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# Pre-analysis of North Pacific sei whale marking and recovery data

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INTERNATIONAL  
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# Pre-analysis of North Pacific Sei Whale marking and recovery data

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## ABSTRACT

Data on marks placed in north Pacific sei whales *Balaenoptera borealis* during 1949-81 were reviewed with regard to species taking particular account of species uncertainty and uncertainty over the number of marks placed in each whale and in sei whales in total. Whales recorded as multiply marked were significantly more likely to be recovered than singly marked whales, but usually with fewer marks than were recorded as placed. The recovery rate *per mark* was also higher in multiply marked whales, for reasons which are not obvious. Taking account of species uncertainty (particularly between sei, Bryde's and fin whales) each mark was assigned to one of three categories: A (marks placed and size of recapture sample known); B (size of recapture sample known but number of marks placed uncertain); and C (both mark and recapture samples unknown). Category A marks convey information about movement and abundance: category B marks provide information only on movement; and category C marks provide only anecdotal information about movements.

## 1 INTRODUCTION

This is a proposal for how the North Pacific sei whale marking and recovery data can be used in assessment modelling for North Pacific sei whales.

## 2 REVIEW OF DATA ISSUES

The marking data set includes 2,286 marks fired at whales in the North Pacific where the species was recorded as sei whale. These data contain 2,265 marks fired by Japanese expeditions, 18 by US expeditions and 3 Canadian. Of these, 165 marks were recovered, including 147 marks recovered in whales recorded as sei whales. In addition, 3 marks fired at other species were recovered in sei whales. The marks were fired between 1949 and 1981 and recovered between 1950 and 1976.

### 2.1 Hits vs. non-hits

Of the 805 marks fired at sei whales and recorded as "hits", 126 (15.6%) were recovered. Of the 1,481 marks with other verdicts (e.g. "miss", "possible hit" etc), 39 (2.6%) were recovered, with no significant differences between the various non-hit verdicts. Excluding same-season recaptures, 98 (12.6%) hits and 28 (1.9%) non-hits were recovered. The recovery rate of non-hits is clearly lower than the recovery rate of hits, hence these categories need to be distinguished in the analysis.

### 2.2 Multiply hit whales

Of the 805 hits, 589 were recorded as single hits, 156 were recorded as one of double hits on 78 whales, and 60 were recorded as one of triple hits on 20 whales.

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Table 1. Recovery rates of whales with 1, 2 or 3 marks

Marks				Whales				
Hits per whale	Marks placed	Marks recovered	Recovery rate (%)	Hits per whale	Marked whales	Recovered whales	Recovery rate (%)	
1	589	77	13.1%	1	589	77	13.1%	
2	156	30	19.2%	2	78	20	25.6%	
3	60	19	31.7%	3	20	10	50.0%	
Total	805	126	15.7%	Total	687	107	15.6%	

The recoveries (Table 1) show that a whale marked multiple times are more likely to be found with a mark than a whale marked once. This is to be expected if any of the following factors are less than 100%: the effective lodgement rate of “definite hits”; the retention rate of lodged marks; the recovery rate of retained marks in the catch. The “recovery efficiency” is defined as the product of these three factors.

A comparison of marks recovered with marks placed in each recovered whale is shown in Table 2. Assuming that the recovery efficiency of marks is independent of the number of marks in a whale, the results in Table 2 yield a maximum likelihood estimate of recovery efficiency of 0.63 (95% CI 0.48 to 0.76).

Table 2. Recoveries by number of marks placed per whale

Marks placed	Whales by #marks recovered			Total whales	Total marks
	1	2	3		
1	77			77	77
2	10	10		20	30
3	2	7	1	10	19

However, the results in Table 1 also suggest that a mark placed in a multiply marked whale has a higher recovery efficiency than a mark placed in a singly marked whale. It may be that the discovery of a mark alerts crews to the possible presence of further marks. In that case, the estimate of 0.63 for the recovery efficiency would be positively biased for single marks. If we assume that the lower recovery rate of marks in singly-marked whales is due to this factor, then the 0.63 recovery efficiency estimate applies only to multiply marked whales. The estimate for singly-marked whales would be 0.36 (0.63 times the ratio 13.1/22.7 of the recovery rates of multiply and singly marked whales).

We conclude that 100% recovery efficiency should not be assumed in any analysis.

### 2.3 Species uncertainty

There can be uncertainty as to the species of both the marked whale and the recovered whale, and also with respect to the species composition of the total catch. Uncertainty of the marked species reflects uncertainty in field identification and can affect any species at any time. Uncertainty in the species of captured whales was probably only significant with respect to the sei/Brydes whale distinction and only before 1962. Some recoveries were found after processing (e.g. in the cooker or refrigerator) and could not be assigned to a unique whale, such that species uncertainty at the time of marking can remain after recapture.

Brydes whales began to be distinguished from sei whales in Japanese catch records from 1955, with the distinction complete by 1962. The first recovery recorded in a Brydes whale was in 1958; prior to 1958 it can be supposed that recoveries in Brydes were logged as recoveries in sei whales, but some further recoveries in Brydes during 1958-61 may also have been logged as recoveries in sei whales. No marks were recovered in Brydes whales north of 40°N.

Of the 178 marks that hit “sei” whales south of 40°N prior to 1962 (all of which were prior to 1954), 9 were recovered before 1958 and hence in ambiguous species, 9 were recovered in Brydes whales during

1958-71, and 4 were recovered in sei whales during 1958-62. It is likely that these marked whales were mainly Brydes whales.

Of 17 marks that hit “sei whales” north of 50°N in 1956 or earlier, 5 were recovered in fin whales and 2 were recovered in sei whales.

The above information indicates:

- Catches and mark recoveries prior to 1962 south of 42.5°N should be treated as unreliable with respect to species.
- Unrecovered marks fired prior to 1957 north of 50°N or south of 40°N should be treated as having uncertain target species, but some of the later recoveries have reliable species id.

## **2.4 USSR catches and recoveries**

There were no recoveries by USSR fleets of marks fired at sei whales in the USSR catch (after correction for data falsification) of 5,626 sei whales from 1962 onwards. This compares with 125 recoveries by Japanese vessels in the same period from a catch of 35,914 sei whales. Therefore, USSR catches should not be included in the effective catch for analysing recovery rates.

## **3 RECOMMENDED USE OF MARK AND RECOVERY DATA IN MODELLING**

In order to draw inference about abundance from mark-recovery analysis, the sizes of both the capture (marked) sample and the size of the recapture sample (the catch in which recoveries are found) must be well-defined and known. In cases where only the size of the recapture sample, but not the size of the marked sample, is well-determined, recoveries may still give useful information about whale movements. If the size of the recapture sample is not known, the recoveries provide only qualitative information.

### **3.1 Effectively marked samples**

The effectively marked sei whales are those receiving one or more definite hits in one of the following area/period combinations:

- south of 42.5°N from 1962 onwards (none were fired during 1954-61)
- between 42.5°-50°N from 1949 onwards
- north of 50°N from 1957 onwards

but excluding whales recaptured within the same season.

Same-season recaptures are marks fired and recaptured within a single summer (Apr-Oct). Marks fired in winter and recaptured in summer of the same year are not considered same-season recaptures.

The sample sizes of effectively marked sei whales by subarea, year and season are given in Table 3. The numbers are broken down by marking multiplicity (singly, doubly or triply marked whales, counting only definite hits). The subareas are defined as in IWC (2019).

### **3.2 Effective catch for potential recoveries**

The effective catches for potential recoveries samples are all non-USSR catches which were taken north of 42.5°N in 1950 or later or south of 42.5°N in 1962 or later. The effective catches by subarea and year are listed in Table 4, broken down by subarea, year and season of marking. Although the last recorded recovery in a sei whales was in 1975, it is assumed that if a mark had been found in more recent catches (up to 2017), it would have been returned.

### **3.3 Categories of recoveries**

For modelling purposes distinction should be made between recoveries of Type A, B and C:

- A: recoveries in sei whales contained in both an effective marking (capture) sample and an effective catch (recapture sample), as defined above;
- B: other recoveries from within an effective catch
- C: all other recoveries

Type B recoveries include marks recovered in sei whales which do not meet the time/area criteria for Type A, or which were not recorded as definite hits, or where the target species was not identified as a sei whale at the time of marking. Type C recoveries include same-season recoveries of summer marks (35), USSR recoveries (1) and recoveries in catches south of 42.5° prior to 1962.

Type A and B recoveries are listed in Tables 5a and 5b. Type C recoveries are not considered further.

### **3.4 Recommended treatment of categories in likelihood function for model fitting**

Type A recoveries, along with the effective numbers marked, can be modelled using the likelihood function of SC/67b/IA1, but amended to allow for a recovery efficiency of less than 1.0. The number of marks removed by fishing mortality should perhaps be based on the expected rather than observed numbers, given that the latter do not include all marks that hit subsequently caught whales.

Type B recoveries can be modelled by amending the likelihood to condition on the mark being recovered (somewhere and sometime), so that the effective size of the marked sample need not be specified. Type B recoveries provide information on movements but not on abundance.

Type C recoveries should not be used.

## **4 NEXT STEPS**

The subcommittee needs to consider:

1. How to treat the recovery efficiency. Options include:
  - assume (a) value(s)
  - assume a prior distribution
  - whether to take account of marking multiplicity
2. Whether it is practicable to modify the likelihood to use Type B recoveries. If not, they should be excluded from the assessment modelling, but can be used to evaluate plausibility of results.

## REFERENCE

IWC 2019. Report of the subcommittee on in-depth assessments, Appendix 2. *JCRM* 20:000-000.

Table 3. Sample sizes of effective amrks placed

Year	Summer /Winter	SubArea	# of hits in whale			Total	Year	Summer /Winter	SubArea	# of hits in whale			Total
			1	2	3					1	2	3	
1952	S	WC	4	2	0	6	1968	S	Pel	5	0	0	5
1954	S	Pel	0	2	0	2	1969	S	Alt	4	0	0	4
1954	S	WC	1	0	0	1	1969	S	Mix	2	0	0	2
1957	S	Alt	9	0	0	9	1969	S	Pel	19	2	0	21
1958	S	Alt	5	0	0	5	1969	S	WC	7	0	0	7
1959	S	Alt	4	2	0	6	1970	S	Alt	1	0	0	1
1960	S	Alt	10	0	0	10	1970	S	Pel	17	2	0	19
1961	S	Alt	5	0	0	5	1970	S	WC	1	0	0	1
1961	S	Pel	4	1	0	5	1971	S	Alt	6	0	0	6
1962	S	Alt	5	0	0	5	1971	S	Pel	12	0	0	12
1962	S	Pel	6	0	0	6	1972	W	Pel	22	15	10	47
1963	S	Alt	9	0	0	9	1972	S	Alt	7	0	0	7
1963	S	Mix	10	0	0	10	1972	S	Pel	10	0	0	10
1963	S	Pel	7	0	0	7	1973	W	Pel	17	2	0	19
1964	S	Alt	5	1	0	6	1973	S	EC	4	0	0	4
1964	S	EC	6	0	0	6	1973	S	Pel	21	3	0	24
1964	S	ENP	17	1	0	18	1974	S	Pel	14	1	0	15
1964	S	Mix	1	0	0	1	1975	S	Pel	8	0	0	8
1964	S	Pel	1	0	0	1	1976	S	Mix	1	0	0	1
1965	W	EC	1	0	0	1	1976	S	Pel	8	0	0	8
1965	W	Rem	2	0	0	2	1977	S	EC	3	0	0	3
1965	S	Alt	3	0	0	3	1977	S	ENP	3	0	0	3
1965	S	EC	7	1	0	8	1977	S	Mix	1	0	0	1
1965	S	Mix	3	1	0	4	1977	S	Pel	23	0	0	23
1965	S	Pel	2	0	0	2	1978	S	Alt	1	0	0	1
1966	S	Alt	21	0	0	21	1978	S	EC	1	0	0	1
1966	S	Mix	7	0	0	7	1978	S	Pel	24	0	0	24
1966	S	Pel	5	0	0	5	1979	S	Alt	1	0	0	1
1967	S	Alt	15	2	0	17	1979	S	Pel	17	0	0	17
1967	S	Pel	12	1	0	13	1980	S	Pel	3	0	0	3
1968	S	Alt	4	0	0	4	1981	S	Pel	2	0	0	2
1968	S	Mix	2	1	0	3							

Table 4. Effective catches for recovery samples

Year	Western Coastal		Aleutian		Pelagic		Mixed		ENP		Eastern Coastal		Total	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
1950	16	33	0	0	0	0	0	0	10	14	0	0	26	47
1951	0	0	0	0	0	0	0	0	5	0	0	0	5	0
1952	53	57	8	6	0	0	0	0	17	5	0	0	78	68
1953	92	60	51	47	0	0	0	0	2	12	0	0	145	119
1954	120	113	74	50	2	3	0	0	74	60	0	0	270	226
1955	41	65	12	9	0	0	0	0	84	55	0	0	137	129
1956	63	68	28	20	0	0	0	0	12	25	0	0	103	113
1957	48	54	74	65	17	10	0	0	36	57	0	0	175	186
1958	43	50	109	140	35	46	0	0	15	24	0	0	202	260
1959	62	57	10	22	0	0	0	0	116	69	0	0	188	148
1960	20	23	114	51	17	23	0	0	0	0	0	0	151	97
1961	54	92	0	3	8	1	0	1	0	0	0	0	62	97
1962	366	358	104	69	33	19	18	18	211	128	5	18	737	610
1963	324	319	36	36	1	1	324	268	309	126	34	63	1028	813
1964	397	402	589	378	13	8	279	175	409	294	4	9	1691	1266
1965	264	182	566	402	23	36	188	122	390	287	7	15	1438	1044
1966	71	154	563	421	206	146	556	327	179	187	22	38	1597	1273
1967	203	283	1031	607	1058	768	13	5	34	55	2	1	2341	1719
1968	402	402	1257	791	911	749	78	37	0	0	5	9	2653	1988
1969	227	220	850	416	1194	1150	0	0	0	0	4	6	2275	1792
1970	222	254	326	288	1148	1072	32	20	187	132	23	19	1938	1785
1971	126	132	269	212	832	967	9	5	35	27	51	33	1322	1376
1972	117	85	63	57	933	983	9	6	0	0	1	1	1123	1132
1973	20	11	12	8	896	795	4	4	0	0	3	0	935	818
1974	13	16	35	43	520	534	1	2	18	20	13	23	600	638
1975	12	9	0	0	237	221	1	1	2	1	0	0	252	232
2001	1	0	0	0	0	0	0	0	0	0	0	0	1	0
2002	0	0	0	1	16	23	0	0	0	0	0	0	16	24
2003	3	2	0	0	20	25	0	0	0	0	0	0	23	27
2004	0	0	15	13	32	40	0	0	0	0	0	0	47	53
2005	0	0	1	0	50	49	0	0	0	0	0	0	51	49
2006	2	3	0	0	47	49	0	0	0	0	0	0	49	52
2007	5	1	0	0	49	45	0	0	0	0	0	0	54	46
2008	0	0	3	3	41	53	0	0	0	0	0	0	44	56
2009	0	0	0	0	47	54	0	0	0	0	0	0	47	54
2010	5	5	0	0	38	52	0	0	0	0	0	0	43	57
2011	0	0	13	3	42	38	0	0	0	0	0	0	55	41
2012	0	0	0	0	44	56	0	0	0	0	0	0	44	56
2013	0	0	6	3	38	53	0	0	0	0	0	0	44	56
2014	0	0	0	0	38	52	0	0	0	0	0	0	38	52
2015	0	0	0	0	29	61	0	0	0	0	0	0	29	61
2016	2	2	0	0	36	50	0	0	0	0	0	0	38	52
2017	1	2	17	29	45	40	0	0	0	0	0	0	63	71
2018	1	2	0	0	62	69	0	0	0	0	0	0	63	71

Table 5. Recoveries of type A and B

----- number of hits -----

Category	Year marked	Winter/summer	SubArea marked	Year recov.	SubArea recov.	0			1			2			3		
						U	M	F	U	M	F	U	M	F	U	M	F
A	1952	S	WC	1955	WC	0	0	0	0	0	1	0	0	1	0	0	0
A	1952	S	WC	1959	WC	0	0	0	0	1	0	0	0	0	0	0	0
A	1957	S	Alt	1967	Pel	0	0	0	2	2	2	0	0	0	0	0	0
A	1958	S	Alt	1967	Alt	0	0	0	1	1	1	0	0	0	0	0	0
A	1959	S	Alt	1965	Mix	0	0	0	1	1	1	0	0	0	0	0	0
A	1960	S	Alt	1962	ENP	0	0	0	0	1	0	0	0	0	0	0	0
A	1962	S	Alt	1964	Alt	0	0	0	0	1	0	0	0	0	0	0	0
A	1963	S	Alt	1964	Mix	0	0	0	0	1	0	0	0	0	0	0	0
A	1963	S	Alt	1965	Alt	0	0	0	0	0	1	0	0	0	0	0	0
A	1963	S	Alt	1966	Alt	0	0	0	0	2	0	0	0	0	0	0	0
A	1964	S	Alt	1973	Pel	0	0	0	0	2	0	0	0	0	0	0	0
A	1964	S	EC	1966	Mix	0	0	0	1	1	1	0	0	0	0	0	0
A	1965	S	EC	1969	Pel	0	0	0	0	0	0	1	1	1	0	0	0
A	1965	S	Mix	1970	Pel	0	0	0	0	0	0	0	0	1	0	0	0
A	1965	S	Pel	1967	Alt	0	0	0	0	1	0	0	0	0	0	0	0
A	1966	S	Alt	1968	Pel	0	0	0	0	1	0	0	0	0	0	0	0
A	1966	S	Alt	1969	Alt	0	0	0	1	1	1	0	0	0	0	0	0
A	1966	S	Mix	1968	Pel	0	0	0	1	1	1	0	0	0	0	0	0
A	1966	S	Mix	1971	Alt	0	0	0	1	1	1	0	0	0	0	0	0
A	1967	S	Alt	1968	Alt	0	0	0	0	1	0	0	0	0	0	0	0
A	1967	S	Alt	1971	Pel	0	0	0	0	0	0	0	1	0	0	0	0
A	1967	S	Pel	1974	Pel	0	0	0	0	1	0	0	0	0	0	0	0
A	1968	S	Mix	1970	ENP	0	0	0	0	0	1	0	0	0	0	0	0
A	1969	S	Pel	1971	Pel	0	0	0	0	1	0	0	0	0	0	0	0
A	1969	S	Pel	1972	Pel	0	0	0	0	0	1	0	0	0	0	0	0
A	1969	S	Pel	1973	Pel	0	0	0	0	1	0	0	0	0	0	0	0
A	1969	S	Pel	1975	Pel	0	0	0	0	1	0	0	0	0	0	0	0
A	1969	S	WC	1971	WC	0	0	0	0	0	1	0	0	0	0	0	0
A	1969	S	WC	1973	Pel	0	0	0	0	1	0	0	0	0	0	0	0
A	1970	S	Pel	1971	Pel	0	0	0	0	1	1	0	0	0	0	0	0
A	1970	S	Pel	1971	WC	0	0	0	0	0	0	0	1	0	0	0	0
A	1970	S	Pel	1972	Pel	0	0	0	0	1	0	0	0	0	0	0	0
A	1970	S	Pel	1973	Pel	0	0	0	0	0	1	0	0	0	0	0	0
A	1970	S	Pel	1974	Pel	0	0	0	0	1	0	0	0	0	0	0	0
A	1970	S	WC	1972	Pel	0	0	0	0	0	1	0	0	0	0	0	0
A	1971	S	Pel	1972	Pel	0	0	0	0	0	1	0	0	0	0	0	0
A	1972	W	Pel	1972	Alt	0	0	0	0	1	0	0	0	0	0	0	0
A	1972	W	Pel	1972	Pel	0	0	0	0	3	0	1	2	3	0	0	1
A	1972	W	Pel	1973	Pel	0	0	0	0	0	0	1	1	1	0	0	3
A	1972	W	Pel	1974	Alt	0	0	0	1	1	1	0	0	0	0	0	0
A	1972	W	Pel	1974	Pel	0	0	0	0	0	0	0	0	1	0	2	0
A	1972	W	Pel	1975	Pel	0	0	0	0	0	0	0	0	0	0	1	0
A	1973	W	Pel	1973	Pel	0	0	0	0	0	1	0	0	0	0	0	0
A	1973	W	Pel	1974	Pel	0	0	0	1	1	3	0	0	0	0	0	0
B	1952	S	WC	1959	WC	0	1	0	0	1	0	0	1	0	0	1	0
B	1953	S	Pel	1962	WC	0	0	0	0	1	0	0	0	0	0	0	0
B	1954	S	Alt	1958	Pel	0	0	1	1	1	2	0	0	1	0	0	1
B	1954	S	Alt	1964	Alt	0	1	0	0	1	0	0	1	0	0	1	0
B	1954	S	Alt	1965	Alt	0	0	1	0	0	1	0	0	1	0	0	1
B	1954	S	Alt	1965	Mix	0	0	0	1	1	1	0	0	0	0	0	0
B	1956	S	Alt	1964	Alt	0	0	1	0	0	1	0	0	1	0	0	1
B	1959	S	Alt	1966	Pel	0	1	0	0	1	0	0	1	0	0	1	0
B	1961	S	Alt	1963	Mix	0	0	0	0	1	0	0	0	0	0	0	0
B	1961	S	Pel	1964	Alt	1	1	1	1	1	1	1	1	1	0	1	1
B	1962	W	EC	1966	ENP	1	1	1	1	1	1	1	1	1	1	1	1
B	1962	S	Pel	1969	WC	0	0	1	0	0	1	0	0	1	0	0	1
B	1963	S	Alt	1966	Alt	0	1	0	0	1	0	0	1	0	0	1	0
B	1963	S	Pel	1966	Alt	0	1	0	0	1	0	0	1	0	0	1	0
B	1965	S	Mix	1966	Alt	0	1	0	0	1	0	0	1	0	0	1	0
B	1965	S	Pel	1967	Alt	0	1	0	0	1	0	0	1	0	0	1	0
B	1965	S	Pel	1967	Pel	0	1	0	0	1	0	0	1	0	0	1	0
B	1967	S	Alt	1968	Pel	1	1	1	1	1	1	1	1	1	0	1	1
B	1969	S	Alt	1970	Pel	0	0	1	0	0	1	0	0	1	0	0	1
B	1969	S	Pel	1971	Pel	0	0	1	0	0	1	0	0	1	0	0	1
B	1970	S	Pel	1971	Pel	0	1	0	0	1	1	0	1	0	0	1	0
B	1970	S	Pel	1971	WC	0	1	0	0	1	0	0	1	0	0	1	0
B	1972	W	Pel	1972	Pel	0	0	1	0	0	1	0	0	2	0	0	1
B	1972	W	Pel	1973	Pel	0	0	0	0	0	1	0	0	0	0	0	0

Sex: M male F female U unknown