEA(s)nT_{si}$$

Total catch in 1 day by all catchers

$$= kqEA(s)nT_{si}C(sv)$$

Chasing and handling time on target species by all catchers

$$= C(sv)h$$

Approaching time at each encounter

$$= (V - 1)g$$

(NB. if all boats wait until the last arrives before attacking

$$= Vg)$$

Chasing and handling time on other whale species at each encounter by all catchers

$$= \sum b_j h'_j / qEA(s)nT_{si}$$

Searching time by all boats in 1 day

$$= kT_{si} = k - kqEA(s)n \{C(sv)h + (V - 1)g\} - kT_w - k \sum b_j h'_j \quad (1)$$

from which, since $n = P/S$

$$T_{si} = \frac{1 - T_w - \sum b_j h'_j}{1 + EA(s)P \{C(sv)h + (V - 1)g\} / S} \quad (2)$$

Also, since the catch by 1 catcher in 1 day

$$= qEA(s)P T_{si} C(sv) / S \quad (3)$$

Catch per unit searching time

$$= qEA(s)P C(sv) / S \quad (4)$$

Thus, the catch is only proportional to population size and to searching time if $C(sv)/S$ is constant. If $C(sv)/S$ changes within a given set of data (e.g. due to changes in school size or number of catchers) these proportionalities will no longer hold. Consequently the amount of searching time ceases to be of direct interest, and while it can be calculated from the above expressions there is little purpose in doing so.

In practical application there are two other quantities or more immediate interest. These are:

- (a) the expected catch per catcher days work, since this is used and compared with the actual catch in current estimating procedures, such as CHPOP and POPDYN.
- (b) an index proportional to the population size which can be directly derived from the catch per CDW. This can be used to examine the calculated population levels corresponding to a set of catch per CDW data.

From (2) and (3) the expected catch per CDW =

$$\frac{qEA(s)P C(sv) (1 - T_w - \sum b_j h'_j)}{S + qEA(s)P \{C(sv)h + (V - 1)g\}} \quad (5)$$

Since $C(sv)/S$ may be a ratio which can conveniently be examined, this may also be usefully written as:

$$\frac{qEA(s)P (1 - T_w - \sum b_j h'_j) C(sv) / S}{1 + qEA(s)P (hC(sv) / S + (V - 1)g / S)} \quad (6)$$

Writing I for catch/CDW we can rewrite the above expression to relate the expected population size to the observed value of I. We then obtain:

$$P = \frac{IS}{qEA(s) \{C(sv) (1 - T_w - \sum b_j h'_j) - I(C(sv)h + (V - 1)g)\}} \quad (7)$$

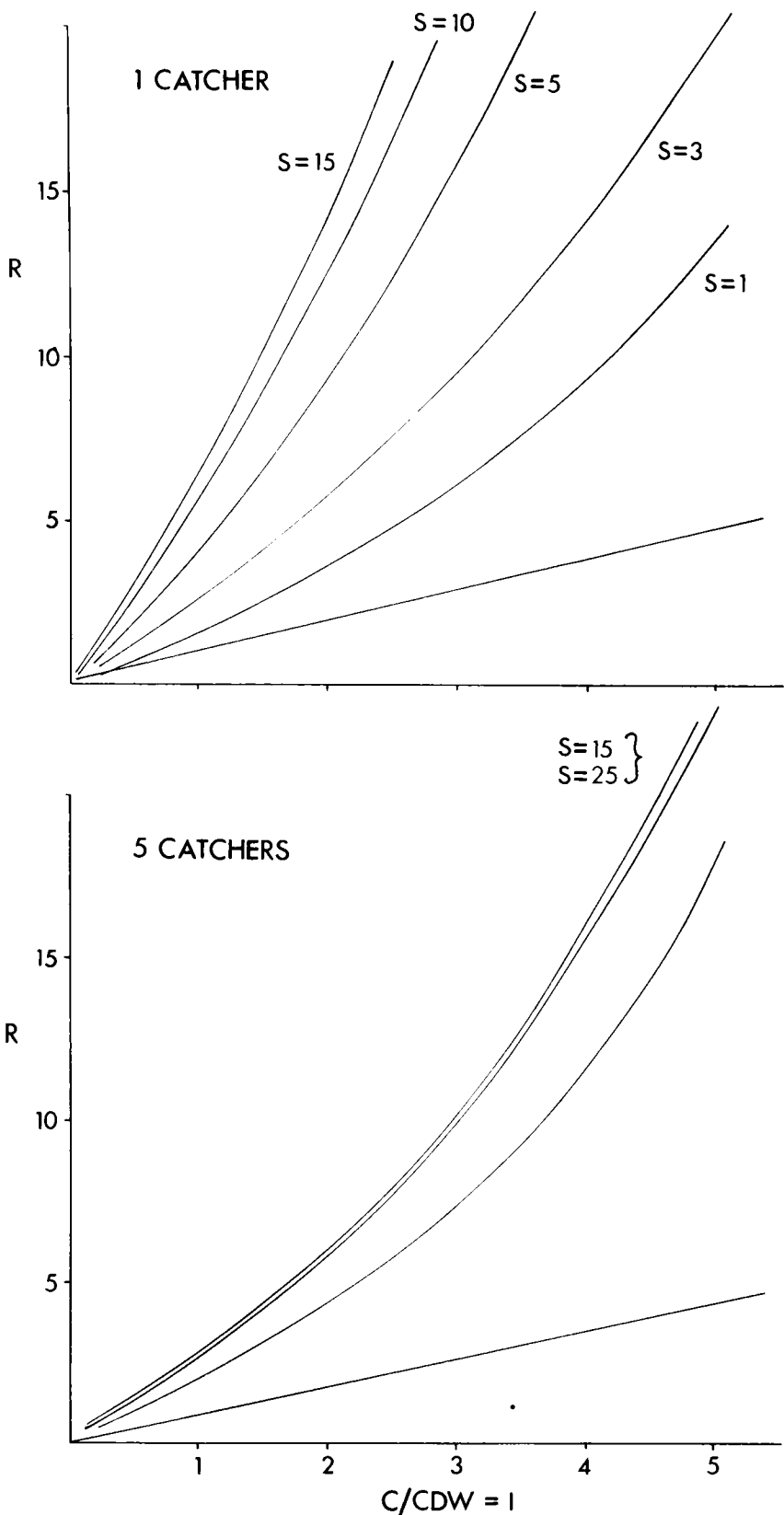


Fig. 1. Relation between relative population size (R) and catch per CDW (I) for schools of different sizes and with 1 or 5 catchers employed. The expected catch for a given school size and number of catchers is taken from Table 1 of Allen (1980) using $d = 0.5$, $g = 0$ and $v = 0$. The relation between R and I is then calculated from equation (8) of the present paper using $h = 0.05$, $g = 0.02$ and $T_w = 0.4$.

Table 1.
The relative changes in population index (R) and catch per CDW (I) expressed as $R_5/5R_1$, where R_1 and R_5 are the values of the population index for $I = 1$ and $I = 5$ respectively. The table is based on the same model and parameter values as Fig. 1.

Number of catchers	School Size					
	1	3	5	10	15	25
1	1.57	1.57	1.57	1.57	1.57	1.57
3	—	1.89	1.80	1.72	1.69	1.66
5	—	—	1.98	1.84	1.75	1.68
10	—	—	—	2.05	1.95	1.82

Since q is a constant and $A(s)$ may be set at 1.0 in the absence of data the proportionality expression becomes:

$$P \propto \frac{IS}{E \{C(sv)(1 - T_w - \sum b_j h'_j) - I(C(sv)h + (V - 1)g)\}} = R \quad (8)$$

where R is the index of population abundance.

This analysis is, in part, similar to that of Beddington (1979). His expression (13) for number of whales caught in 1 catcher day resembles equation (5) above in structure, although it does not include explicitly either the number of whales in a school or the catch taken from it. More importantly, Beddington's analysis assumes that all the k catchers in an expedition take part in each attack on a school.

The effect of school size on the relationship between C/CDW and the index of population size is illustrated in Fig. 1, which shows the curves for 1 or 5 catchers used on schools of various sizes from 1 to 15. All the curves are clearly non-linear, with a concave curvature which will lead to under-estimates of population size unless $C(sv)/S$ is constant. A relevant index of the degree of non-linearity is given by comparing the relative rates of change of the population index (R) and the catch per CDW (I) over a likely range of values of I. Table 1 shows this index calculated for a range of I of 1 to 5 whales per CDW. It appears that the degree of non-linearity, and therefore of bias in population estimates, tends to decrease with either the school size or the number of catchers.

Table 2 summarises data kindly provided by Y. Fukuda and S. Ohsumi on recent school sizes, catches and number

Table 2.
Numbers of sperm whales caught and average size of school attacked when different numbers of catchers were used. Data for Japanese coastal operations in 1973–77 and Japanese North Pacific pelagic operations in 1977–78, kindly supplied by Y. Fukuda and S. Ohsumi.

	Number of Catchers						
	1	2	3	4	5	6	Total
<i>Coastal</i>							
No. of encounters	120	56	20	—	—	—	196
Average school size	18.5	26.8	35.2	—	—	—	22.7
Average catch	5.45	10.6	15.0	—	—	—	7.9
C(sv)/S	0.29	0.40	0.43	—	—	—	0.35
Average number of catchers	—	—	—	—	—	—	1.5
<i>Pelagic</i>							
No. of encounters	91	41	41	32	18	17	240
Average school size	2.7	7.8	9.6	14.4	16.3	28.2	9.2
Average catch	1.5	4.5	7.0	10.3	13.5	23.2	6.5
C(sv)/S	0.55	0.58	0.73	0.72	0.83	0.82	0.71
Average number of catchers	—	—	—	—	—	—	2.9

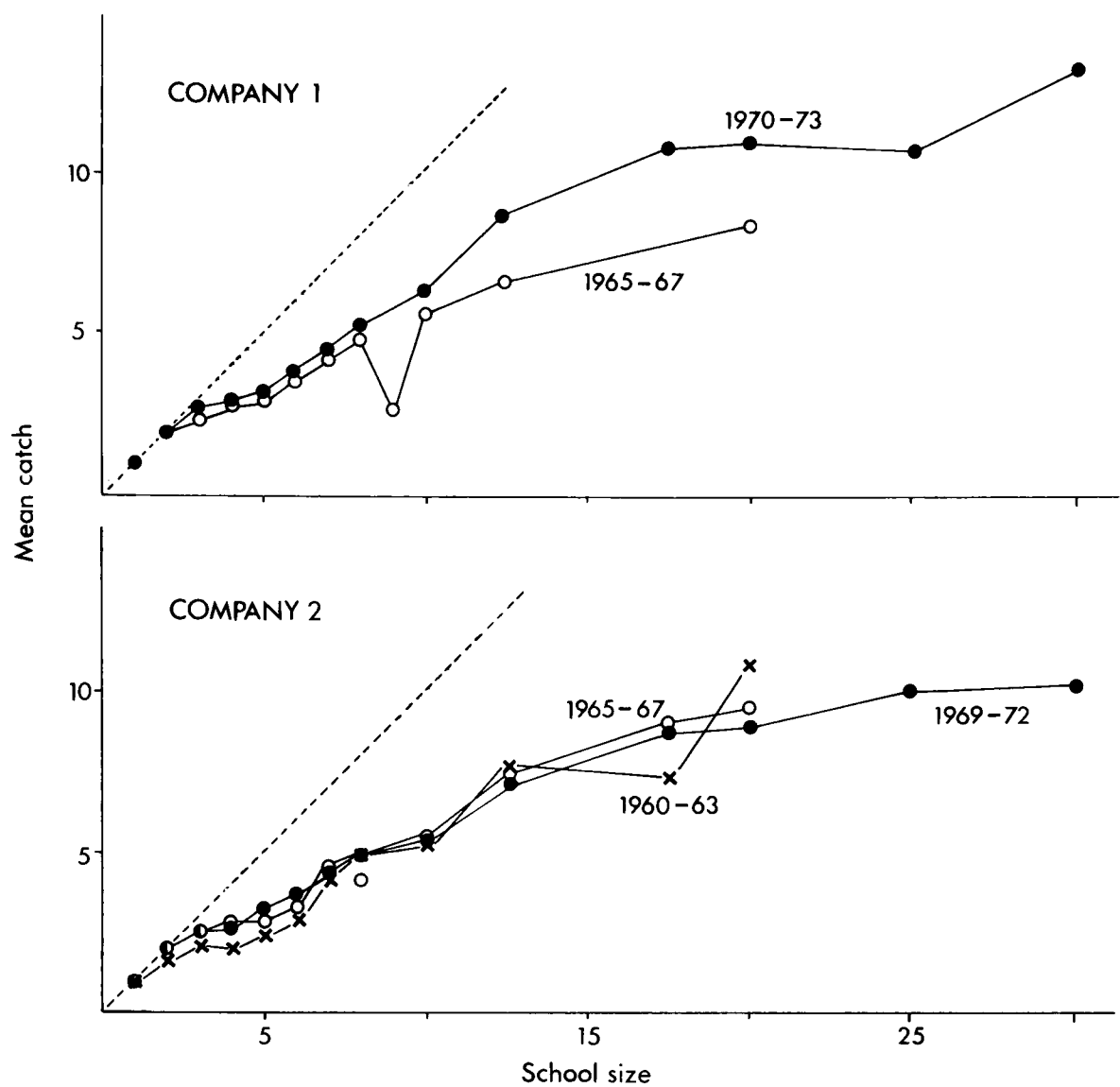


Fig. 2. The mean number of whales caught plotted against school size in Japanese coastal operations. Results for two whaling companies in different periods shown separately.

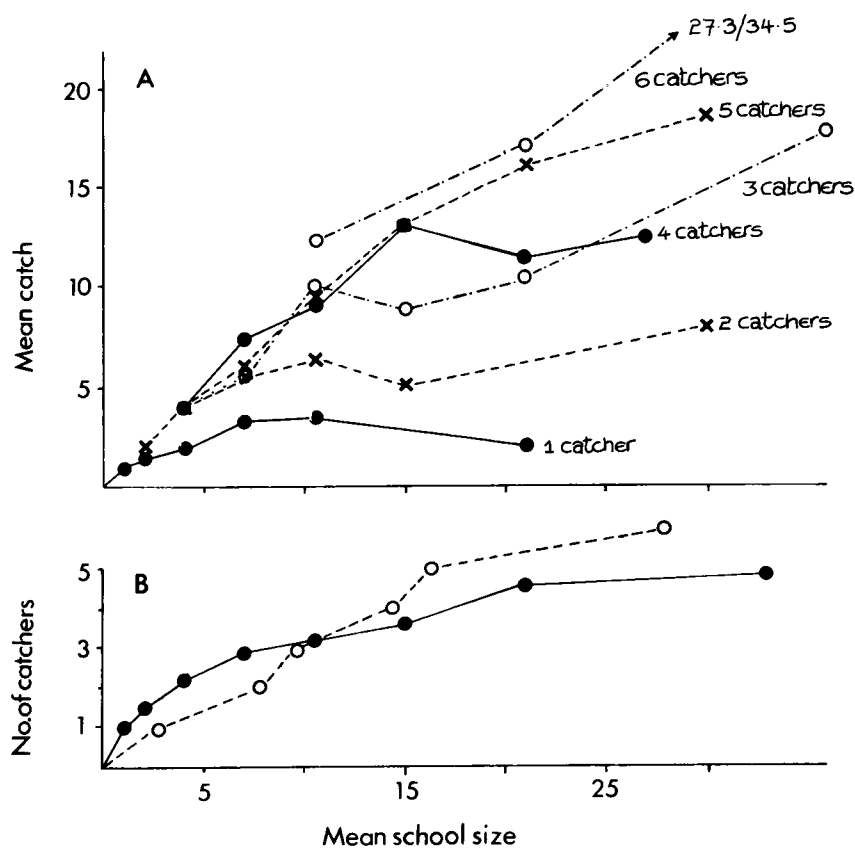


Fig. 3A. Relation for the Japanese pelagic data between catch and school size for various numbers of catchers. Data have been grouped in the following school sizes: 1, 2, 3-5, 6-8, 9-12, 13-17, 18-24, 25-.
B. Relation for the Japanese pelagic data between school size and number of catchers used. The broken line shows mean school size for each number of catchers, and the solid line the mean number of catchers against school size, grouped as in Fig. 3A.

of catchers in Japanese North Pacific pelagic and coastal operations. The table shows in both operations a strong positive correlation between school size and number of catchers, implying that with increasing school size more catchers cooperate in the attack. There is also, in both operations, a tendency for the proportion caught to increase with the number of catchers used, despite the associated increase in school size. Between the two operations, the large size of schools in the coastal operations is associated with a much lower proportion caught when the same number of catchers is used.

Fig. 2, kindly provided by S. Ohsumi, shows clearly that in the Japanese coastal operations, if the effect of number of catchers used is removed by pooling, the proportion caught declines as school size increases.

In practice, the size of schools, number caught from a school, and number of catchers used, will all vary from day to day in a single operation. It is important therefore to identify the appropriate way of calculating the single values of S , V and $C(sv)$ which should be used in the above expressions for expected catch and index of abundance. In developing these expressions, the quantities of primary interest are the school size corresponding to the population size and given number of schools, the total number of vessels engaged in attacks, and the total number of whales caught. The values of S , V and $C(sv)$ used should therefore be the true means for a given data set, and these are the values given in Table 2. It should be noted that this value of $C(sv)$ may not be the same as the expected catch by V vessels attacking a school of size S .

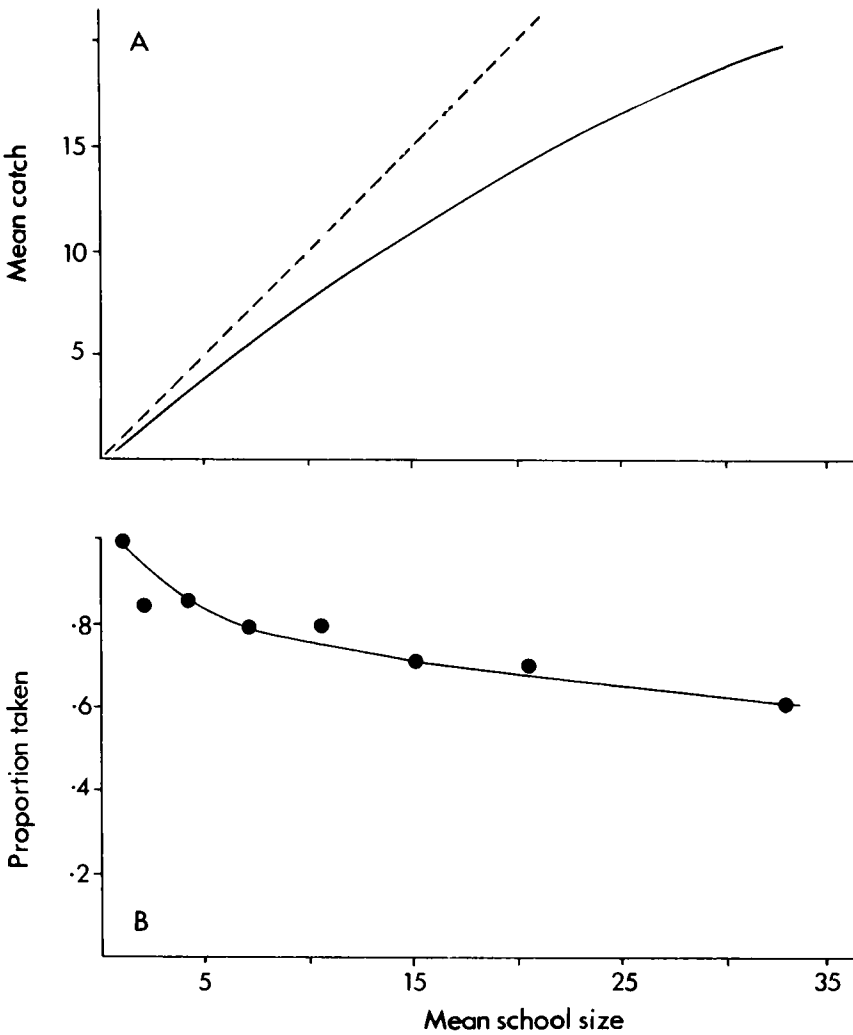


Fig. 4A. Mean catch for all numbers of catchers combined plotted against school size for the Japanese pelagic data. Calculated from freehand curve drawn through the points in Fig. 4B.
B. Ratio of catch to school size plotted against school size for all numbers of catchers combined for the Japanese pelagic data.

Fig. 3A shows for the Japanese pelagic data the relation between catch and school size for each number of catchers. These curves suggest that for any number of catchers in the range of the data (1–6) the proportion of the school taken is very large if the school is less than about three times as numerous as the catchers, but that beyond this school size catches tend to level off rapidly.

Fig. 3B shows for the same data both mean numbers of catchers plotted against mean school size and mean school size attacked by a given number of catchers plotted against number of catchers. Both curves tend to an asymptote determined by the number of catchers available, but, as would be expected, they cross at an intermediate value.

Figs 4A and B show respectively, also for these data, the mean catch and corresponding ratio of catch to school size both plotted against school size for all numbers of catchers pooled. The ratio appears to decline quite rapidly initially with increasing school size, but then tends to level off at about 0.6–0.7.

REFERENCES

Allen, K. R. 1980. The influence of schooling behaviour on CPUE as an index of abundance. Paper SC/SP78/Doc 3 (published in this volume).
Beddington, J. R. 1979. On some problems of estimating population abundance from catch data. Paper SC/30/Doc 3 *Rep. int. Whal. Commn* 29: 149–54.

Calculations from Best, SC/30/Doc 33 Table 3 – Apparent Pregnancy Rates

by S. J. Holt

(1) 1962–65 + 1967

The mean apparent pregnancy rate of mature females in the sample is 20.6%.

Assuming that these data give the age (corpora) – specific rates in the unexploited female population and that $M = 0.55$, then the expected mean rate in the stock is 21.0%; so the age distribution of the sample is not much different from what would be expected in a steady-state unexploited stock with $M = 0.055$.

(2) 1973–75

The mean apparent rate in the sample is 23.8%. However, the age distribution in the sample is not what would be expected in a steady-state stock held at 80% of initial level; it is in fact not greatly different from that in the earlier data. This is because the stock had been reduced in less than a decade and its age composition was, therefore, still far from the steady state.

We therefore apply the age (corpora) – specific pregnancy rates in the 1973–75 samples to the expected age distribution with $Z = 0.07$ (which would lead to a reduction to 80% of initial stock). The expected mean pregnancy rate is then 22.8%, i.e., an increase of 8% over the expected value in the unexploited stock. The expected increase is insensitive to the degree of stock reduction; in this case it is unchanged to within 1% for reduction to 70% of initial instead of 80%.

This increase is partly due to the relative reduction in the number of older animals, which have lower pregnancy rates than the younger ones, and partly to an increase in the pregnancy rate of the older animals. These two effects can be distinguished by applying the age (corpora) – specific rates in the earlier data to the theoretical age distribution corresponding to a reduction of stock to 80% of initial. This gives a mean value of 21.6%, i.e., an increase of 3%. Thus, one-third of the increase is due to the change in age-composition and two-thirds to the increase in pregnancy rate of the older animals.

(3) The pattern of change in age (corpora) – specific pregnancy rate, from the earlier to the later data can be summarised as follows:

No. of corpora (grouped)	Presumed age range (Years)	Pregnancy rate		% change
		1962–67	1973–75	
1–4	10–18	.240	.224	– 7
5–8	19–28	.240	.275	+15
9–12	29–37	.171	.223	+30
13–15	38–43	.114	.188	+65
16+	44+	.057	.105	+84

Relative Increases in Population Pregnancy Rate of Sperm Whales

J. W. Horwood

Ministry of Agriculture, Fisheries and Food, Fisheries Laboratory, Lowestoft NR33 0HT, UK

ABSTRACT

Age specific pregnancy rates from collections from Durban (Best, 1980) are related to changes in population pregnancy rate. A 15% increase is observed over the period 1962/67–1973/75. This change would indicate a density dependent exponent nearer to 1.4 than zero unless there was a substantial improvement in the male to female ratio over the period.

INTRODUCTION

The model used in the assessment of sperm whale stocks assumes that *per capita* pregnancy rates can increase from 0.2 to 0.25 provided that the male to female ratio is sufficiently high. However, yields and relative MSY levels are sensitive to the way in which the pregnancy rate increases with decreasing population densities of females (e.g. Kirkwood, 1980). In the model it is the 'density dependent exponent' (b) which regulates the shape of the increase such that,

$$\text{pregnancy rate} = 0.05 (1 - r^{1+b}) + 0.2, \text{ where}$$

r is the relative density of females (Fig. 1).

Best (1980) has provided age specific pregnancy rates from the catches of sperm whales off Durban during two time periods; 1962–67 (excluding 1966) and 1973–75.

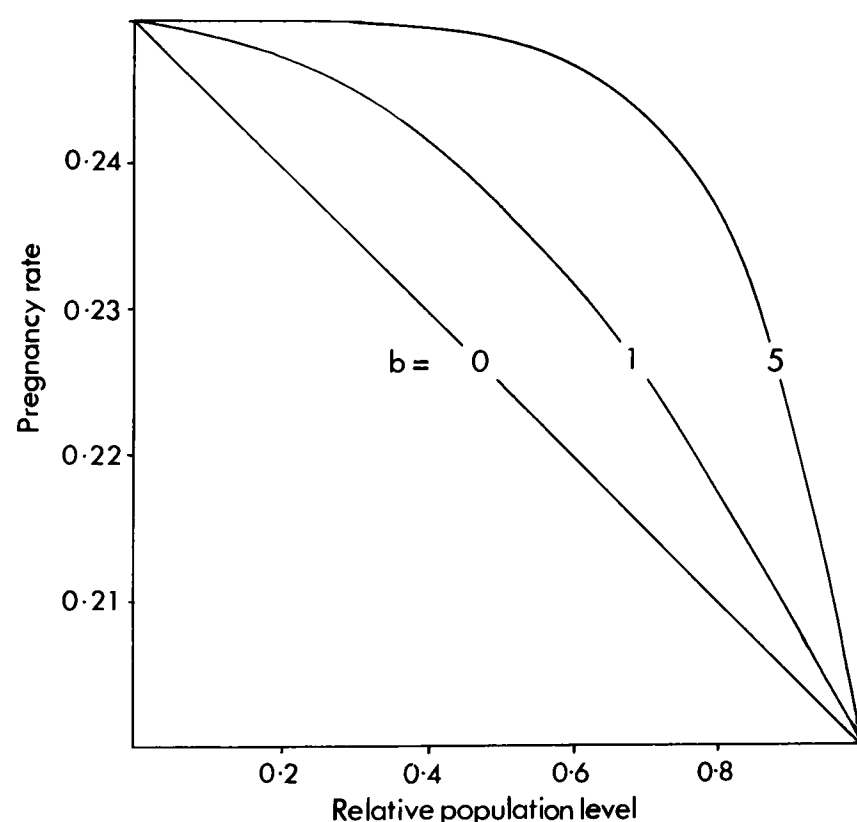


Fig. 1. Effect of different density dependent exponents on pregnancy rate with relative stock density.

Seventy-five per cent of the total post-war catch from this Division was taken after the 1961/62 season and an increase in pregnancy rate is evident. From Best's data the change in

population pregnancy rate over this period can be found from the age specific rates. If a further assumption is made about the relative decline of the female population, given a particular level of male stock, then an estimate of the density dependent exponent can be found. This exercise is performed here.

THE MODEL

In the model the population pregnancy rate (P^1) is applied to the total mature stock and this is defined in terms of the age specific rates (P_i) by

$$P' = (P_k N_k + P_{k+1} N_{k+1} + \dots) / (N_k + N_{k+1} + \dots)$$

where N_i is the size of age group i and k is the age at maturity. With a stable age structure then,

$$P' = (P_k + P_{k+1} \exp(-z) + P_{k+2} \exp(-2z) + \dots) / (1 - \exp(-z)) \quad (1)$$

If the basic age specific model is defined for females as,

$$N_0^{t+1} = 0.5 (P_k N_k^t + P_{k+1} N_{k+1}^t + \dots)$$

$$N_i^{t+1} = N_{i-1}^t \exp(-M_j) \quad i = 1, 2$$

$$N_i^{t+1} = N_{i-1}^t \exp(-M) \quad i = 3, k,$$

where M_j and M are the juvenile and adult mortality rates, and if it is assumed that the age at maturity is the same as the age at recruitment, then

$$N_i^{t+1} = N_{i-1}^t \exp(-z) \quad i = k+1, \infty.$$

The balance equation from this gives

$$2 \exp(2M_j) \exp((k-2)M) = P_k + P_{k+1} \exp(-z) + P_{k+2} \exp(-2z) + \dots \quad (2)$$

The present model takes a value of $P = 0.2$ at initial stock size so, from (1) and (2),

$$2 \exp(2M_j) \exp((k-2)M) = 0.2 (1 - \exp(-M))^{-1}.$$

The present model has an age of recruitment and maturity of 10, and since $z = M = 0.055$, this gives M_j , the juvenile mortality rate, as 0.0926.

Holt (1980) compared pregnancy rates in three age groups from Best's data; 10–23 years, 24–37 years and 38–50 years (Table 1a). During the early period pregnancy rates are highest in the first group and then decline in the ratio 1.0: 0.77: 0.42 compared with the first group. If the

*This paper is a revision of the original paper presented to the meeting.

Table 1

Relative increases in age specific pregnancy rates from Holt (1980) plus initial relative pregnancy rates

(a)	1-6	corpora, (10-23 years)	+	1%	1.00
	7-12	corpora, (24-37 years)	+	25%	0.77
	13+	corpora, (38+ years)	+	74%	0.42
(b)	1-4	corpora, (10-18 years)	-	6.7%	1.00
	5-8	corpora, (19-28 years)	+	14.6%	1.00
	9-12	corpora, (29-37 years)	+	30.4%	0.71
	13-15	corpora, (38-43 years)	}	+ 76.3	0.37
	16+	corpora, (44+ years)			

pregnancy rate of the first group is defined as P_a then equation (2) may be rewritten as,

$$0.2(1-\exp(-M))^{-1} = P_a \sum_{i=10}^{23} \exp(10-i)z$$
$$+ 0.77P_a \exp(-14z) \sum_{i=24}^{37} \exp(24-i)z$$
$$+ 0.42P_a \exp(-28z) \sum_{i=38}^{\infty} \exp(38-i)z$$
$$\therefore 3.7373 = P_a((1-\exp(-14z))$$
$$+ 0.77 \exp(-14z)(1-\exp(-14z))$$
$$+ 0.42 \exp(-28z))(1-\exp(-z))^{-1}$$

(3)

Solving this equation for $z = M = 0.055$ gives $P_a = 0.244$ which, although the model has used no information from Best's data on absolute levels, is very similar to the absolute rate in the first age group of 0.237. Holt's analysis showed increases of 1.01, 1.25 and 1.74 for the pregnancy rates in the three groups between the two time periods. This information can be incorporated into equation 3 to find what value of z would be necessary to stabilise the stock. Thus,

$$3.7373 = P_a(1.01(1-\exp(-14z))$$
$$+ 1.25 \times 0.77 \exp(-14z)(1-\exp(-14z))$$
$$+ 1.74 \times 0.42 \exp(-28z))(1-\exp(-z))^{-1},$$

and with $P_a = 0.244$, $z = 0.0643$. The population pregnancy rate can now be calculated from equation 1, but note that the right hand side of equation 2 is always a constant. Hence the ratio of the first population pregnancy rate (P') to the second (P'') is given by,

$$\frac{P''}{P'} = \frac{(P''_k + P''_{k+1} \exp(-z'') + \dots)(1-\exp(-z''))}{(P'_k + P'_{k+1} \exp(-z') + \dots)(1-\exp(-z'))}$$
$$= (1-\exp(-z''))/(1-\exp(-z'))$$
$$= 1.164.$$

A similar operation was carried out with results from a modified interpretation of Best's data given in Table 1b which is taken from Holt (1980). This gave a similar initial population pregnancy rate to the previous one and the relative increases in age specific rates needed a value of $z = 0.063$ to stabilise the population. Hence $P''/P' = 1.141$.

DENSITY DEPENDENT EXPONENT

The two results indicate that the age specific changes would have resulted in a 14-16% increase in population pregnancy rate. Since,

$$P = 0.05(1-r^{1+b}) + 0.2,$$
$$b = \ln(1.0 - (P-0.2)/0.05)/\ln r - 1$$

and if, for a given level of r , $P = 1.15 \times P_o = 0.23$ then values of b can be found. These are given in Table 2 and indicate that, if the female population was near initial levels during the 1960s and has not decreased below 75% of that level, then a density dependent exponent of greater than 1.0 would be needed to explain the change in pregnancy rates.

Table 2

Values of the density dependent exponent (b , zero for the linear/logistic model) for different relative levels of female population (r)

r	0.95	0.9	0.8	0.7	0.6
b	17	7.7	3.1	1.6	0.8

DISCUSSION

The age specific model initially only makes an assumption about the female age structure. From this and Best's data it appears that population pregnancy rates would have increased by about 15%. In the assessment model with an initial rate of 0.2 this would be raised to 0.23. The values need no compensation for the age structure effects described by Holt (1980) for they are implicit in the technique.

The relationship between these results and the density dependent exponent is more obscure for it relies on a knowledge of both the relative female population levels and the relative number of males to females. It is possible that the pregnancy rate was initially low and the observed increase is due to an improvement in the male to female ratio. Indeed if this has not been the case to some degree then the density dependent exponent would be very high since the assessment for Division 3 indicates the females are at about 84% of their initial level (Best, 1980). However, Holt (1980) has speculated that the numbers may be lower than this. If the assumption is made that the male population has not significantly improved over the female population during this period, then it is likely that the density dependent exponent is over 1.0 and thus the females might be expected to have their MSYL nearer to 60% of initial levels rather than 50%.

CONCLUSIONS

- (1) Population pregnancy rates of sperm whales in Division 3 have increased by about 15% over the period 1962/67 to 1973/75.
- (2) If presented with the necessity to select a density dependent exponent of zero (logistic model) or 1.4 (60% MSYL model) then this study gives weak support to the higher figure.

REFERENCES

Best, P. B. 1980. Pregnancy rates in sperm whales off Durban. Paper SC/30/Doc 33 (published in this volume).
Holt, S. 1980. Calculations from Best, SC/30/Doc 33 - apparent pregnancy rates. A combination of Papers SC/SP78/25 and 27 (published in this volume).
Kirkwood, G. P. 1980. Sensitivity tests for the sperm whale model. Paper SC/30/Doc 15 (published in this volume).

An Alternative Procedure for the Scientific Committee's Recommendations with Respect to Sperm Whale Management

D. G. Chapman

The Scientific Committee and those who are acquainted with its debates at special and regular meetings over the past decade are well aware that there are crucial gaps in our understanding of the population dynamics of the sperm whale which is a very complex species. Even obtaining good estimates of the total population size has been difficult, and we have changed the estimates rather substantially over the past decade as we have modified the models required to calculate these estimates. In view of these substantial and crucial gaps in our information, I recommend that the Committee should not necessarily try to achieve a single estimate of so-called maximum sustainable yield but should instead note the deficiencies, and the assumptions that may be made and their basis and present the Commission with a series of alternative estimates. The estimate that the Commission chooses is essentially the result of a political decision which the Committee should not attempt to usurp.

The rational scientific procedure is to admit the data gaps and the alternative ways of bridging them by assumption with the resulting consequences these have with respect to quota recommendations. Finally the Committee should note that if the Commission wishes to adopt a conservative procedure in the absence of information along the lines of the New Management Procedure's guidelines with respect to unexploited stocks, it could proceed as follows.

Since the sperm whale is polygynous, there is a male surplus at least on a short term basis. We do not know the long term genetic and ecological effect of removing the so-called surplus males from the population but at least a harvest based on removal of the male surplus has been carried out for relatively long time periods on other polygynous species. Thus a minimum quota could be based on harvesting the annual male replacement to the surplus male population. That is, the quota could be recommended equal to the replacement yield of males.

There is an additional consideration with respect to males: the present status of the male stock relative to the females. This may give rise to standing accumulated surplus as well as the annual replacement yield. The decision to reduce the accumulated surplus to some level but not below a reasonable safety margin is again a political rather than a scientific decision and should be left to the Commission. In

addition, in keeping with its mandate as a *Scientific* Committee, the Committee should recommend strongly that additional scientific data be collected to try to resolve the problems that we have. This should consist of additional data from any catches as well as catches under permit of females from which complete data on pregnancy, age, etc. should be obtained.

In brief, the gaps in our knowledge include at least the following:

- (1) The response if any of the pregnancy rate to female exploitation. This includes:
 - (a) the type of response function,
 - (b) the parameter of the response function,
 - (c) the range of response.
- (2) The response of the pregnancy rate to male exploitation which according to present theory might be in the opposite direction to that in No. 1.
- (3) The response of the immature mortality rate to exploitation:
 - (a) because of disturbance,
 - (b) due to the reduced calving interval,
 - (c) as a population feedback response.
- (4) The response of the age of maturity to exploitation through changes in growth rates or otherwise.

The factors could be elaborated on and other factors listed that have been discussed in this or other meetings, but it is not necessary to do so.

In summary, I recommend that:

- (1) we indicate when there are gaps in our model that we fill with assumptions,
- (2) we indicate what the assumptions are and what are their basis,
- (3) we provide alternative recommendations for alternate assumptions,
- (4) we include as one of the alternatives a recommended quota based only on replacement yield of surplus males,
- (5) we recommend a research take of females that would assist in monitoring the population and assist in filling the data gaps, and
- (6) we strongly urge the collection of additional data from males towards solving the problems of the models.

Reasons for Recommending Zero Female Catch Limits for Sperm Whales

J.-P. Fortom-Gouin and S. J. Holt

In the first week of the present meeting it became clear that it would not be possible to reach consensus on the CPUE-based population estimates and on the crucial parameters of the population models for sperm whales. The numbers produced by a mechanical application of the model, using 'best' estimates, or assumed values are likely to have little resemblance with reality. Here, we attempt an analysis from a common sense point of view, with a minimum of theoretical and untestable modelling. We believe each of the several reasons for stopping the hunting of female sperm whales, outlined below is valid on its own. Together, they constitute a strong argument to recommend zero female catch limits.

Weight is a more rational measure of economic value than number

Adult female sperm whales are very much smaller than adult males, and we have age-weight data for both. It therefore makes practical nonsense merely to add them together to give a basis figure for the choice of management options. This has been written and said almost *ad nauseam* (e.g. Holt, 1976; IWC, 1977, p. 242) but must be repeated until the Commission takes notice, that the choice of weight leads to smaller immediate quotas (particularly of females) but better long term results.

- (a) From an economic point of view, weight is more meaningful than number, since the value of oil and other products is directly proportional to the weight of the whale.
- (b) According to all models used, the weight of the combined MSY by weight is larger than the weight of the combined MSY by number.
- (c) MSY by weight is also more conservative because it is reached at a higher percentage of the original populations, and because it involves the catching of fewer individuals (principally the so-called adult surplus males).
- (d) The choice of combined MSY by weight produces small female quotas, but the MSY by weight even with zero female catches is smaller than the combined MSY by weight at most by only a few percent, and may actually be greater than the weight obtained by MSY by number. The hypothetical advantages of small female catches are more than counterbalanced by the negative effects of the hunt, described below.
- (e) Even if number rather than weight were to remain as the 'optimisation' criterion, it is important to note that the weight of the maximum catch, by number, of males, with zero female catch can be greater than the weight of the combined MSY catch by number in the models used.

Hunting has negative effects on the nursery groups hunted

When a pelagic fleet encounters a nursery school, the catcher boats kill a high percentage of the adults in that group. This will have a number of negative consequences on the reproductive success of that group.

- (a) *Reduction in the total number of the mature females.*
Provided that food is not locally limiting, the maximum population increase would be expected by having the maximum number of mature females living in undisturbed association with sufficient breeding males.
- (b) *Removal of successful 'school masters'.*
This will have a direct negative effect on the reproduction of the group until the breeding male has been replaced by another one. We do not know how long it takes for the breeding male to be replaced. It cannot be advantageous to the reproductive success of the group for breeding males within the nursery groups to be killed when they are successfully fulfilling their reproductive role.
- (c) *An increased mortality rate of the young is probable.*
Due to the tight flight behaviour of the nursery group, it is often impossible for gunners to distinguish which have calves, and a number of lactating females are harpooned. Nursery groups are stable matriarchal societies. The removal of the larger females will in fact dislocate the social structure, destroy many individual roles and bonds and impose a heavy stress on the survivors, particularly because raising the young appears to be a collective undertaking of the nursery group (e.g. Berzin, 1972).

It is very doubtful that further hunting of females will sufficiently increase the pregnancy rates of the survivors to compensate for the number of females killed

Hunting females reduces the total number of fertile females. There is no advantage of this unless the pregnancy rate of the remaining females not only increases, but also increases sufficiently to more than compensate for the lost reproductive capacity of the females caught, and for a possible increase in the pre-recruit mortality rate; we have no measures of how this pregnancy rate varies between limits and no proof that it does increase sufficiently.

There is no indication that exploitation has any positive effect.

When a population is reduced from its maximum level by natural causes, it is a reasonable assumption that the improved food supply may have positive effects such as increased pregnancy rate, decreased mortality and lower age at sexual maturity.

However the present situation is quite different in two aspects:

- (a) Present populations are not near their maximum. Both males and females have already been reduced over a long period, sometimes drastically so. Female populations may be already below the zone where the pregnancy rate is density dependent.
- (b) The decrease in density is not due to natural causes, but to selective hunting which has various negative

effects on the reproduction of the nursery groups. Hunting nursery groups may not produce the density-dependence effect speculated for the overall pregnancy rate. There is absolutely no reason to suppose that in the terms of millions of years of their evolution sperm whales have needed, for survival, to develop mechanisms which protect the populations against the effects of massive depletion of one sex only, the elimination of entire breeding units, drastic lowering of average age etc.

- (c) There is no evidence of an increase in pregnancy rates except off Durban where Best (1980) showed an increase for the older females only. On the contrary, there is evidence of decrease in pregnancy rates in several areas (e.g. Chapman and Beddington, 1980; Clarke *et al.*, 1980); it has been presumed that this is due solely to the relative depletion of males, but there is no proof of this.

We do not know the effect of hunting large brained social animals

The sperm whale brain is characterised by an extraordinary quantitative and qualitative development. There are documented examples of human populations which collapsed under the pressure of land colonisation by other humans with little overt violence by the intruders (e.g. Turnbull, 1973). One feature is a apparent loss of 'will to reproduce'. Is it not possible that such psychological effects could be found in some cetaceans, as well as in other higher primates?

Hunting on the nursery groups of the sperm whales may also have negative effects beyond the direct ones. Nothing in its long mental evolution has prepared the sperm whale to cope with the new type of threat represented by whaling.

A final question is whether 'scientific' catches of females would be needed to monitor pregnancy rates?

Arguments put forward in favour of this are not convincing. There have been catches of females in the thousands but we still know very little about how the pregnancy rate varies with density and sex ratio. It is clear that the detection of a decline in pregnancy rate is statistically difficult, and successful only several years after a substantial decline has occurred. In the circumstances it would be more reasonable to base our estimates of the sex-ratio threshold for protection on the best possible appraisal of existing data from Division 5 and elsewhere.

In any event, it is not really the pregnancy rate that we need to know, but rather the juvenile survival rate which can only be observed on live whales. For further research it is far more important that we make sure our estimates of male numbers are realistic, and in particular, are not overestimated. In this connection we continue to be concerned that as stock number's decline the true and apparent densities would not decline so fast because of a tendency for survivors to concentrate in most favourable areas and for whales to concentrate on those areas. This effect is enhanced as the total whaling effort itself declines, while knowledge of where to go is based on accumulated experience from more extensive whaling in earlier years. This effect, which has not been investigated, could well be introducing overestimation biases in the degree of depletion of the male stocks.

A further and, we believe, decisive argument against

encouraging 'scientific' catches is that there are already very large samples of teeth and gonads in laboratory collections, which have not yet been worked up. Since all present assessments depend on a few age determinations and minimal age-length keys from a few years and places which are applied to all years and places, the first priority is for governments to make sufficient effort quickly to provide data from existing materials.

CONCLUSION

It seems to us that none of the three categories of whales in the nursery groups should be caught: the mature females and the breeding males because it would reduce the reproductive success of the groups, with only at best a small increase in the pregnancy rate of the surviving older mature females; the younger ones because they are below their optimal size during their association with the nursery groups. In addition, since it is virtually certain (from experience with other cetaceans as well as primates) that survival behaviours are learned over a considerable period, from parents as well as from other members of the group, disruption of the nursery groups is likely substantially to decrease, eventually, the survival possibilities and well-being of the untrained or incompletely trained animals which are not killed at an early age.

In recent years, the Scientific Committee has introduced in its model a number of refinements which have tended to reduce the estimated yields. It would be prudent to expect additional refinements likely to further reduce the estimates.

Over-exploitation is a different kind of risk. The damage from acting on overestimates of yields cannot be undone for many decades. Due to the asymmetrical risks of over and underestimating the catch limits, it is more prudent to underestimate the small theoretical yield of females by assuming a zero sustainable yield of females. Present knowledge of sperm whale population boundaries and migrations, and the variations of biological parameters, is in any case, negligible. Catching no females would at least help ensure that no separate population will unwittingly be depleted; prohibiting hunting on nursery groups would be an added safeguard.

No argument in favour of a female catch on the grounds of thus acquiring scientific knowledge should be entertained until such time as all existing materials (teeth, ovaries) have been analysed and the results published and evaluated by the Scientific Committee.

REFERENCES

- Best, P. B. 1980. Pregnancy rates in sperm whales off Durban. Paper SC/30/Doc 33 (published in this volume).
- Berzin, A. A. 1972 *The Sperm Whale*. [Translated from Russian by the Israel Program for Scientific Translations, Jerusalem, 1972] 394 pp.
- Chapman, D. G. and Beddington, J. R. 1980 Statistical evaluation of apparent pregnancy rate trends over time in western North Pacific. Paper SC/SP78/29 (published in this volume).
- Clarke, R., Aguayo, L. and Paliza, O. 1980. Pregnancy rates of sperm whales in the Southeast Pacific between 1959 and 1962, and a comparison with those from Paita, Peru between 1975 and 1977. Paper SC/SP78/5 (published in this volume).
- Holt, S. J. 1976. Criteria for management – weight or numbers? The relevance of whaling effort. *Rep. int. Whal. Commn (Sci. Rep.)* 26: 409–12.
- International Whaling Commission. 1977. Report of the Sperm Whale Meeting, La Jolla, 16–25 March 1976. *Rep. int. Whal. Commn* 27: 240–52.
- Turnbull, C. 1973. *The Mountain People*, Jonathan Cape, UK.

Catches of Male and Female Sperm Whales
by 2-Degree Square by Japanese Pelagic
Whaling Fleets in the North Pacific, 1966-77

T. Smith
*National Oceanic and Atmospheric Administration,
National Marine Fisheries Service, Southwest,
Fisheries Center, La Jolla, California 92038*

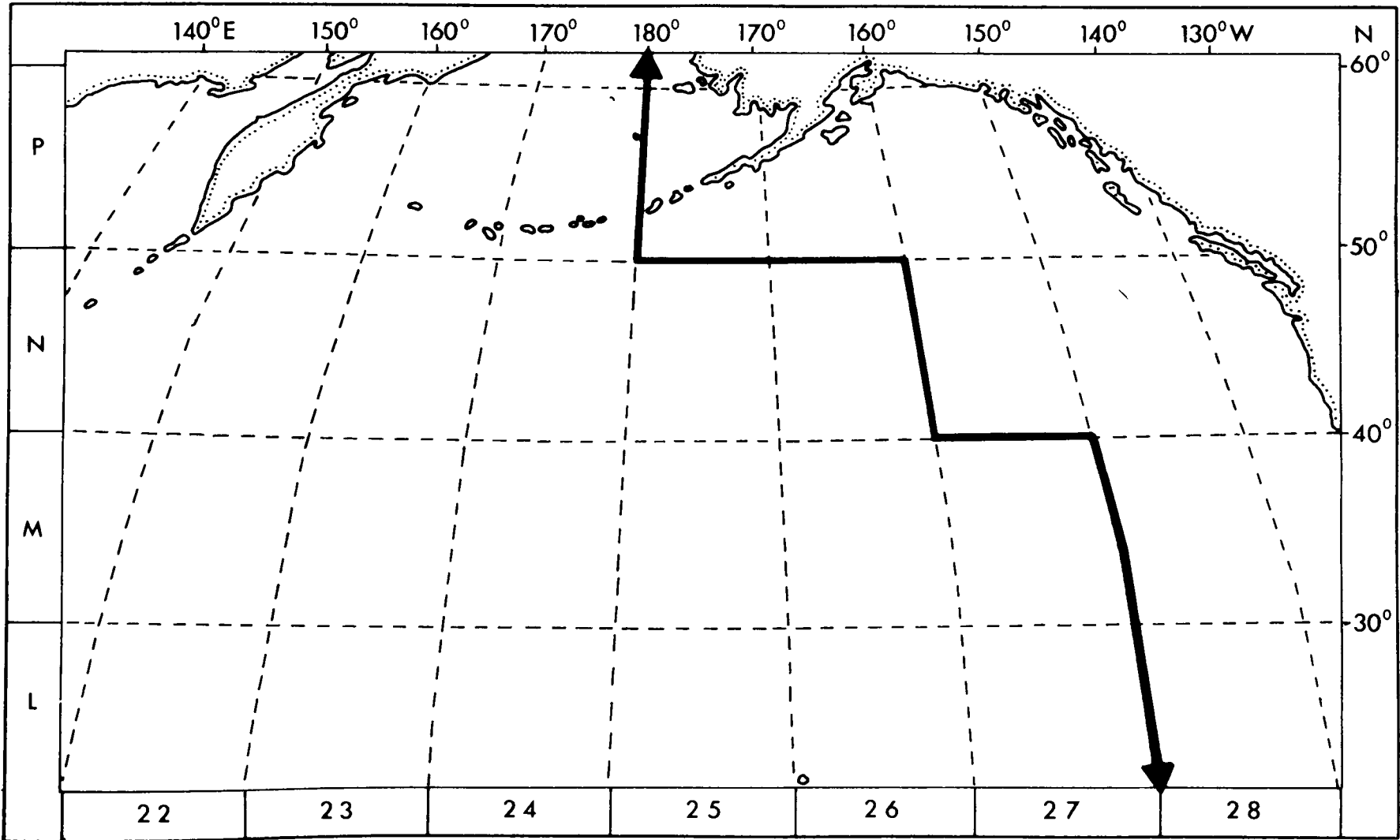


Fig. 1. Map of the North Pacific showing the boundary between Eastern and Western Divisions adopted by the IWC in 1978.

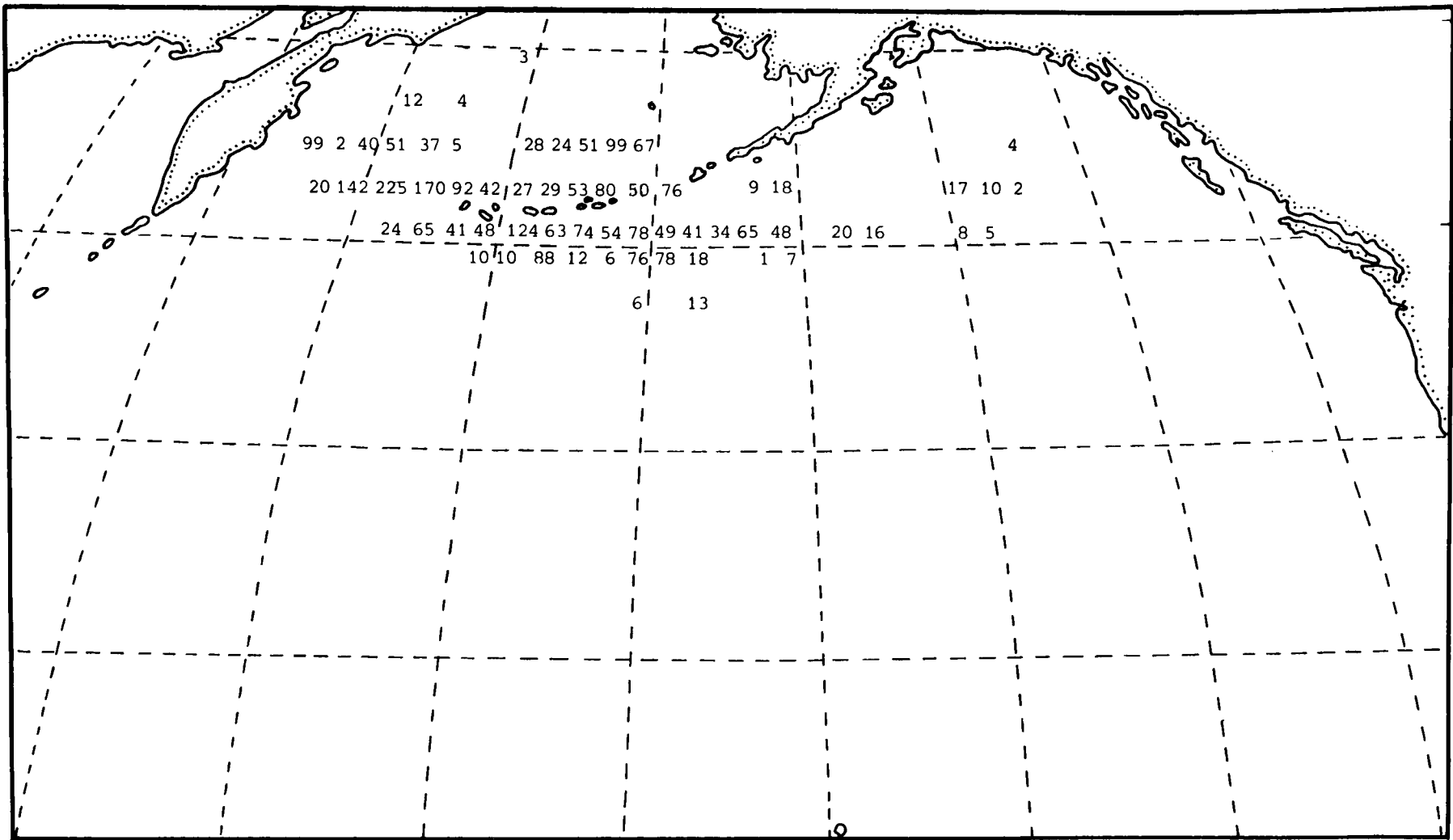


Fig. 2. Catch of male sperm whales in each 2-degree square for 1966

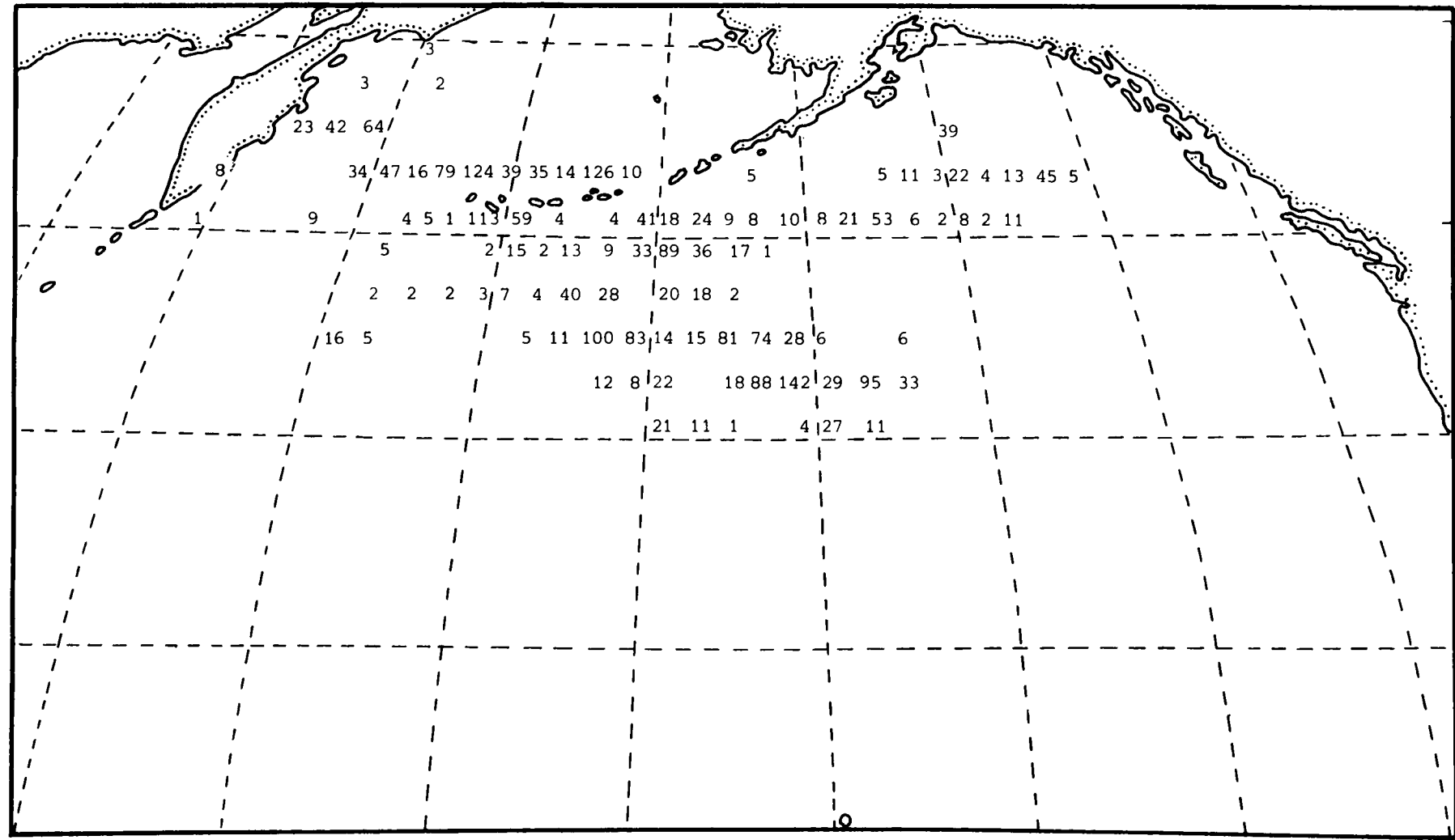


Fig. 3. Catch of male sperm whales in each 2-degree square for 1967

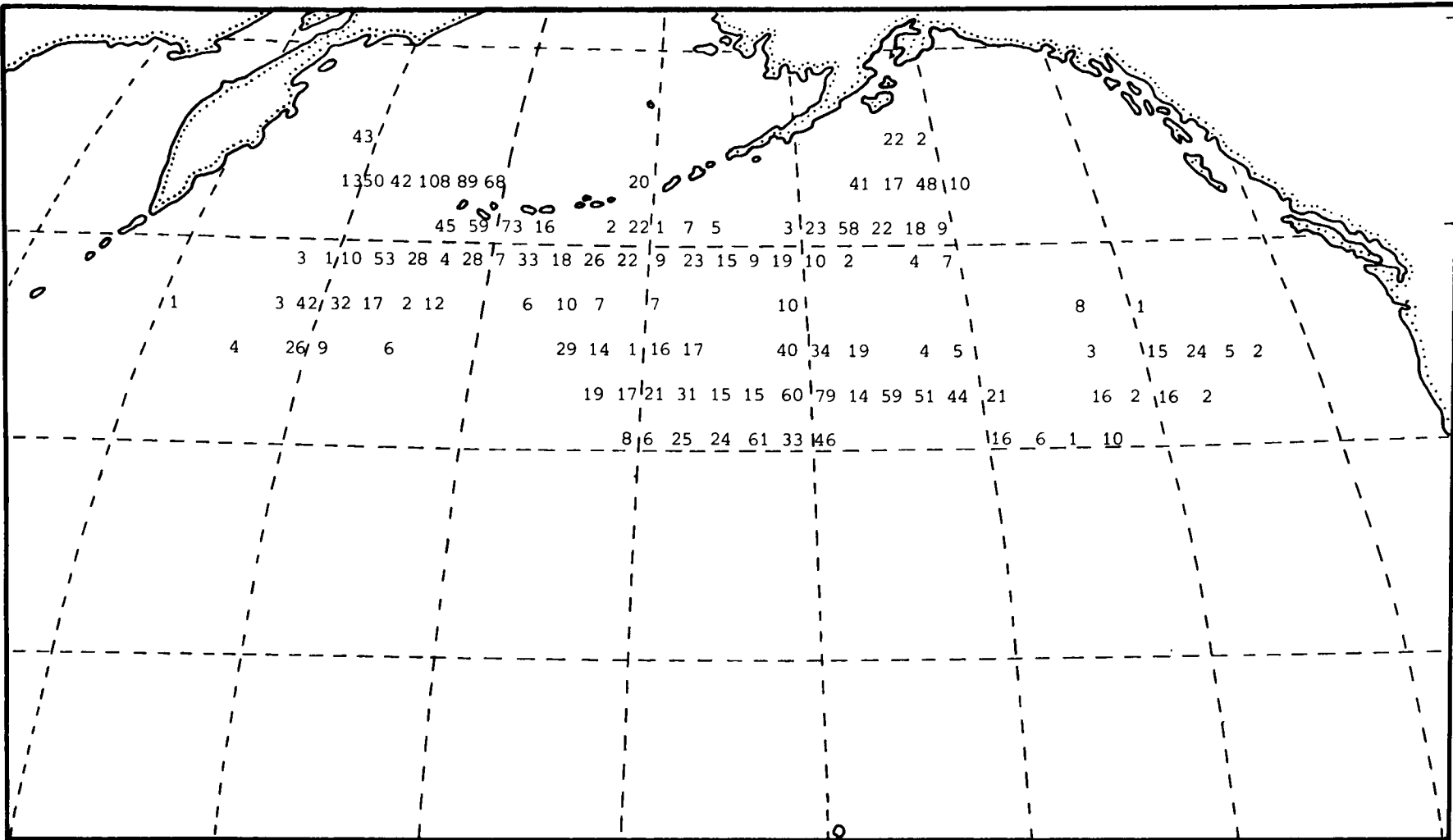


Fig. 4. Catch of male sperm whales in each 2-degree square for 1968

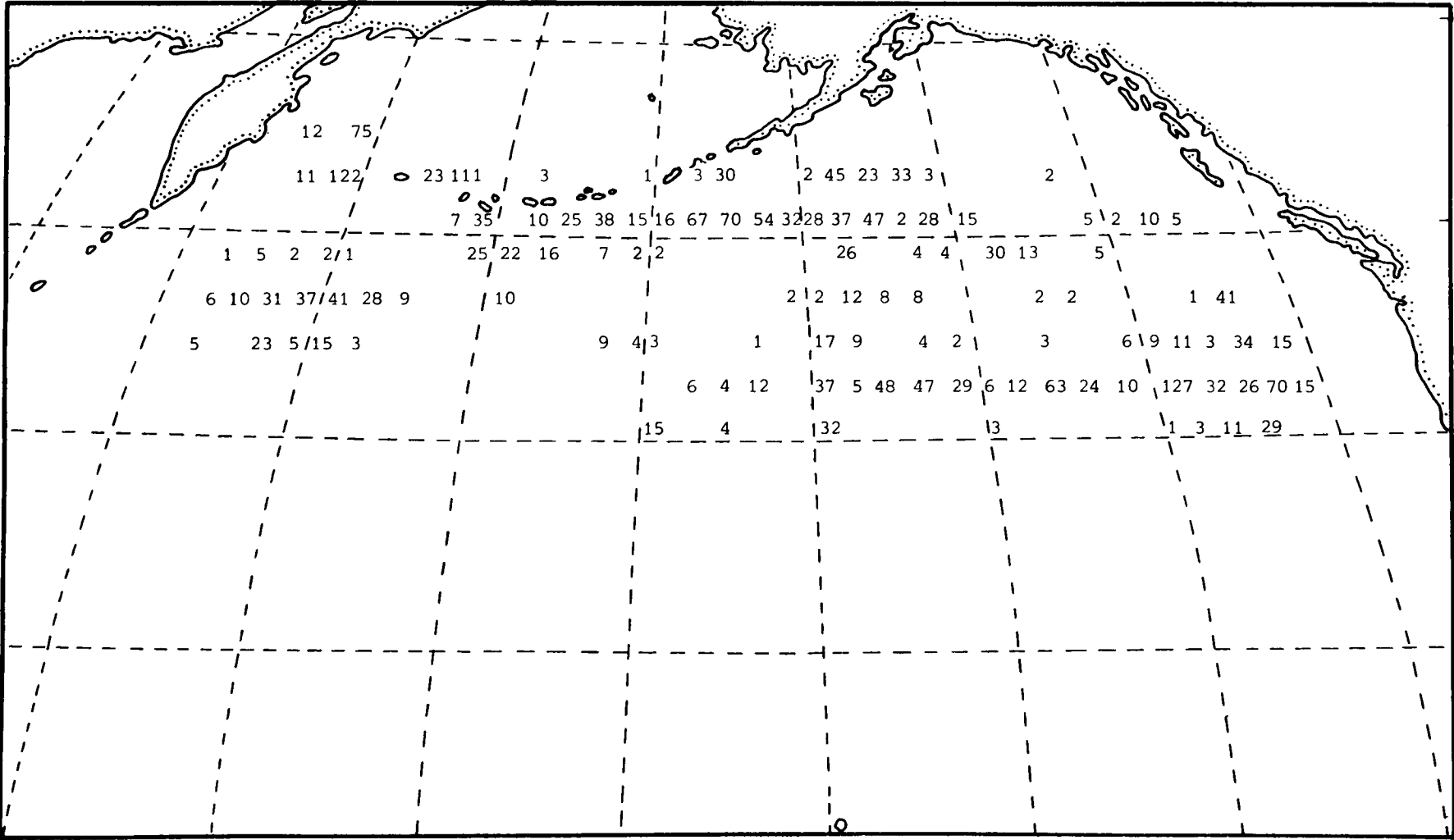


Fig. 5. Catch of male sperm whales in each 2-degree square for 1969

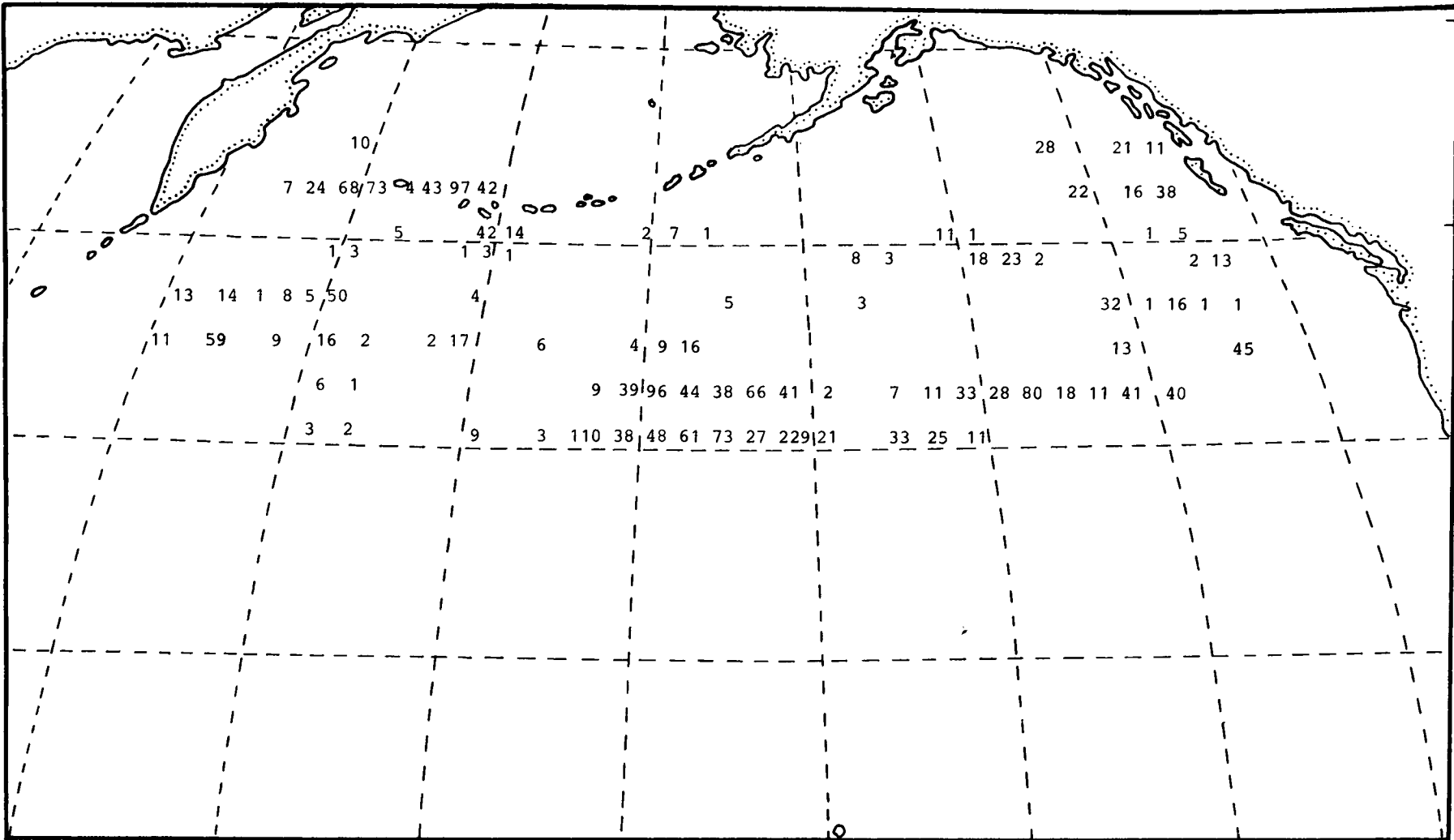


Fig. 6. Catch of male sperm whales in each 2-degree square for 1970

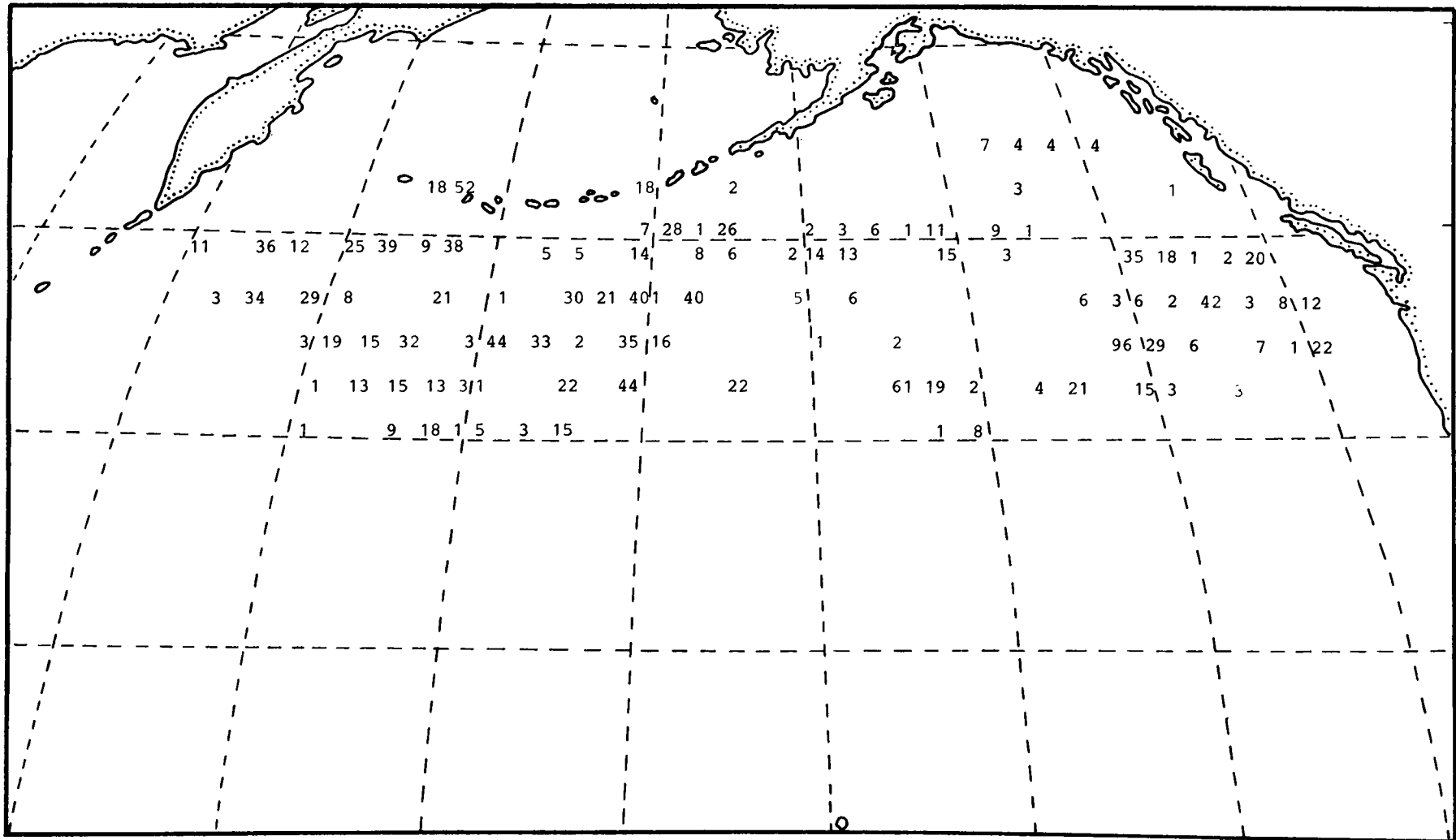


Fig. 7. Catch of male sperm whales in each 2-degree square for 1971

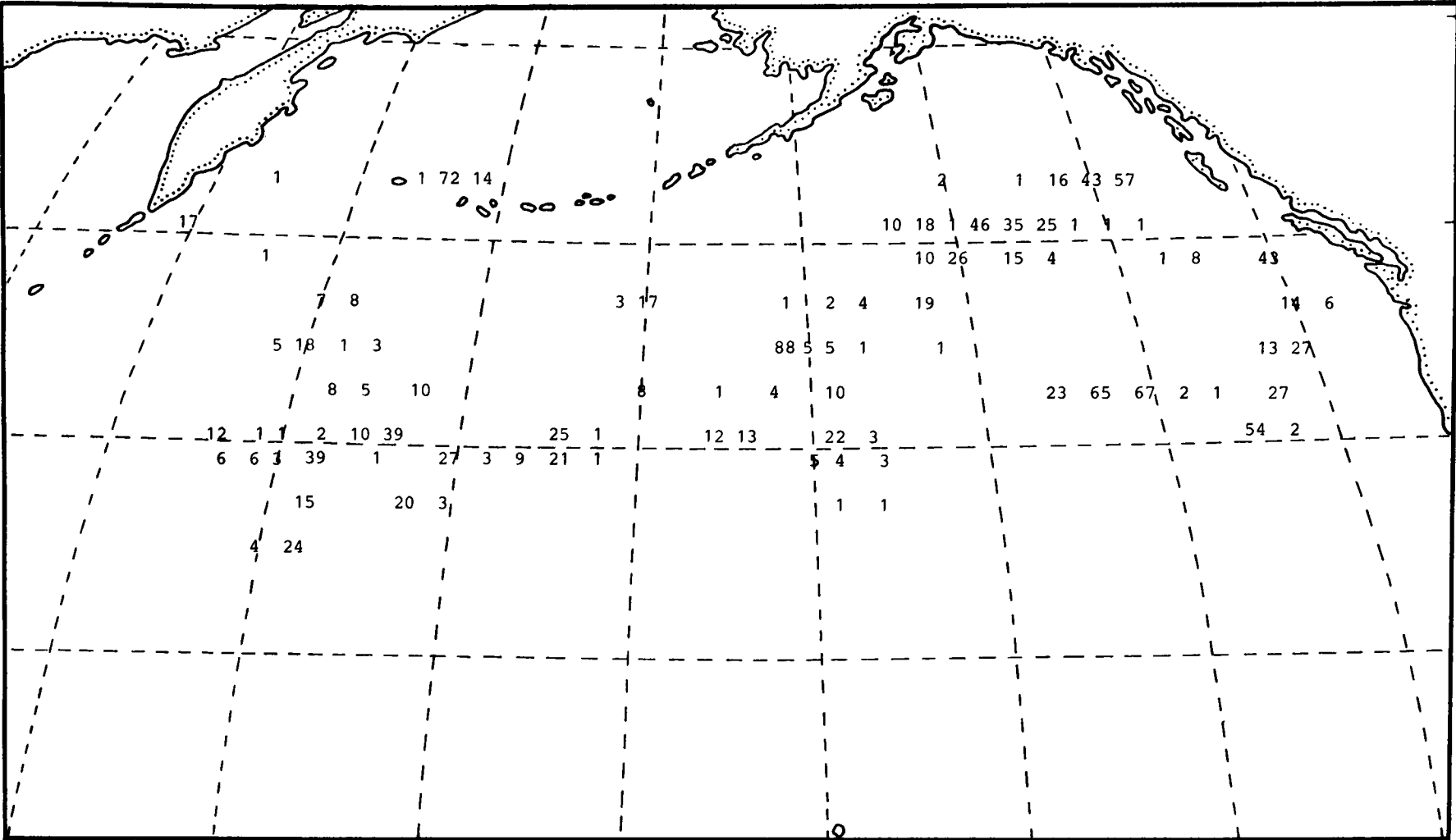


Fig. 8. Catch of male sperm whales in each 2-degree square for 1972

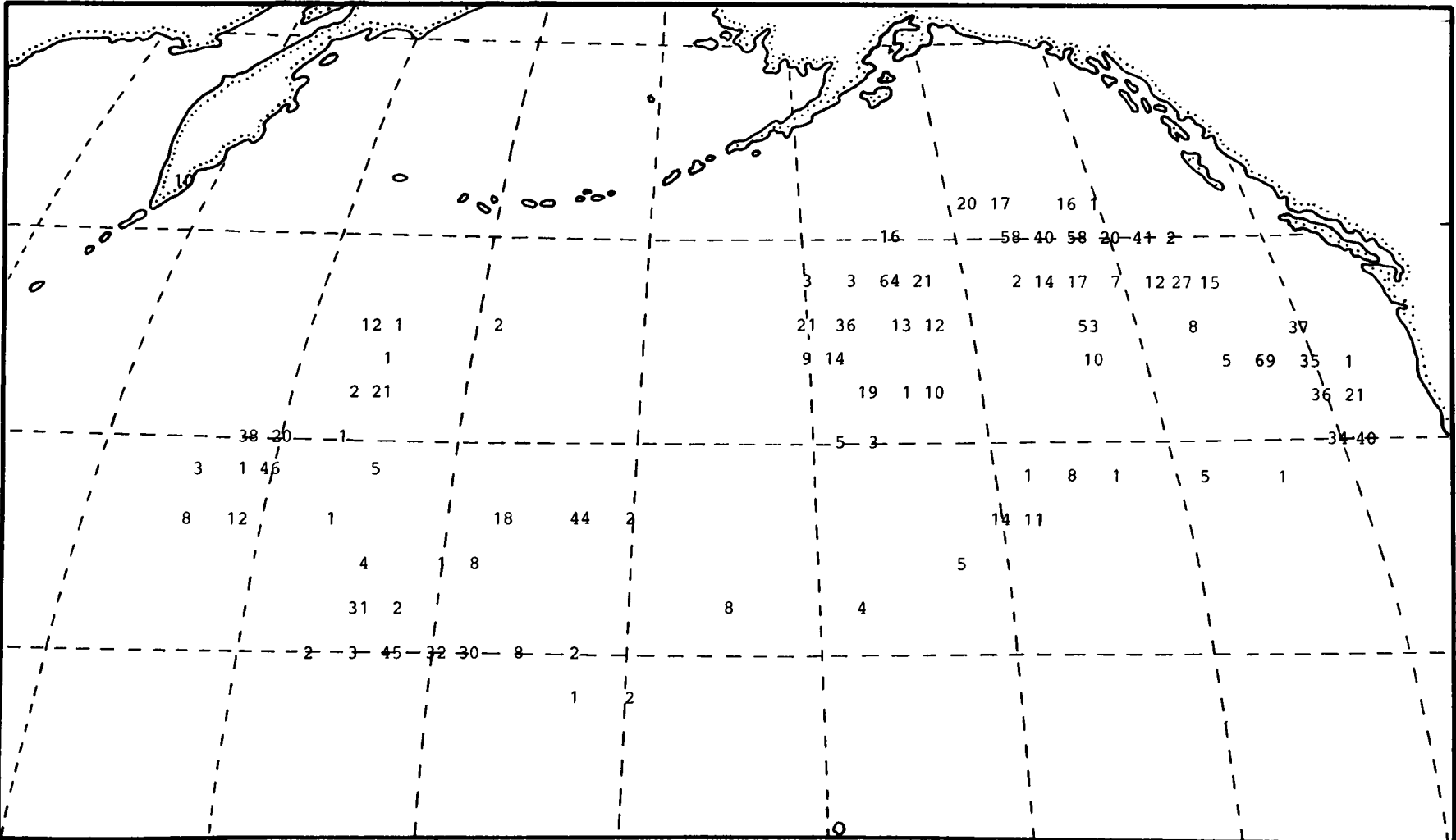


Fig. 9. Catch of male sperm whales in each 2-degree square for 1973

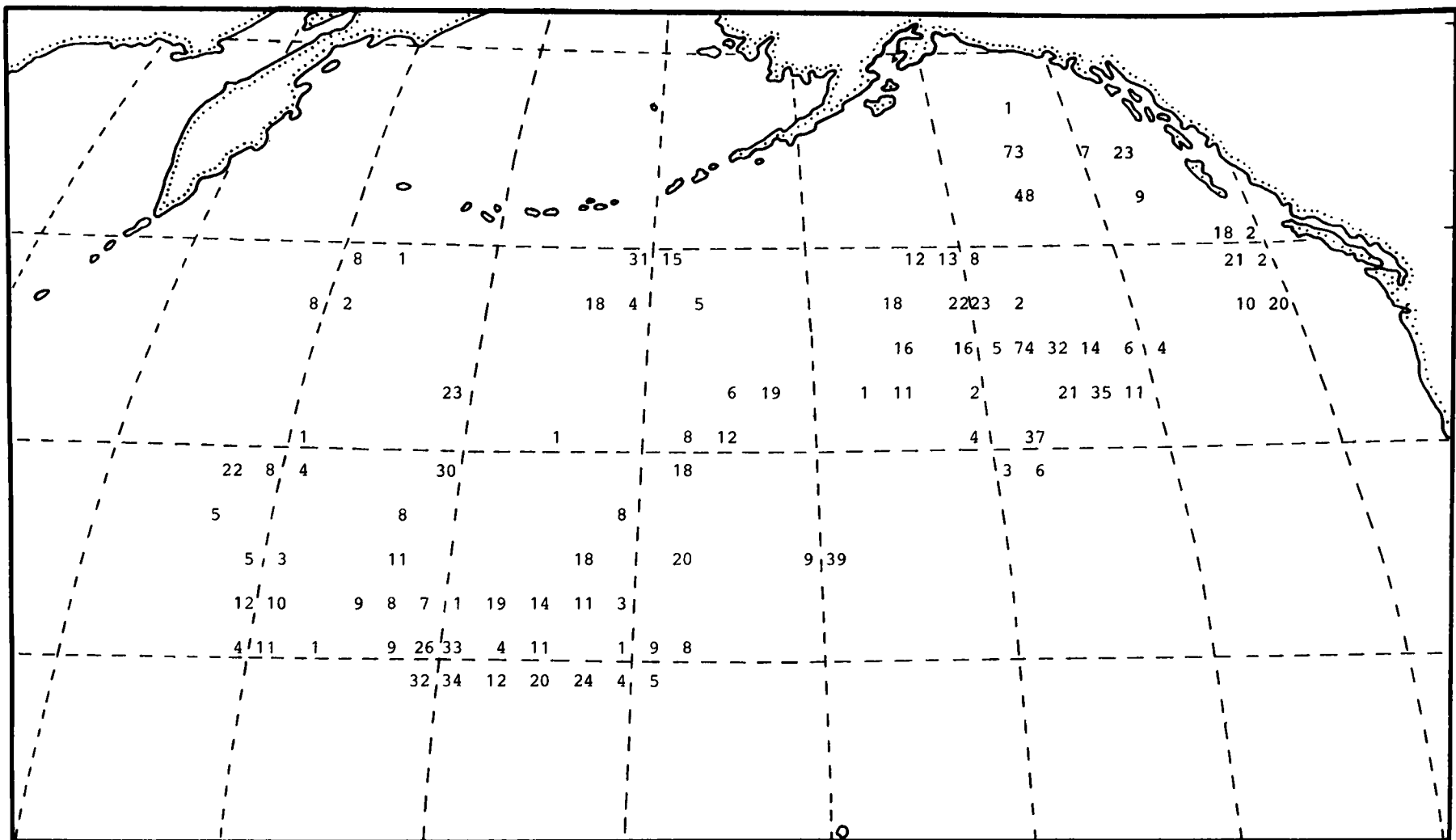


Fig. 10. Catch of male sperm whales in each 2-degree square for 1974

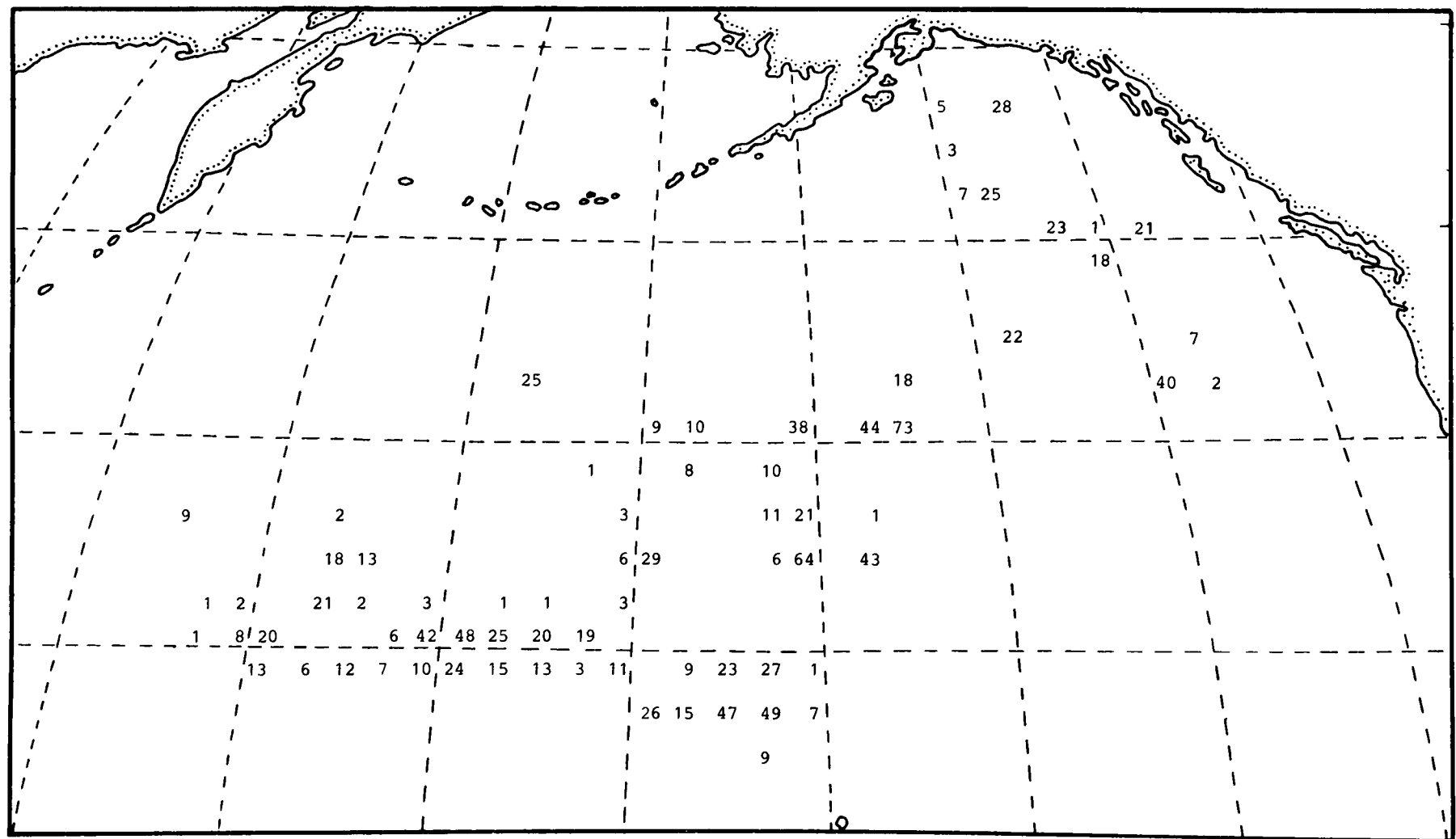


Fig. 11. Catch of male sperm whales in each 2-degree square for 1975

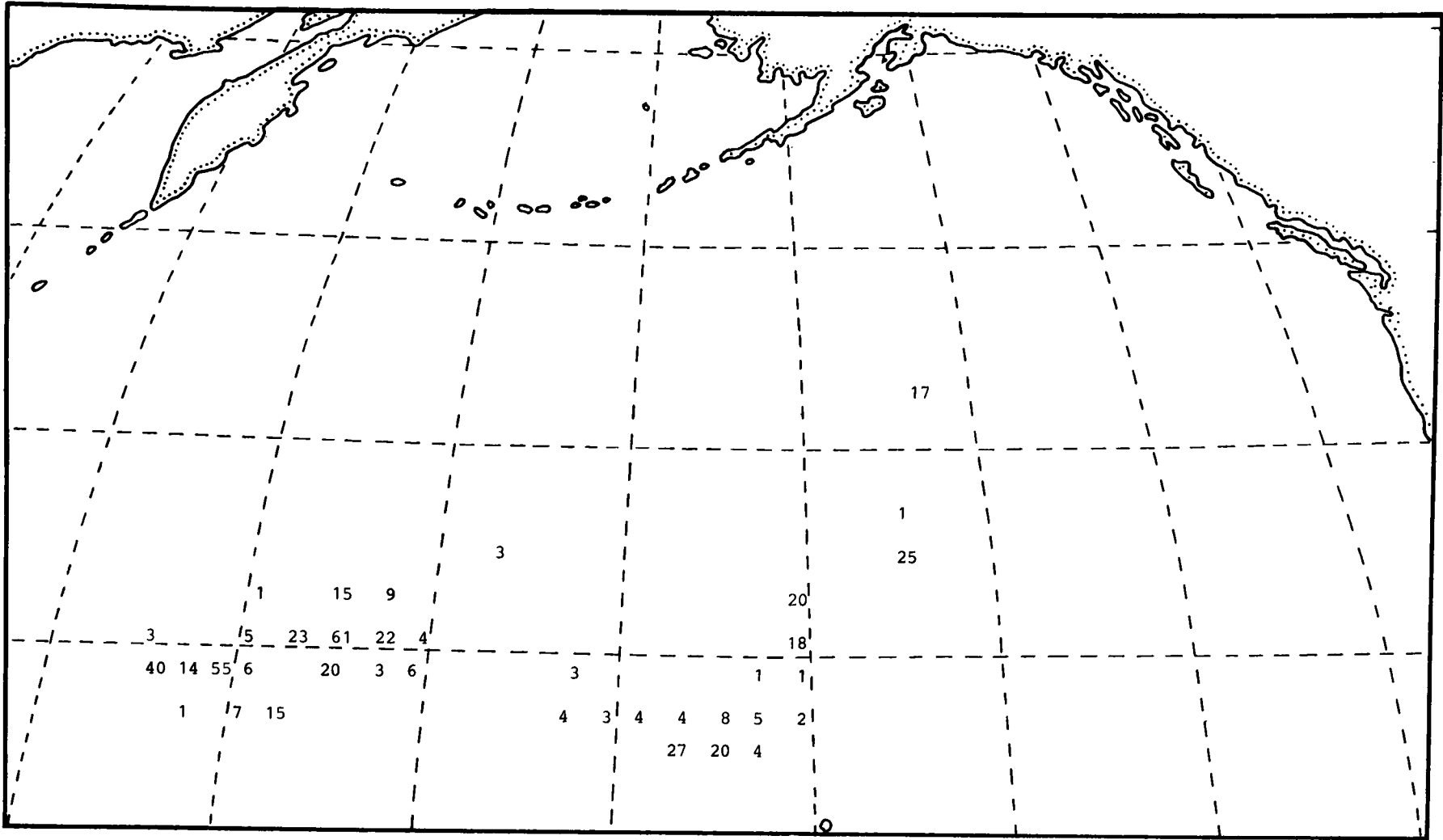


Fig. 12. Catch of male sperm whales in each 2-degree square for 1976

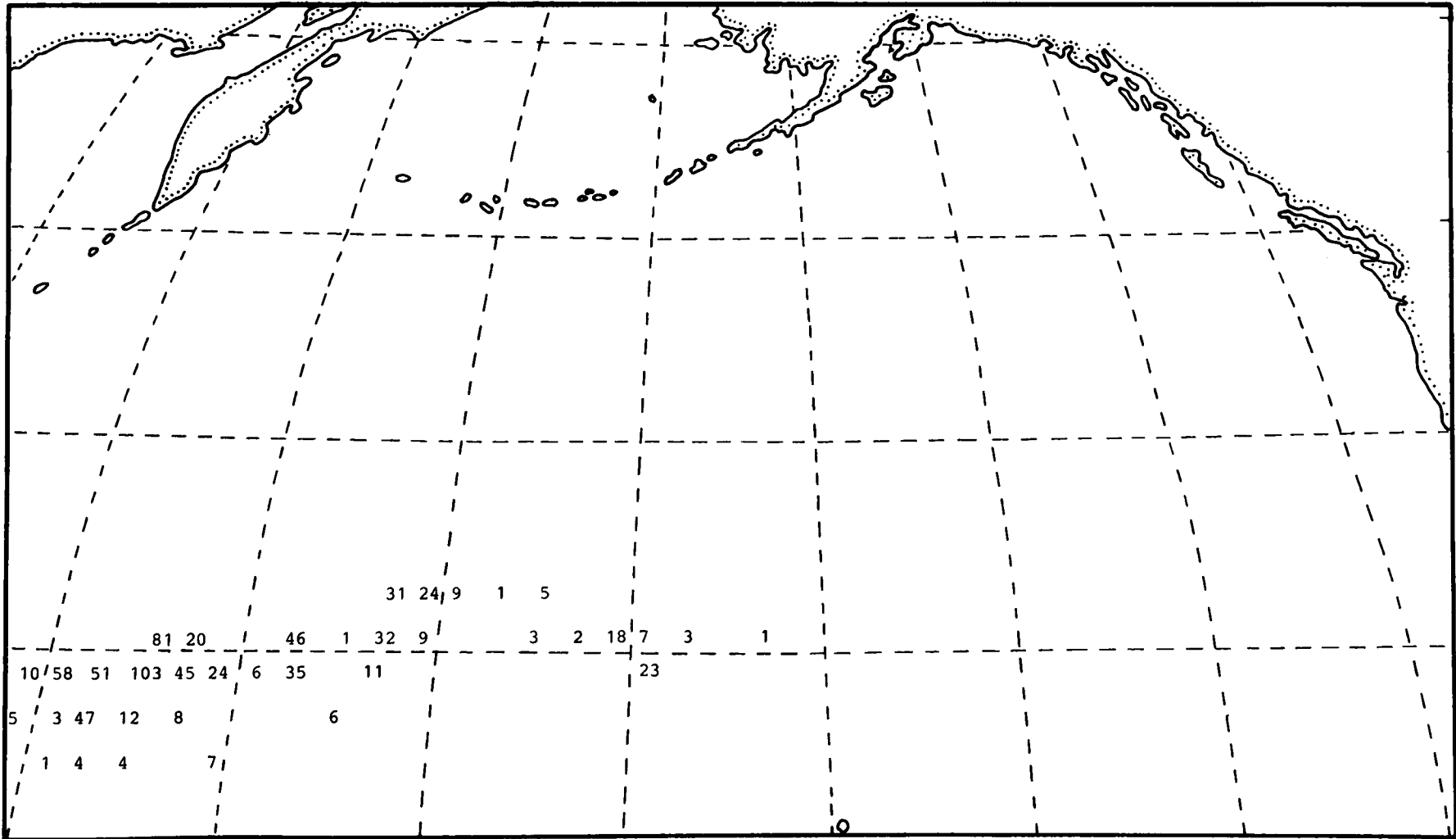


Fig. 13. Catch of male sperm whales in each 2-degree square for 1977

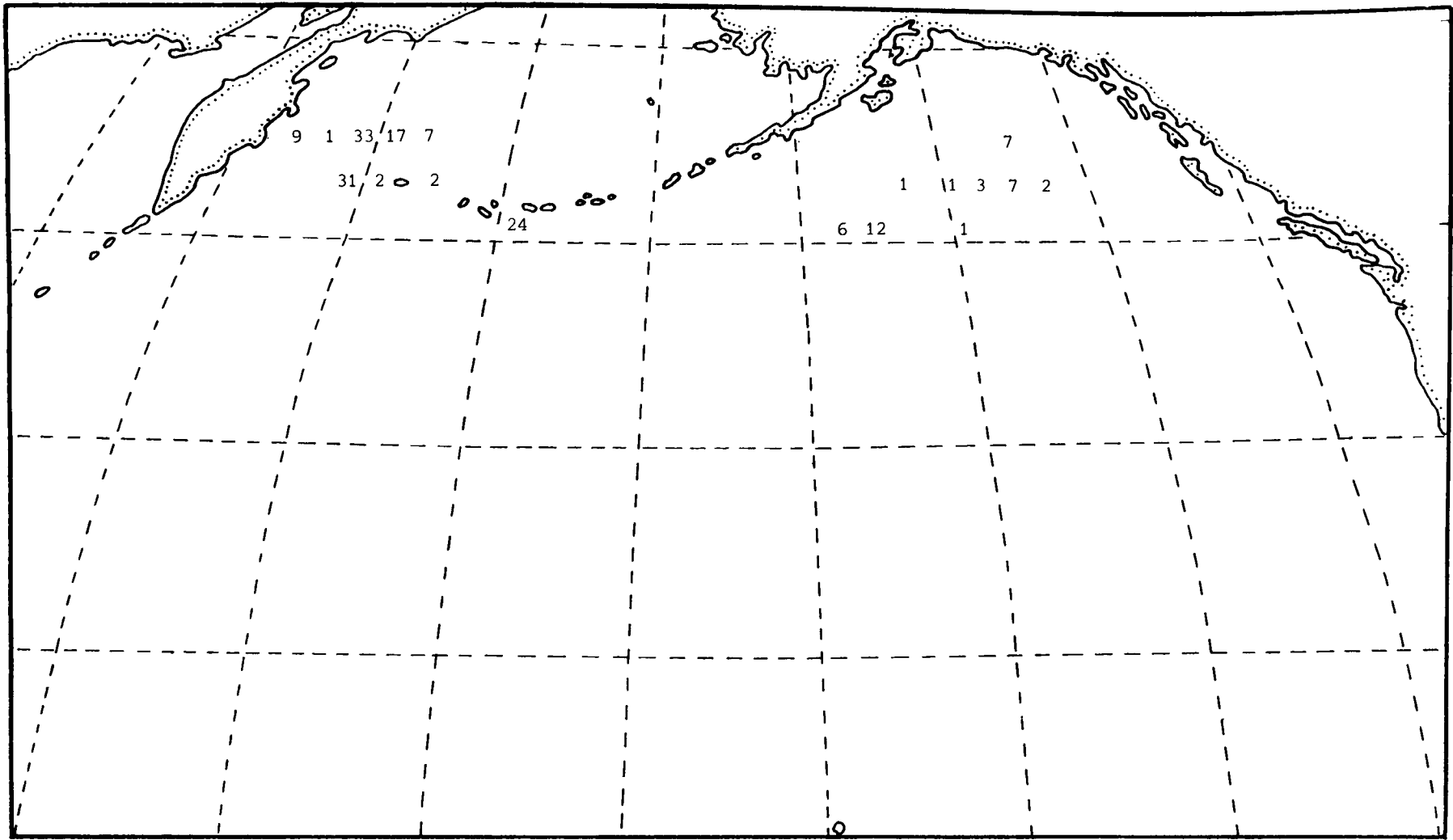


Fig. 14. Catch of female sperm whales in each 2-degree square for 1966

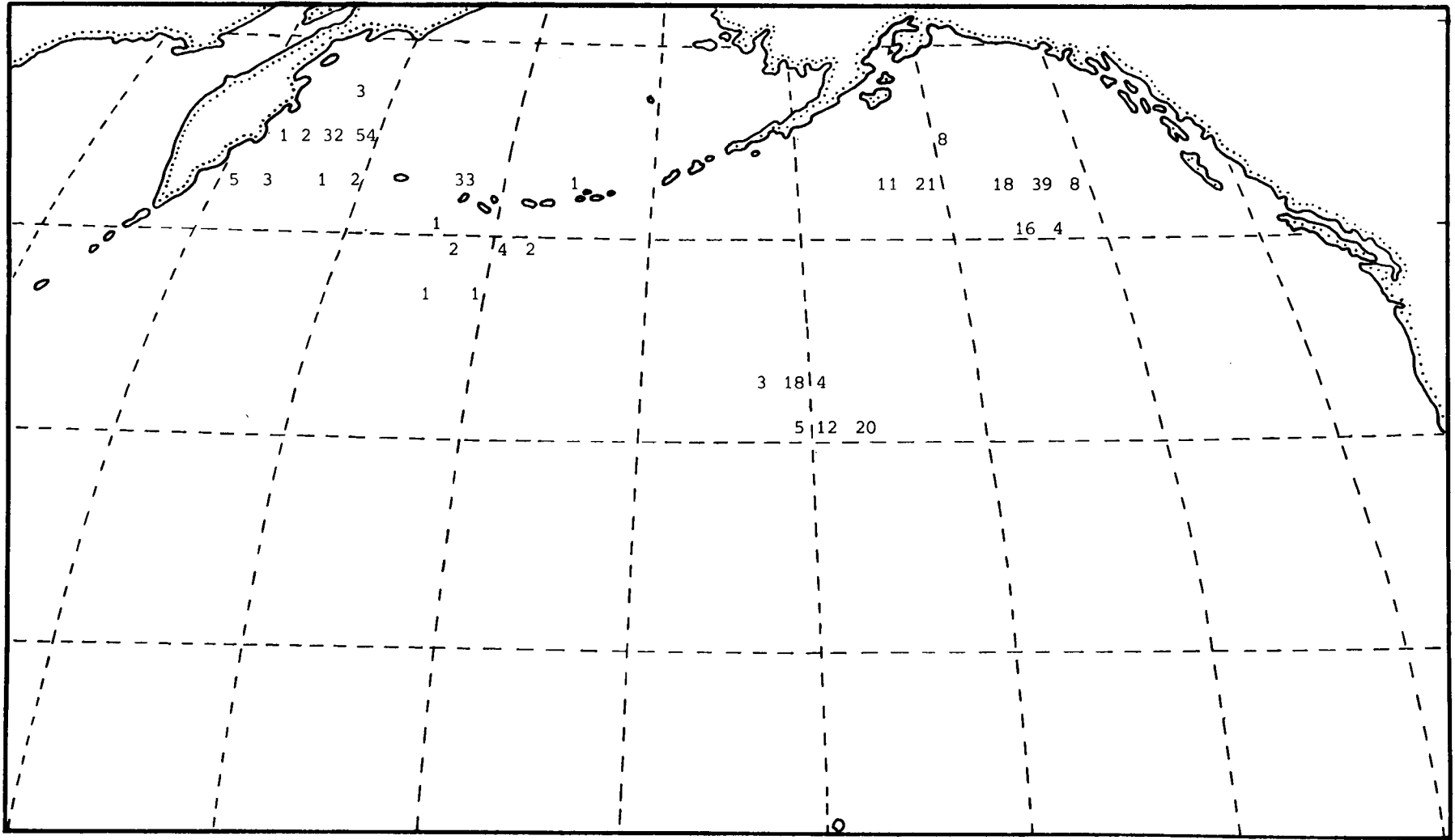


Fig. 15. Catch of female sperm whales in each 2-degree square for 1967

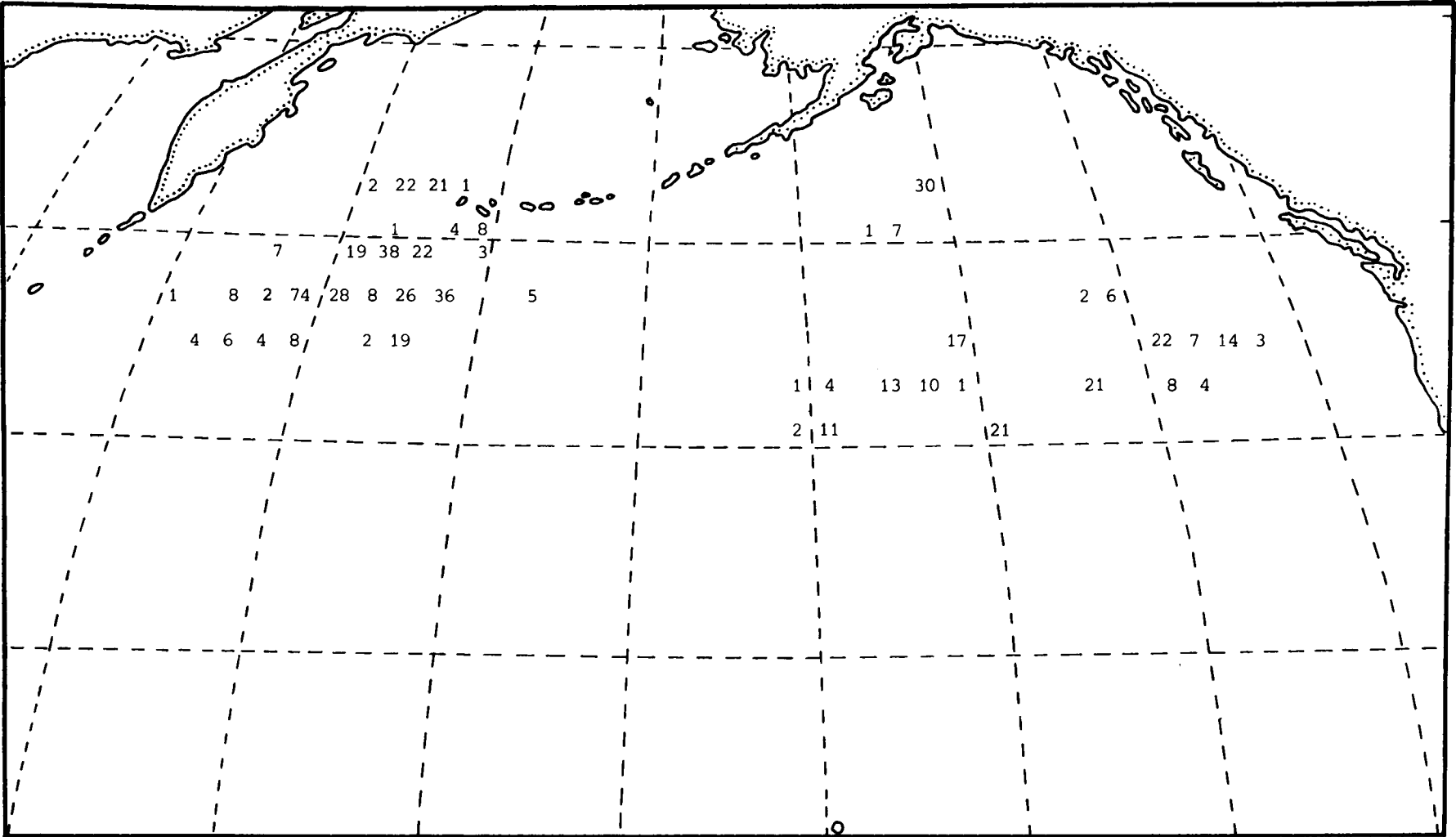


Fig. 16. Catch of female sperm whales in each 2-degree square for 1968

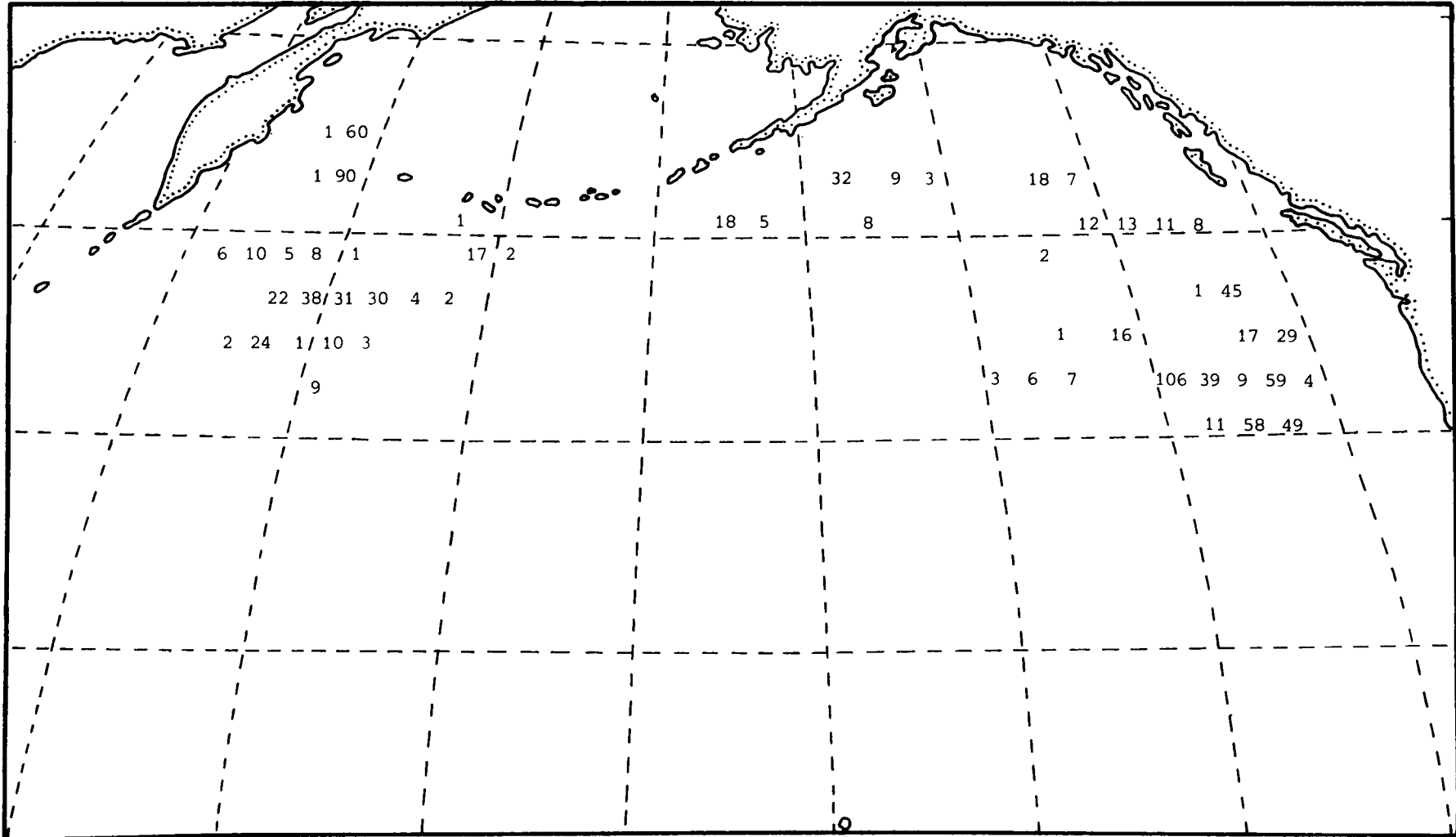


Fig. 17. Catch of female sperm whales in each 2-degree square for 1969

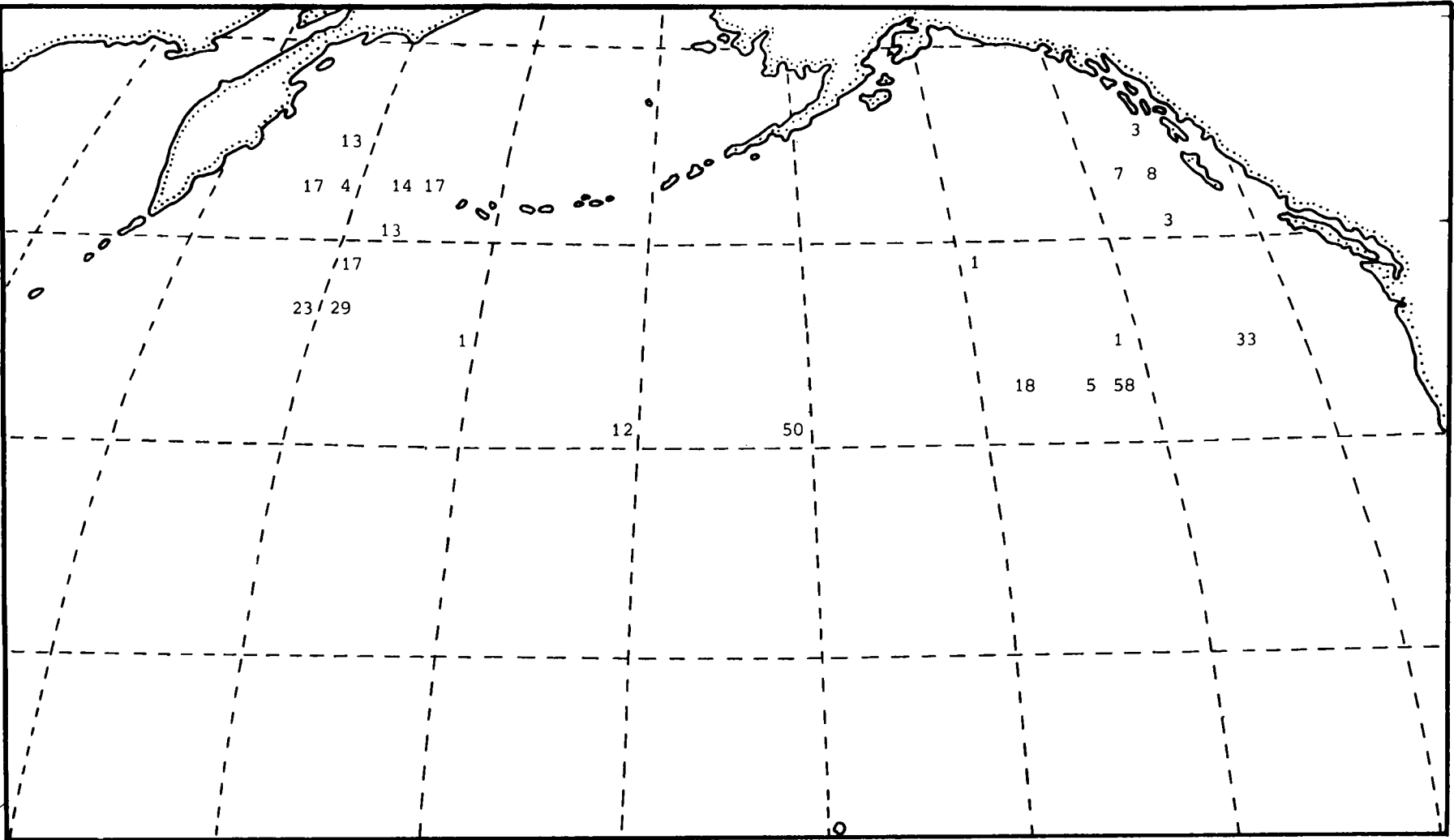


Fig. 18. Catch of female sperm whales in each 2-degree square for 1970

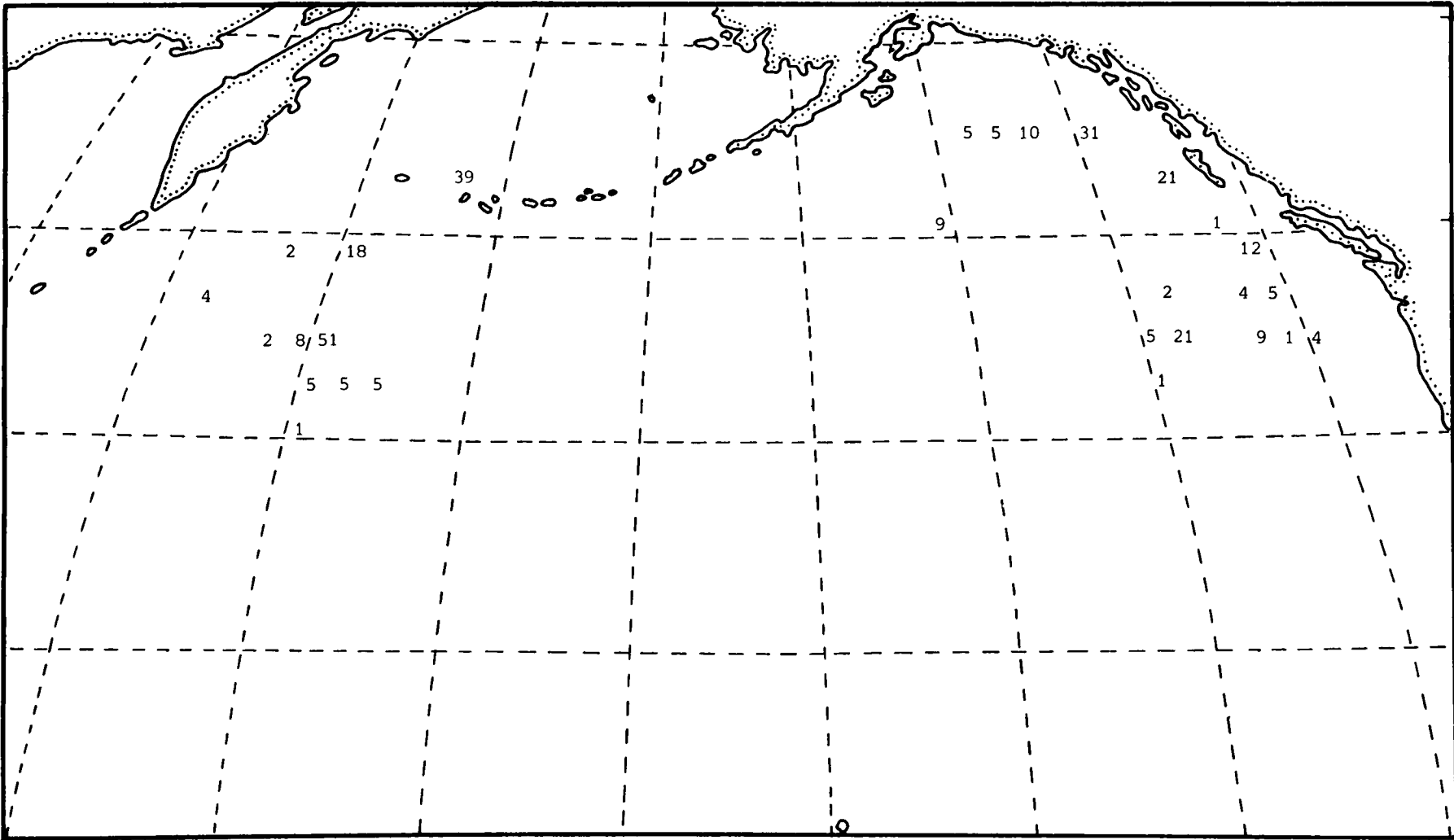


Fig. 19. Catch of female sperm whales in each 2-degree square for 1971

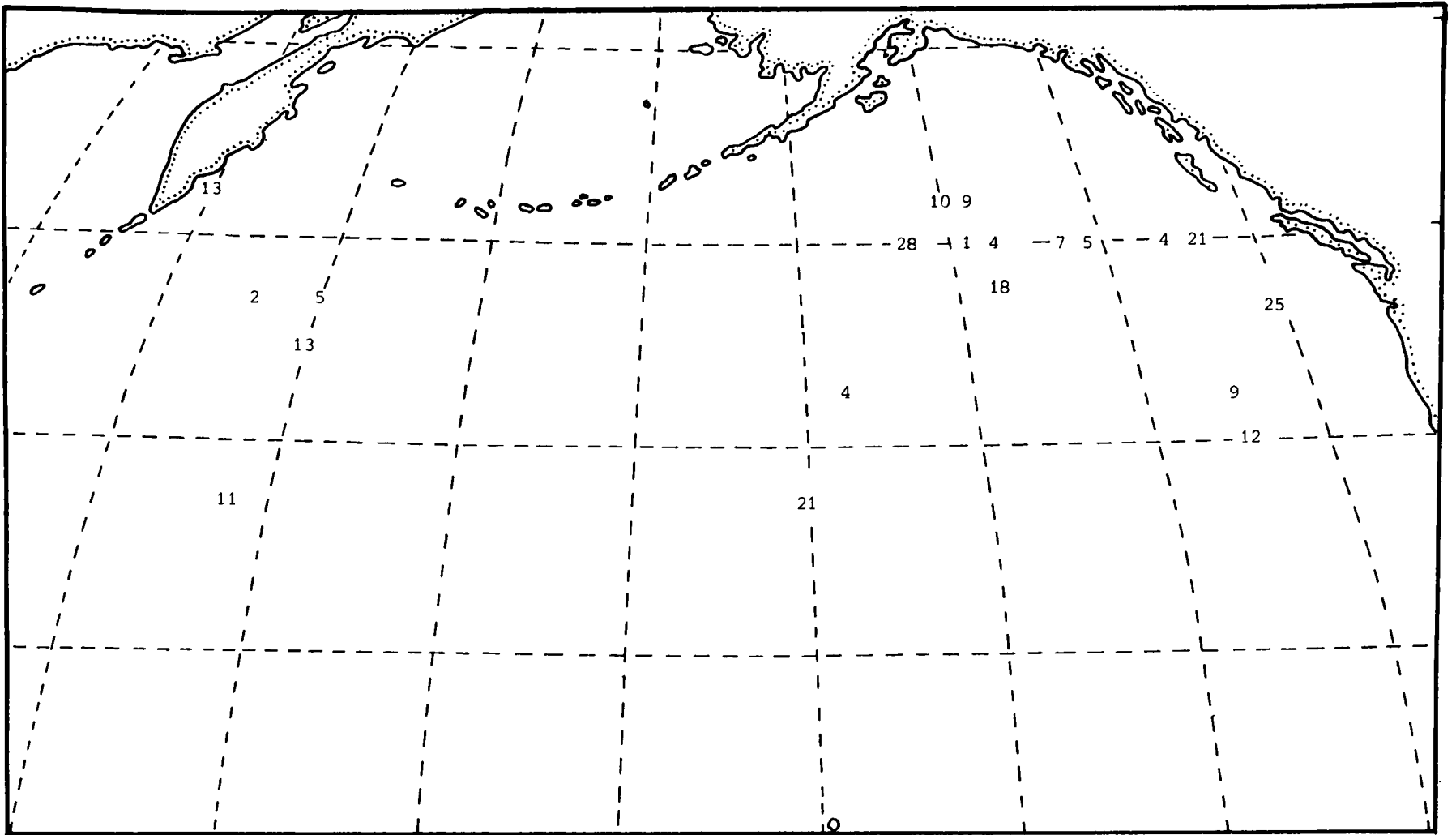


Fig. 20. Catch of female sperm whales in each 2-degree square for 1972

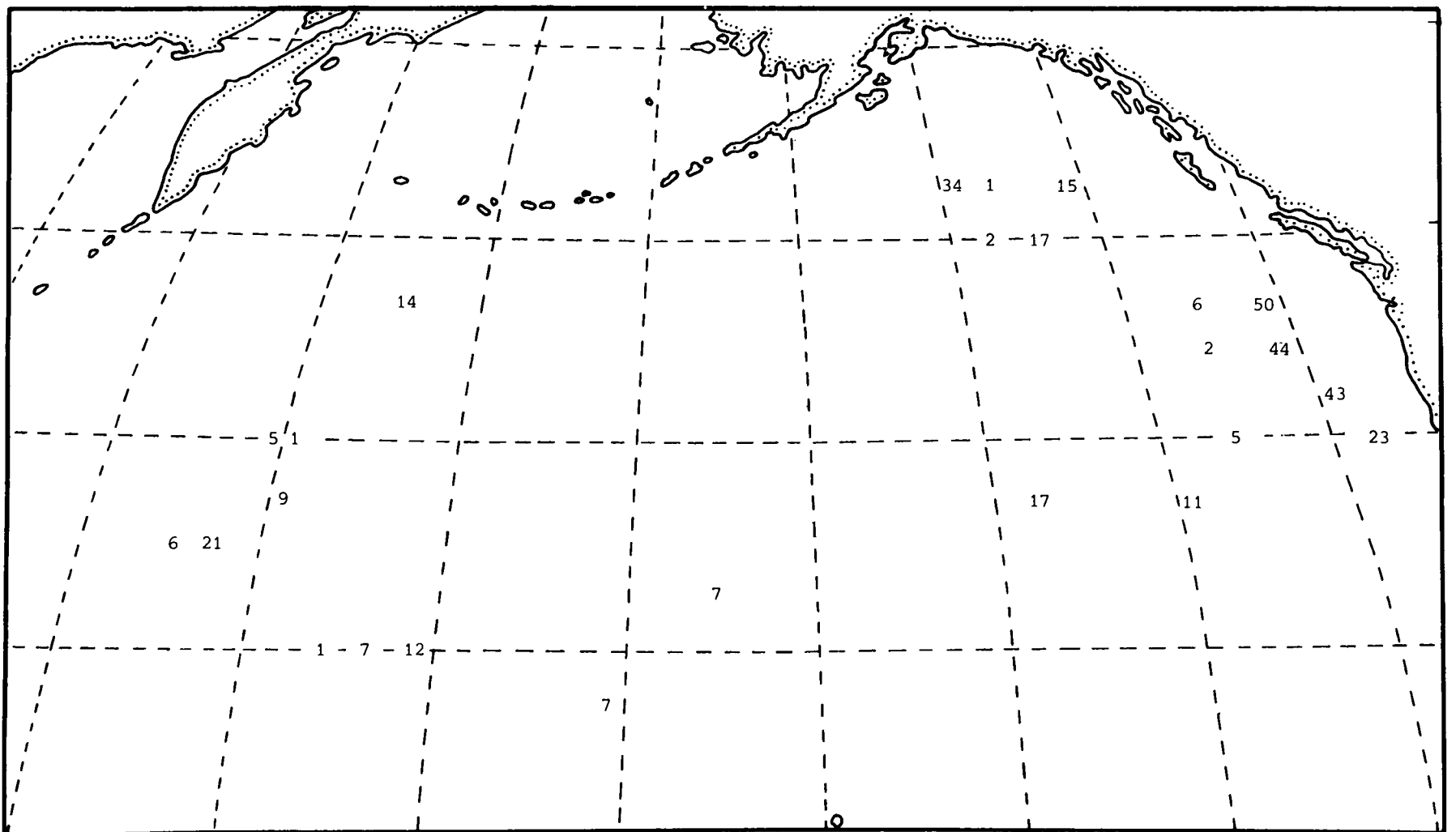


Fig. 21. Catch of female sperm whales in each 2-degree square for 1973

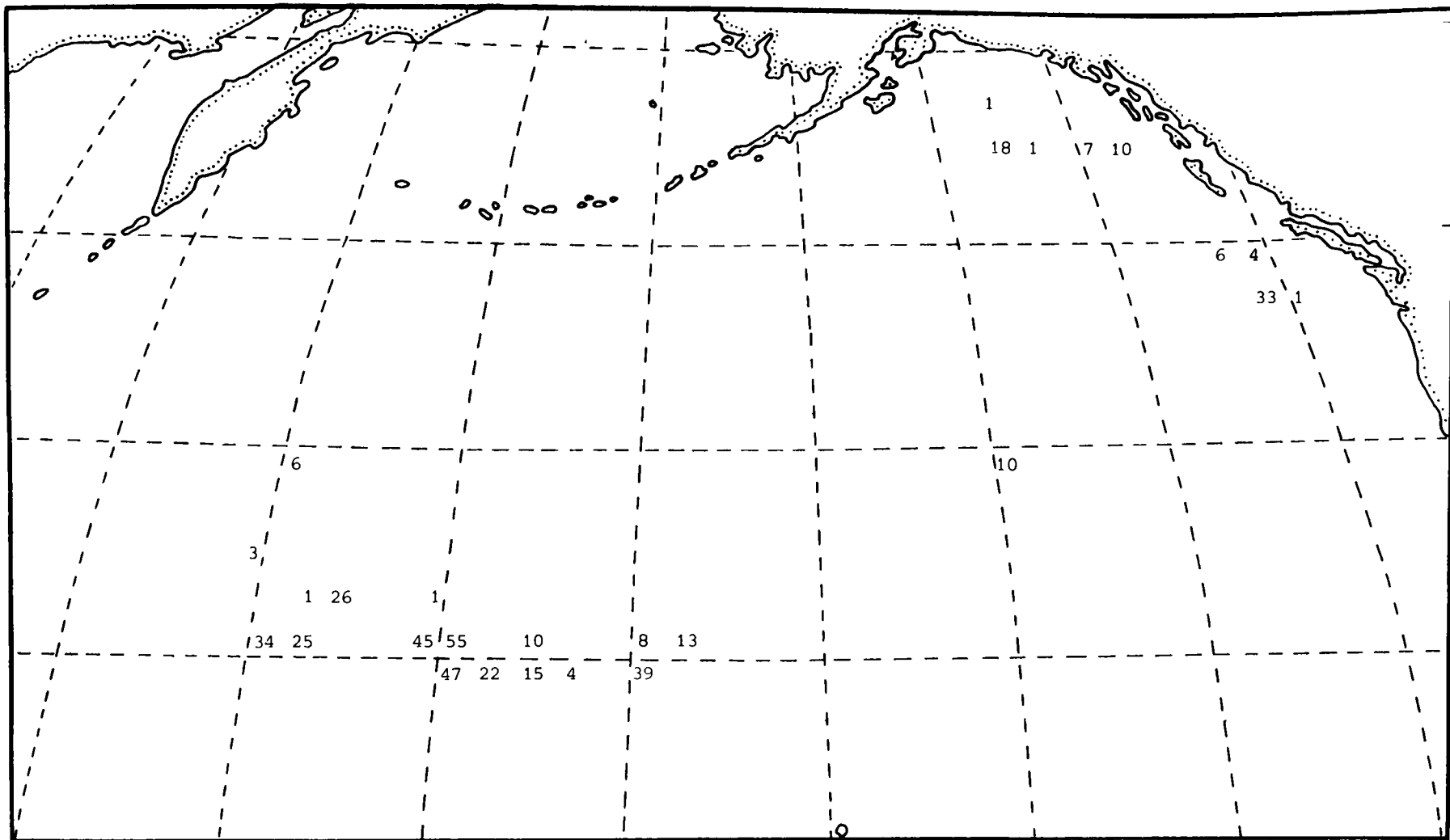


Fig. 22. Catch of female sperm whales in each 2-degree square for 1974

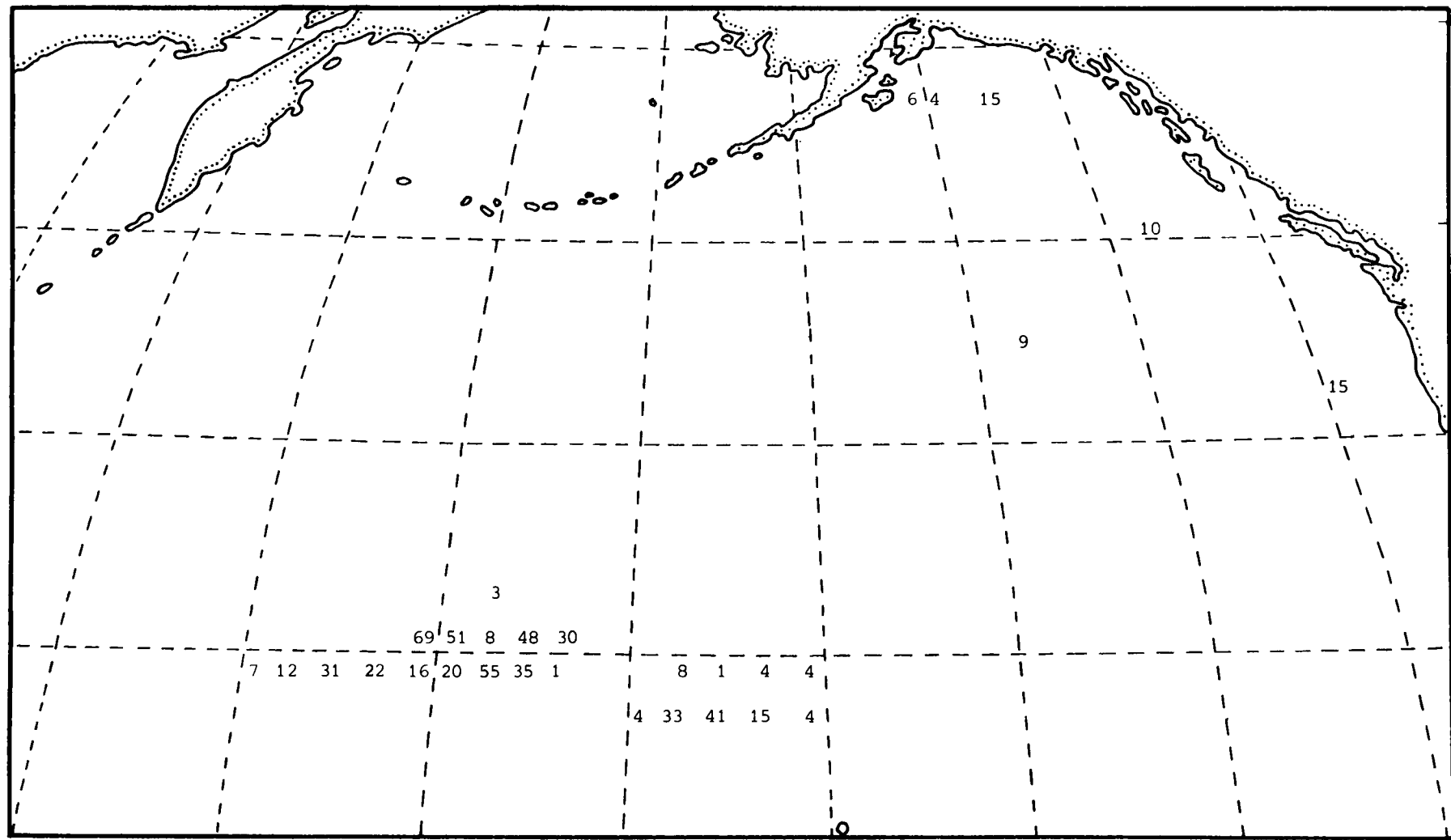


Fig. 23. Catch of female sperm whales in each 2-degree square for 1975

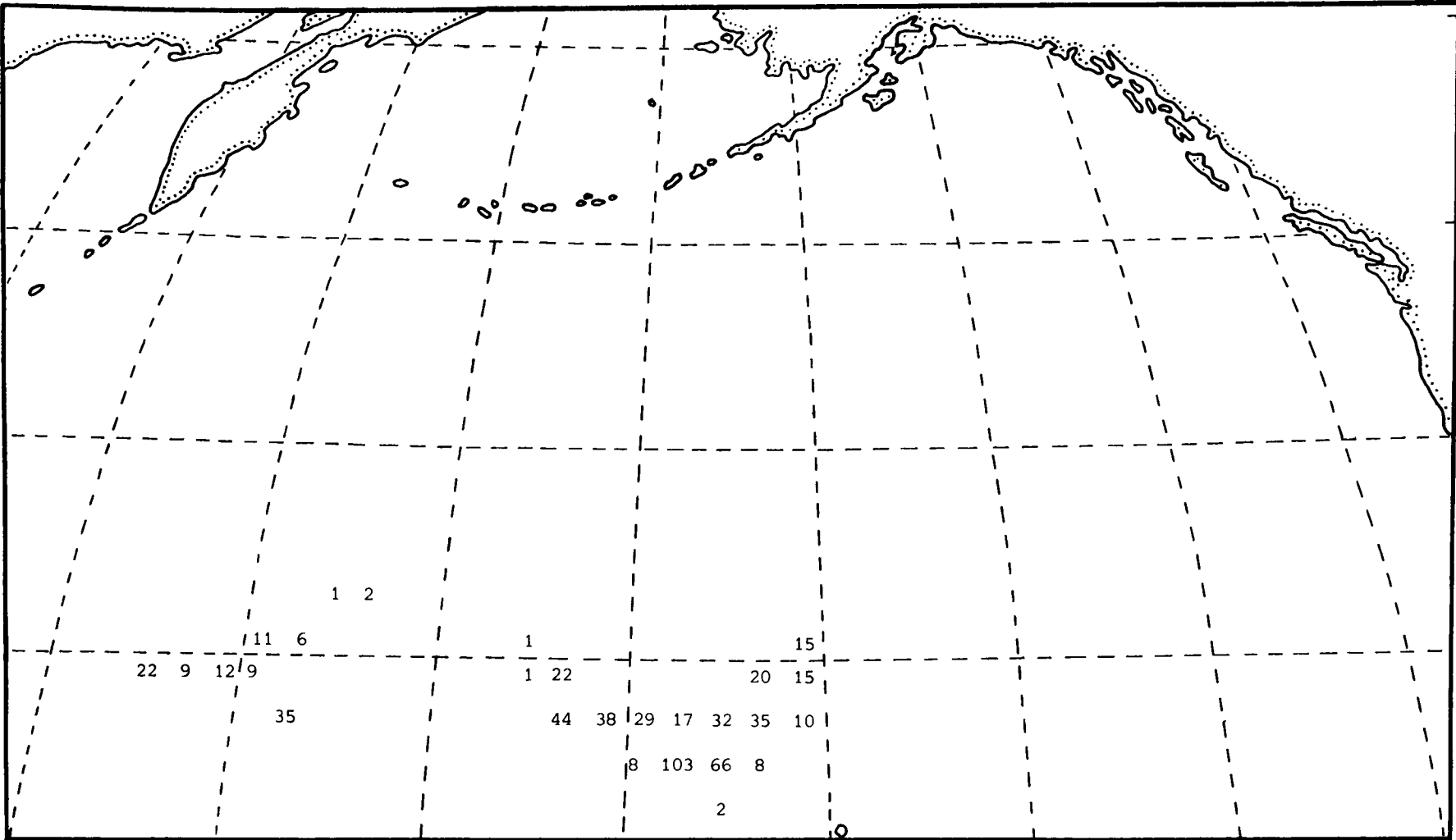


Fig. 24. Catch of female sperm whales in each 2-degree square for 1976

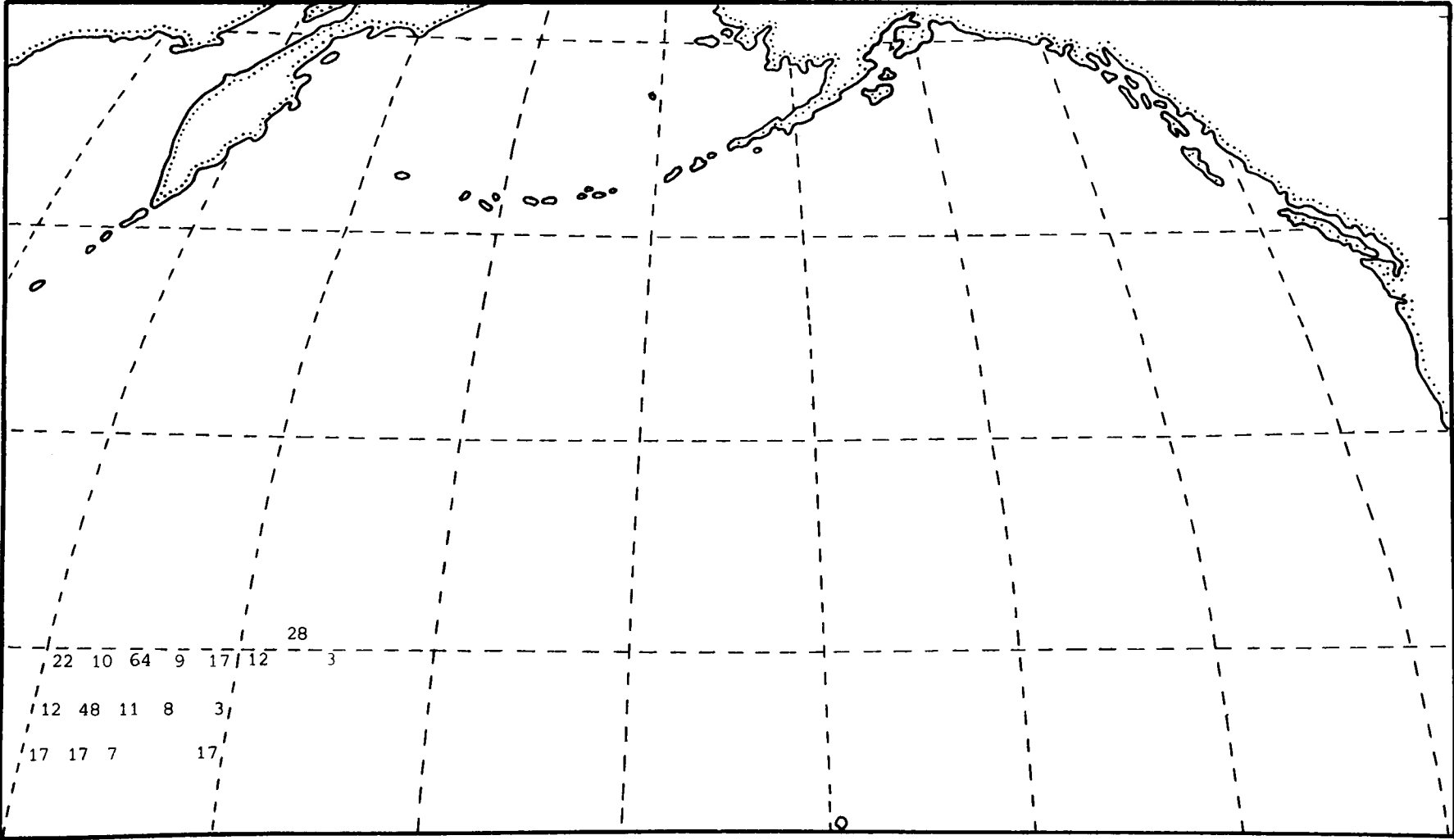


Fig. 25. Catch of female sperm whales in each 2-degree square for 1977