Annex G
Report of the Sub-Committee on Aboriginal Subsistence Whaling

Members: Walløe (Convenor), Addison, Albert, Allison, Baker, Berggren, Best, Born, Borodin, Breiwick, Brownell, Buckland, Butterworth, Carlson, Childerhouse, Clark, Cooke, DeMaster, Donahue, Donovan, Ensor, Finley, George, Givens, Goto, Gunnlaugsson, Hakamada, Hatanaka, Hester, Innes, Kamatsu, Kasuya, Kawachi, Kock, Lawrence, Lens, Magnusson, Martin, Melnikov, Moronuki, Nakamura, Nishiwaki, Øien, O'Hara, Ohsumi, Okamura, Peréz-Cortés, Pinedo, Polacheck, Poole, Punt, Read, Reeves, Reijnders, Rogan, Rooney, Schweder, Senn, Skaug, Smith, Stachowitsch, Swartz, Sweeney, Tomita, Wade, Walters, Witting, Yagi, Yamamura, Zeh, Zhu.

1. CONVENOR'S OPENING REMARKS

Walløe welcomed the participants.

2. ELECTION OF CHAIRPERSON AND RAPPORTEURS

Walløe was elected Chair. DeMaster and Smith agreed to act as co-rapporteurs.

3. ADOPTION OF THE AGENDA

The adopted Agenda is given as Appendix 1.

4. REVIEW OF THE DOCUMENTS

Documents available to the sub-committee and discussed by it included SC/50/AS1-15, SC/50/AWMP1 and Raftery and Zeh (1998).

5. BOWHEAD WHALES

5.1 Comprehensive Assessment of the Bering-Chukchi-Beaufort Seas Stock

A thorough assessment of bowhead whales was carried out in 1991, and in-depth discussions have taken place in the Aboriginal Subsistence sub-committee in subsequent years. This occurred especially in 1994, following the successful census of the Bering-Chukchi-Beaufort stock in 1993, and in 1995, following the identification of a possible serious theoretical difficulty (Borel's Paradox) with the Bayesian synthesis method which had been used for the stock assessment beginning in 1993. Extensive sensitivity analyses in the years since the discovery of this problem have not identified a strong effect for the bowhead assessment.

The Bayesian synthesis method was developed to allow various sources of direct and indirect data to be integrated through a deterministic population dynamics model to provide a unified analysis. Being a Bayesian method, it collects the direct data in a likelihood function and the indirect data (or subjective judgements) in prior distributions. The results from a Bayesian Synthesis are presented in the format of posterior distributions.

In some cases there are more items of indirect data (prior distributions) than there are free parameters in the population dynamic model. Without harmonising these priors, the results from the original Bayesian synthesis model depend on the way the model is parameterised. This unfortunate indeterminance is called Borel's Paradox.

Partly because of this concern, a likelihood method was discussed as being an alternative to Bayesian synthesis that could improve on standard maximum likelihood methods and more properly incorporate uncertainty. Furthermore, after much discussion over several years, in 1997 it was agreed that at least one solution to the Borel paradox was to avoid having more than one prior distribution for a parameter, and to use a standard Bayesian analysis, rather than use the specific Bayesian synthesis method. For this reason, the sub-committee dropped the use of a prior distribution on juvenile survival (for which there was in any case little information available, even from comparison with similar species) to avoid creating a second prior distribution on MSYR, the growth rate parameter.

Debate has also occurred regarding the merits of two standard Bayesian analysis methods. In one, a prior distribution is specified for *K* (carrying capacity) and the population model is projected 'forwards' to the current time. In the second, a prior is specified for current abundance, and the model is projected 'backwards' to find the value of *K* that would be necessary for this value of current abundance.

An alternative solution was developed, which involved the geometric pooling of multiple prior distribution. 'full pooling' of the joint prior distributions would lead to an analysis that was invariant to transformations, and thus could resolve the Borel paradox. This was recognised as a significant result and a correct method for combing multiple priors in cases where this was necessary, but some felt that it would be better in the bowhead assessment to simply avoid the use of multiple priors for a single parameter, especially since (they argued) these priors did not have equal levels of reliability.

5.1.1 Biology, genetics and distribution

Melnikov reported (SC/50/AS3) bowhead whale sightings data collected around the Chukotka Peninsula between 1994-6. Sightings were reported by thirty observers working at fifteen locations spread along the three sides of the Peninsula. Observations were made from April-November in 1994 and year round in 1995. In 1996, observers worked in January and from March-September, with limited observations in November. Observations were made primarily from shore stations using binoculars. The distance offshore at which whales were sighted, the height of the shore stations and several factors affecting visibility were recorded. Special care was taken with determining the numbers of whales sighted, especially for groups of twenty or more animals. The average number of whales observed per person per day worked was calculated for separate villages or regions. Most whales were sighted within 5km from the shore. In addition, some observations were made from hunting boats 10 or more km from shore.

Bowhead whales winter in leads and polynas along the southwestern shore of the Chukotka Peninsula, in the Anadyrskiy Gulf. Some whales remain along there year round. In May, some whales migrate north along the southeastern shore of the Peninsula. In August or September bowhead whales are sighted along the northern shore of the Chukotka Peninsula. Whales then migrate east along the northern side of the Chukotka Peninsula, still feeding, before freeze-up begins. The timing and numbers of whales observed along this coast varied between years related to the ice conditions in the Chukchi and, perhaps, the Beaufort Seas.

The authors related their observations to seasonal observations made by others in the Bering, Chukchi, East-Siberian and Beaufort Seas. They noted that the timing of northward migration out of the Anadyrskiy Gulf, along the southeastern side of the Chukotka Peninsula, is later in years when the ice persists longer. They also noted that whales are observed feeding in this area in the spring, in areas where high concentrations of euphausiids have been observed. In contrast, they suggest that some whales migrating north toward Point Barrow earlier in the spring are travelling to Barrow Canyon to feed on the high zooplankton concentrations that develop in that highly productive area, and that they disperse after the zooplankton concentrations decrease. It is not known where the whales arriving along the north coast of the Chukotka Peninsula in the autumn are coming from, and it is speculated that they could be animals migrating out of the Beaufort Sea.

In discussion, it was asked what these observations tell us about interpreting the shore-based counts made at Barrow, Alaska. For example, are some whales circulating in the region? The authors suggest that animals leaving Barrow Canyon could disperse northeast towards the Beaufort Sea and perhaps also towards the west. From ice-based census data, aerial surveys north and west of Barrow, and from photogrammetric evidence, it appears, however, that the migration is uni-linear, with few animals sighted travelling south and few animals seen twice in a season.

Zhu briefly presented SC/50/AS4. Dissections of the eyes of bowhead whales have revealed that the muscles are well developed. The musculature of the eye possesses some unusual features. For example, some fibres of the extra-ocular muscles also insert into the eyelids, thereby suggesting these muscles also play a role in movement of the eyelids. The ventral oblique muscle also passes through a pulley-like structure derived from the fibrous connective tissue of the ventra rectus. Based upon morphological data, particularly the size and complexity of the eye muscles, the author concluded that the bowhead whale probably has significant eye mobility.

George presented SC/50/AS10. Age was estimated for 42 bowhead whales using the aspartic acid racemisation ageing technique. This technique estimates age based on intrinsic changes from the L (left) enantiomeric isomeric form of aspartic acid in the eye lens nucleus to a mixture of the D and L (right) forms. Racemisation rate for aspartic acid was estimated using data from earlier studies of humans and fin whales. The ratio of right to left enantiomeric isomeric forms at birth (D/L_0) was estimated using animals $\leqslant$ 2yrs ($n = 8$), since variability in the D/L measurements is large enough that differences among ages in this range are immeasurable. Age is then estimated by dividing the difference between the D/L ratio of the sample and the D/L_0 estimate, by the racemisation rate. The standard error of the age estimates increased with estimated age, but coefficients of variation were lower for older animals.

Based on these data, growth appears faster for females than males and age at sexual maturity occurs in the mid 20s. Age at sexual maturity and growth rates agree reasonably well with estimates based on photogrammetric recaptures and from 'baleen' ageing techniques. Growth slows markedly for both sexes at roughly 40-50 years but does not stop altogether. Age estimates for four whales (all males) were considerably greater than 100 years. These results generally confirm other independent approaches at ageing bowhead whales and estimating survival rates, which suggest slow growth, great longevity and high survival rates.

Six 'traditional' Eskimo harpoon points, four of which were stone, have been recovered from dorsal caudal blubber of whales harvested by Eskimo whale hunters. Archaeologists suggest that *stone* tools have generally been out of use for over 100 years.

The authors plan to apply this ageing method to additional whales, to continue work on error estimation and attempt to estimate ovulation rates.

In discussion, the fit of the modified von Bertalanffy curve to the age and length data was noted to be poorer for females, with the possibility of higher growth rate and asymptotic size. The high variability of the age estimates was noted, and it was suggested that the error structure may be more complex than assumed. A higher survival rate for males could account for the fact that the five oldest animals were male. However, it was also noted that this could be a residual effect of the fishery, because the age of the oldest females corresponds to the time of cessation of the commercial hunt, which was directed toward large females. The oldest ages were noted to be consistent with the apparently slow increase in degree of scarring that has been observed in photographic identity studies.

Brownell presented SC/50/AS11. To investigate the possibility that bowheads in the Okhotsk Sea were derived from the Bering-Chukchi-Beaufort Seas population, the authors analysed tissue samples collected from 25 whales in the Okhotsk Sea and from 29 whales harvested off Barrow, Alaska. Both mtDNA d-loop sequences and genotypes from three microsatellite loci were determined. The number of mtDNA nucleotide differences, and microsatellite allelic and genotypic differences all showed small but significant differences between the two groups, suggesting that the sampled animals are from separate gene pools. Further studies are planned.

Future sampling in the Okhotsk Sea is planned to cover a wider geographic area in order to obtain a better understanding of genetic variation, and hopefully to allow a genetic mark-recapture estimate of population size. The possibility of collaborative US and Russian studies have recently been discussed, including collection of biopsy material, and historic and recent baleen for genetic analyses.

In discussion, it was noted that the differences in haplotype diversity imply differences in historical population sizes, and that these are consistent with previous estimates of historical abundance (Mitchell, 1977).

Rooney presented SC/50/AS14. The primary objectives of the investigation were: (1) to quantify genetic variability in the Bering-Chukchi-Beaufort Seas stock using mtDNA control region sequences; and (2) to determine the likelihood of a potential genetic bottleneck in the Bering-Chukchi-Beaufort Seas stock as a result of commercial whaling. The level of potential genetic diversity was found to be 1.63%. This is much higher than certain populations of other marine mammal species. Results show that had a minimum population size of 1,000 occurred, an expected loss of 1×10^{-4} of average pairwise sequence divergence would result. In the case of a minimum residual size of 20 individuals, an expected loss of either 4×10^{-3} or 3.4×10^{-3} average pairwise sequence divergence would ensue, depending on the initial level of diversity used (2.0% or 1.7%, respectively). Given what is known about the extent and time frame of the Bering-Chukchi-Beaufort Seas commercial whaling era, the results show that: (1) any reduction in total population size would result in only a negligible loss of diversity; and (2) the expected pre- and post-bottleneck levels of diversity are not significantly different from each other. Thus, the likelihood of a genetic bottleneck in the Bering-Chukchi-Beaufort Seas stock is tenuous, at best. The fact that genetic variability is slightly lower than in certain populations of other marine mammal species is most likely an historical effect that is best explained by a lowered effective population size due to isolation from the eastern Arctic stocks (caused by changing patterns of sea ice distribution some 10,000 years ago) and subsequently maintained, perhaps, by environmental carrying capacity.

In discussion, Schweder noted that the maximum likelihood estimates of the BALEEN II model in SC/50/AS2 are minimal historical abundances in the hundreds, between the two values considered in this paper. The author noted that he had relied on published estimates (Woodby and Botkin, 1993) but in that case, this would make little difference. The possibility of testing for neutrality was suggested as possibly being useful to determine if a bottleneck has occurred. It was noted, however, that the published test may not be useful in this case because the among site rate heterogeneity was large.

5.1.2 Catch related data

George presented SC/50/AS9. During the 1997 subsistence hunt of bowhead whales, 66 whales were struck and 48 landed, giving an efficiency of 73%. [These numbers include a whale (97S1) taken at Savoonga on 4 January which the AEWC reported in the autumn 1996 harvest.] Of the landed whales, 29 were female and 19 male. Of the females, 10 (34.5%) were larger than 13m and presumably mature. One of the mature females (97G3, 17.1m) was pregnant with a 409cm foetus. A large whale taken at Wainwright (97WW3; 16.1m, male) carried a triangular slate harpoon point 56mm wide × 76mm long embedded in the dorsal caudal lumbar blubber.

Preliminary analysis of weather and harvest records at Barrow confirm what Eskimo whale hunters have long said; hunting success is greatly influenced by wind direction and wind speed. During the spring hunt along the Chukchi Sea coast, open leads, moderate to strong offshore winds (easterly), and stable ice are required to successfully land whales. During the autumn hunt offshore of Point Barrow (Beaufort and Chukchi Seas), calm to moderate winds and relatively ice free waters are required to effectively hunt whales. Wind direction, however, does not appear to affect autumn hunting success. The effect of such variability in hunting conditions argues for flexible hunting regulations which allow for hunting failures (due to environmental factors) during some seasons.

In discussion, the authors noted that the study had been initiated, in part, to determine the effects of environmental influences on the struck and loss rate, and that this was the next step.

5.1.3 Data gathering methodology

SC/50/AS12 provided some background information on the value of acoustic methods in the bowhead census, especially their value for quantifying the proportion of whales that are greater than 4km offshore. SC/50/AS12 also presented a description of a relatively new method for collecting recordings of whale sounds, with possible application to the bowhead census and the remote acoustic sampling of blue whales in the Southern Oceans. The method is an adaptation of the oceanographic technique of deploying autonomous data collection systems on the sea floor. The acoustic data collection system discussed in SC/50/AS12 is referred to as a 'pop-up'. An array of pop-ups deployed across the direction of the migration, in conjunction with an array deployed along the nearshore ice edge of the lead parallel with the migration, is proposed for the next bowhead census effort. The proposed pop-up array could significantly expand the area of reliable acoustic locations, and extend this area out to ranges of 15-20km. This would improve quantification of the offshore distribution of whales. Furthermore, this could improve the population estimate and reduce uncertainty in that estimate, especially in years when there is variability in offshore distribution and a large percentage of animals are greater than 4km offshore.

5.1.4 Assessment methodology

An intersessional e-mail group had functioned well since the last meeting. This group had clarified an agreed reference set of prior distributions, which should be used to compare the results of the different proposed assessment methods, and had clarified details of calculations, catch history, and abundance estimates (Appendix 2).

Punt presented SC/50/AWMP1. This paper presents the full technical specifications of the BALEEN II population dynamics model. This model forms the basis for the assessments reported in SC/50/AS1 and SC/50/AS6. A variety of methods for parameterising the model are described. These include the 'backwards' and 'forwards' methods, as well as using the maximum rate of increase instead of MSYR as the parameter that determines the productivity of the population. The sensitivity of $MSYL_{1+}$ and $MSYL_{mat}$ to different input specifications for MSYL and MSYR are examined. If $MSYL_{mat}$ is set equal to 0.6, the corresponding $MSYR_{1+}$ can be larger than the pre-exploitation size K. However, if $MSYL_{1+}$ is set equal to 0.6, the corresponding $MSYL_{mat}$ can occur at a population size less than $0.3K$.

In discussion, it was clarified that the population dynamics model incorporated in SC/50/AWMP1 was virtually identical to that developed by de la Mare (1992) much earlier, although several optional methods of parameterising the model are included in the version presented. Noting the differences in the illustrated relationships between sustainable yield and depletion, some members suggested that it was preferable to parameterise the maximum sustained yield level in terms of the 1+ population size rather than in terms of the mature population. Particularly, this avoids the maximum sustained yield level being greater than the carrying capacity when expressed in terms of the full population.

Punt and Butterworth presented SC/50/AS1. Four methodological aspects of the Bayesian approach to assessment of the Bering-Chukchi-Beaufort Seas bowhead population were addressed. It first suggested that the prior on MSYR be replaced by one on the rate of increase at low population size, as this (rather than MSYR) was the parameter for which basic data were available from other stocks. Second, different approaches were developed for the inclusion of abundance information in the analysis, particularly the N_4/P_4 time series and its relationship to absolute abundance. These included the authors' preferred approach of taking account of correlations in the N_4/P_4 series. Third, a basis to commence the analysis in a more recent year, rather than 1848 when commercial catching started, was developed. This has the advantage of avoiding the need to consider factors such as uncertainty about the 19th century catch levels and possible changes in parameters, such as the carrying capacity *K*, since that time. Finally, the 'backwards' and 'forwards' variants of the Bayesian assessment approach were tested by simulation using population models where parameters were selected in turn from distributions corresponding first to forwards and then to backwards assessments. Whichever of the latter scenarios was considered, the 'backwards' variant performed better, both in terms of less bias and less variability of estimates. RY98 estimates were indicated to be negatively biased in all instances, though less so for 'backwards' estimates. Preference was expressed for the 'backwards' over the 'forwards' approach on the basis of these simulation test results. An objection to 'forwards' as a method was also expressed because (unlike 'backwards') it would update the prior input for MSYR before any data were included in the assessment; this seems an intuitively undesirable property.

In discussion, the authors noted that, in sampling from the prior distributions, they omit entirely parameter combinations that are inconsistent with the model. The authors clarified that they were sampling from the joint posterior in both the backwards and forwards cases for their simulation study. Butterworth also noted that the present work had avoided one of the problems of over-determination of the model by not specifying a prior on juvenile survival. However, in some cases priors had been set on both the current and the historical population size, thus giving rise to the possibility of Borel's Paradox.

Raftery presented Raftery and Zeh (1998). This paper describes the Bayes Empirical Bayes (BEB) and N_4/P_4 bowhead abundance estimates for 1993, as well as the updated rate of increase estimate. In discussion, Raftery noted that the paper had not accounted for the correlation among the N_4/P_4 values for different years.

Poole and Raftery presented SC/50/AS6. This paper is a continuation of the investigation into the difference between the forwards and backwards results. The full pooling method, which is now known to resolve the difference, is applied to the bowhead assessment using BALEEN II. Results were intermediate between those using forwards and backwards methods, and were invariant to the direction in which the PDM is run. The forwards method makes a prior assumption that K is independent of the other inputs, while the backwards variant makes the same assumption regarding P93 and the other inputs. These assumptions can both be questioned. Full pooling creates a joint prior that reflects relationships between parameters as determined by the population dynamics model. It thus circumvents the independence assumptions of both methods while simultaneously yielding a unique solution. As a result, full pooling does not require a choice between the forwards and backwards labellings of the model.

In discussion, the authors clarified that they treated parameter combinations, which were inconsistent with the model, exactly the same way as the authors of SC/50/AS1, and that indeed they were using the same computer programs. The authors also clarified that while the backwards and forwards methods were special cases of the full pooling method, other methods developed earlier such as 'sideways' were not. However, in concept they could be incorporated into the same framework.

Breiwick presented SC/50/AS7. This paper implemented the reference set of priors and the likelihoods using a forwards method. The analysis was based on the age- and sex-specific Leslie matrix model with density-dependence in the fecundity term. Two methods were used to sample from prior distributions. The first put a prior distribution on λ_{max}, the maximum growth rate of the population, and the 2nd was the 'reference' case where a prior was put on MSYR. The prior distribution for λ_{max} was given a uniform distribution over 1.005 to 1.10. This range was chosen on the assumption that it encompassed the range of likely values for this parameter. In calculating juvenile survival from the populations dynamics equation, all the priors were resampled from, rather than just those necessary to compute juvenile survival, as was done previously. This had the effect that the induced priors from the two methods were more similar than previously.

The first sample size for each method was set at 2.7 million, resulting in about 600,000 trajectories for method 1 and about 400,000 trajectories for method 2. These trajectories were resampled 5,000 times using the SIR method and resulted in 2,193 unique trajectories for method 1 and 1,515 unique trajectories for method 2. Percentiles of the estimated posterior distributions were generally similar for the two methods but RYs where quite different. The 5th percentile for method 1 was 82 while it was 126 for method 2. Posterior medians for the two methods were 178 and 193, respectively. The posterior medians for ROI were 0.017 and 0.019 for methods 1 and 2, respectively.

The earlier discrepancy between some of the induced priors for the two methods is thought to be due to the repeated resampling to obtain a feasible juvenile survival rate for method 1. Many of the solutions finally obtained lie at the edge of the parameter space that satisfies the constraint that juvenile survival be less than adult survival. An examination of trajectories that did not result in a feasible juvenile survival, shows a preponderance of larger λ_{max} values, corresponding to low MSYL values.

In discussion, it was noted that although the results for the two methods were similar for λ_{max}, this was not true for some other parameters of interest.

Wade presented SC/50/AS8. Analyses in this paper investigated the sensitivity of the bowhead assessment to certain assumptions. The particular implementation of the assessment was a forwards projection from *K* (carrying capacity) in 1848. Two versions were used, one where a prior was placed on λ_{max} (the maximum growth rate at low population size) with juvenile survival and MSYR then calculated, and another where a prior distribution was instead placed on juvenile survival with λ_{max} and MSYR then calculated.

In general, the two versions gave similar results. In the first assumption investigated, the assessment was not found to be particularly sensitive to the marginal prior distributions put on adult survival and age of sexual maturity, as using less informative priors than the 'reference set' did not influence the results. Second, the assessment was not found to be very sensitive to the data on the fraction mature and the fraction calves in the population, but was strongly influenced by the rate of increase (ROI) data. It was noted that the estimate of ROI that results from the Bayesian analysis (the median of the posterior distribution, roughly 2%) differs substantially from the estimate of ROI from the observed data on trends in abundance (roughly 3%), even though those data were included in the analysis.

The sensitivity trials mentioned above confirmed that the explanation of this was not because of the particular marginal prior distributions specified or the other data in the analysis. Instead, this resulted because the joint prior distribution favoured very low values of ROI, so that the posterior distribution for ROI was roughly intermediate to this prior and the likelihood from the data. SC/50/AS8, as well as results reported in SC/50/AS1 and SC/50/AS7, indicated that this resulted from the elimination of higher values of λ_{max} (and thus MSYR) when impossible combinations of the marginal prior distributions for life-history parameters (adult survival, age at sexual maturity, fecundity) were combined, such as when the juvenile survival rate needed to be greater than 1.0 to make the other parameters agree with one another.

An additional analysis was presented in SC/50/AS8 that fitted a Leslie matrix (with no density-dependence) projected from 1975-1998 to the data; this analysis confirmed that the marginal prior distributions for the life-history parameters could closely agree with the observed data on ROI. Based on these analyses, the author of SC/50/AS8 suggested that changing the assumption of independence between the prior distributions on the life-history parameters (such as allowing for higher values of ASM to be correlated with higher values of adult survival) would allow the marginal distributions on the life-history parameters to permit greater values of λ_{max}, which, consequently, should lead to results where the posterior median of ROI would be closer to the observed ROI. It was noted that this influence of the joint prior is to favour lower productivity in the current population; assessments based on this joint prior would therefore be more conservative in the estimation of catch related quantities than an alternative joint prior that would allow greater probability of higher values of λ_{max}. Finally, SC/50/AS8 examined the influence of the assumption that the historical catch record is known without error. Even if there was substantial bias in the recorded harvests in the 19th century, there was little effect on the estimated catch-related quantities, although estimates of depletion level were, as expected, much lower.

In discussion, it was noted that there was substantial difference between the MSYL prior and its post-model pre-data distribution. It was suggested that this was caused by the prior on λ_{max}, and that increasing MSYL implies increasing current growth rate as fraction of λ_{max}. The author was encouraged to make a formal statistical model comparison to establish that the density independent Leslie matrix model in fact fit the ROI data better, although a difference in the means was apparent. It was noted that while the width of the intervals increased, in fact the lower bound remained relatively unchanged, suggesting that it may be more important to compare the interval and not just the means of the intervals of the posteriors.

Schweder presented SC/50/AS2. In this paper, the likelihood of direct and indirect data relevant for the 1998 IWC-assessment of the stock of Western Arctic bowhead whales is investigated. The indirect component of the likelihood is constructed from the prior distributions as described in Schweder *et al.* (1997). It is argued that several of the prior distributions are only weakly supported by data, and should be disregarded. The 7-parameter BALEEN II model is fitted to the direct data (ROI, abundance estimate for 1993 and proportion calves and matures in the survey period) and to various subsets of the indirect data. The likelihood is in each case concentrated on a narrow curved band in the 7-dimensional parameter space of the BALEEN II model. Maximum likelihood estimates are found by using automatic differentiation. The model fits the data very well, which is not surprising since the number of free parameters equals the number of data points or is slightly less. Due to this over-parametrisation, a 5-parameter version of the BALEEN II model with no differentiation between juvenile and adult survival was also fitted successfully. The interest parameter, replacement yield for 1998, is a rapidly varying function of the basic parameters of the model. This is reflected in the eigenvalues of its matrix of second derivatives being very large. This sensitivity makes it difficult to find confidence intervals for replacement yield. This sensitivity also shows up in the estimated replacement yield dropping from 197 to 175 when the number of free parameters is reduced from 7 to 5. To obtain a valid lower 5% point for replacement yield using this estimation method, the Baleen II model needs to be reparameterised, or replaced with another model for the population dynamics, to make the likelihood more Gaussian in shape. Bootstrapping is another option, but to bootstrap the indirect data more information on their nature is required.

In discussion, the method being developed was noted to be interesting, and further work was encouraged. The interpretation of prior distribution as confidence intervals as might be derived from bootstrap, was questioned. And here followed the usual frequentists *versus* Bayesians thrust and parry, *sans touché*.

Raftery and Poole presented some additional analyses designed to evaluate the significance of some options presented in SC/50/AS1. They pointed out that omitting the 1993 BEB abundance estimate leads to a simpler analysis, but the posterior on 1993 abundance was then somewhat less than the BEB estimate. They presented an analysis that does incorporate the BEB abundance estimate. They were concerned about differences in SC/50/AS1 due to assuming a prior on λ_{max} instead of MSYR, especially as the results appear sensitive to the prior assumed.

Butterworth and Punt presented some additional comments, noting that the full pooling approach was a valuable method, but that it would be appropriate in this case only if there were equally reliable priors on K and on the 1993 abundance. Furthermore, simulation tests had revealed that the backwards method was preferable to the forwards. Thus, they concluded that backwards is the better method to use.

5.1.5 Stock abundance and trends

The sub-committee agreed on the basic data required for an assessment, as shown in Appendix 3. The catch data are complete through 1997 and thought to be generally reliable (Appendix 3, table 1). Abundance data included the 1993 BEB abundance estimate (8,200, SE = 564) and a series of estimates termed N_4/P_4 (Appendix 3, table 2). These were combined to form an index of abundance, and a relative abundance series with covariances was calculated

(Appendix 3, table 3). It was noted that aerial photographic data had been used to estimate length distributions for the proportions of calves and mature and the rate of adult survival. Further analyses of the survival data are underway. No more recent abundance surveys have been completed, with the next planned for 1999. Relative to the catch data, it was noted that the suggestion that the commercial fishery preferentially took larger females, given to explain the lower maximum age for females in SC/50/AS10, raised questions about sex ratio in the historic catch. This was identified as an issue for future sensitivity investigations.

Of the papers reviewed, concerns were raised in several about technical difficulties encountered in estimating parameters of interest in some situations. The cause of these difficulties and their implications for the present assessment was discussed. Subsequently, possible ways of minimising or avoiding such difficulties in the future were identified. Cooke noted that the BALEEN population model had been developed over the 1970s and 1980s for the purpose of fitting stock trajectories to series of catch and effort data and later also absolute to abundance estimates. Only the carrying capacity, and sometimes also the MSYR, were originally treated as free parameters to be estimated. All the remaining biological parameters were fixed inputs. It is not necessarily the most suitable model for the kinds of assessments performed by this sub-committee in recent years and can be especially problematic in cases where the population was reduced to a very low level at one point in history.

There was disagreement as to whether some of these difficulties were related to the specific parameterisations being used (especially dependencies among parameters, to over parameterisation given the data), or to inadequacies in the underlying population dynamics model. Schweder described the likelihood surface as having a very steep ridge and said that parameters of interest such as replacement yield are very steep saddle-like functions. These characteristics may arise from dependencies among parameter values, and he suggested that the behaviour may relate to how the models have been parameterised. For example, he suggested not distinguishing between juvenile and adult survival, and indeed avoiding parameters that take values near logical boundaries. Butterworth noted that reparameterising, for example working with ratios such as the age of maturity divided by the average age, might make the assumptions of independent priors more defensible. He also noted that distinguishing juvenile and adult survival was essential for this assessment to have sufficient flexibility in the model to fit observations of both rate of increase and the fractions of matures and calves in the population.

There was general agreement that, although there may be issues with the underlying population dynamics model and its parameterisation, these difficulties did not preclude sampling from the posterior in the Bayesian analyses presented. These issues should be addressed in the future.

The sub-committee compared the three basic methods of fitting the models, termed forwards, backwards and full pooling. It was agreed that the forwards procedure had little to recommend it, performing in simulation studies consistently worse than the backwards method. Further, the forwards model requires specifying a prior on pre-exploitation population size, *K*, about which there is little information other than the recorded catch series. It was noted that the forwards and backwards methods assume independence between MSYR and carrying capacity and between MSYR and current abundance, respectively. There were differences of opinion about the validity of these two assumptions, and hence the applicability of the two methods. The full pooling method was agreed to be an important new methodology that combines these two assumptions, while avoiding Borel's Paradox and yielding a unique situation. There was disagreement, nonetheless, about the applicability of this procedure in the present case.

Several members considered the backwards method preferable, while some members considered the full pooling method preferable or preferred to examine the results of both. Based on this, it was agreed to conduct an assessment using the backwards method and to examine the results from full pooling as well.

The group reviewed the prior distributions that it had used previously for input parameters for the assessment. Appropriate values for use in the present assessment were agreed (Appendix 3, table 4), although some noted that for several parameters there were no direct data available to help set prior distributions. This was noted especially for the maximum calving interval, MSYR, survival rate of adults, age of transition between mortality rates and carrying capacity. Relative to the latter, it was noted that the history of catches was likely to have been considered in setting this prior, and it was suggested that using a prior based on that data, and also using that same data in the model calculations, may constitute using the same data twice. There was no agreement on this point.

The relationship between natural mortality and age that is in the present parameterisation was noted to be an approximation to the U-shaped mortality schedule common to mammals. It was noted that recently research was focusing on the degree to which the mortality rates actually increase with older ages, and that this might be reviewed. Several complications resulting from the piecewise approximation to a U-shaped schedule were identified, including the necessity to specify prior distributions for juvenile mortality rates, ages of transition between mortality rates, and maximum ages.

Given that 10% of the sample of animals considered in SC/50/AS10 were estimated to be older than 100 years, the group was concerned about the way the mortality rates for older animals were handled. Here, it was noted that a maximum age of 100 years serves as a proxy for an increasing mortality rate from 80 to 120 years. It was noted that given the timing of the cessation of commercial whaling, there should not yet be a large proportion of the population older than 100, and thus the issue was unlikely to have a significant effect on the assessment. It was agreed that for this assessment it would be sufficient to explore this further, by considering two alternative calculations; one involving not setting a maximum age and constraining adult survival rate to be less than 0.995; and the other of retaining the maximum age but allowing survival to be as high as one.

The relationship between the form specified for a prior distribution and the form induced by the population dynamics model in concert with the catch data (post-model, pre-data prior) was discussed. It was noted particularly that the shape of a prior distribution may not be as important as the shape of the induced prior and that it might be useful to choose priors that would result in uniform induced priors. It was agreed that routinely displaying the prior distributions specified, the induced prior distributions, and the posterior distributions for parameters was useful in allowing the results of an assessment to be better evaluated.

A number of points were identified that should be addressed in the future. As there is no data from the population at very low abundances to use in setting maximum fecundity, it was suggested to reparameterise the model to use current rather than maximal rates. It was also suggested that the current population model might be made more realistic by including density-dependence in juvenile survival as well as in fecundity. The difference between the survey data, which includes young of the year prior to substantial mortality, and the population model component (animals age one and older) that is being compared to the data was noted. Because about 5% of the modelled population can be young of the year, the group agreed that the modelled abundance including calves should be used. The possibility of reparameterising MSYR in terms the maximum population growth rate (λ_{max}) was considered because the actual data from which MSYR values have been inferred are for populations thought to be at low levels. Alternatively, consideration might be given to parameterising MSYR in terms of the current rate of increase. Given the complexity of the way the mortality schedule is incorporated, it was agreed that simplifications might usefully be pursued. For example, it might be possible to parameterise in terms of average age or life expectancy, or other methods that might avoid the 'cliff-hanger' form of survival rates with especially long-lived species. It was also noted that given the extremely high ages, it would be useful to look for female reproductive senescence.

Some members identified the difficulties associated with trying to model population trajectories when the populations have reached very low levels, noting that changes in input values for carrying capacity of much less than an integer could change modelled trajectories greatly. However, others suggested that in their experience this type of sensitivity was not associated with the complexity of the model *per se* because similar behaviour arose (SC/50/Rep4) with much simpler models. There was further discussion of the possibility of avoiding some of these difficulties through rounding to integer numbers of whales. Also, the use of stochastic models as had been suggested last year (Raftery and Poole, 1997) was identified as a promising approach.

5.1.6 Assessment and management advice

Assessments using the methodologies of SC/50/AS1 and SC/50/AS6, making the assumptions agreed under Item 5.1.4 were presented (Appendix 4 and Appendix 5). Both Appendices included calculations using the backwards method under two sets of assumptions. One set assumes a maximum age of 100 and maximum survival of 1.0, and the other set assumes no maximum age and a maximum survival of 0.995. Appendix 5 also presented the results of the full pooling method under these two cases. The authors of Appendix 5 noted, however, that their computations assuming no maximum age were somewhat tentative because approximate methods had to be used given the press of time. They indicated that they will finalise these calculations later.

The authors of Appendix 4 also presented their backeards method results compared to population size including calves, and noted that this resulted in slightly higher values of, for example, the current replacement yield. They also included information on the induced prior distributions.

The posterior distributions of several statistics summarising the assessments are reported, including the replacement yield and another criteria Q_0, that accounts for the situation when the population might be above MSYL. This quantity was defined to be 90% of MSY when a population is above MSYL (IWC, 1998b, item 6.1.1).

The best estimates of replacement yield (RY) from these alternative assessments ranged from 184 to 210. The sub-committee agreed, as in the last bowhead assessment, to use the lower 5[th] percentiles of the posterior distributions of RY and Q_0 to provide management advice. The sub-committee recognised that this was a conservative approach and that the AWMP currently under development will probably provide a better approach. The relevant 5[th] percentiles, along with the best estimates (medians) of depletion, are shown in Table 1.

Table 1

Lower bounds (5[th] percentiles) of replacement yield (RY) and Q_0 for 1998, and the median estimated depletion in terms of 1+ population size for four combinations of assessment method from the two assessments of the status of the Bering-Chukchi-Beaufort bowhead population, extracted from Appendix 4 and Appendix 5. The alternate case results are from the Backward method from the combinations of assumptions considered that resulted in the lowest values among the alternates considered of RY and Q_0, namely assuming no upper bound on life span and comparing the results to the population size including calves

	SC/50/AS6		SC/50/AS1	
Quantity	Full Pooling	Backwards	Backwards	Alternate case
RY	108	119	123	113
Q_0	102	114	120	110
Depletion	61%	68%	68%	66%

The backwards method as implemented by the authors of Appendix 4 and Appendix 5 were noted to be similar, as would be expected given that the method is the same. The differences reflect expected levels because Monte Carlo methods are used. The full pooling method gives lower values of the 5[th] percentile of replacement yield (108) and of the quantity Q_0 (102) than were obtained using the backwards method. The other cases considered resulted in values intermediate between the backwards and the full pooling methods.

It was noted that the differences in the estimates of values which are of management concern are relatively small, and that regardless of the methods used, the management advice would be the same. The population appears to be near MSYL, and would very likely increase under catches of up to 108 animals.

In terms of sub-paragraph 13(a) of the Schedule, appropriate catch levels in these circumstances should not exceed 90% of MSY. The calculations reported therefore indicate that it is very likely that a catch limit of 102 whales or less would be consistent with the requirements of the schedule.

5.2 Other Stocks

5.2.1 Baffin Bay-Davis Strait and Hudson Bay stocks

A brief description of the distribution, current abundance and status of the two putative stocks of bowheads in eastern Canada, the Davis Strait 'stock', which is known to be shared with Greenland and the Hudson Bay/Foxe Basin stock, was given in IWC (1992, pp.138-139). Pertinent new information available since 1991 is summarised in the following paragraphs.

The sub-committee noted that Canada has agreed to the request by the Nunavut Wildlife Management board for Inuit hunters in eastern Baffin Island to strike up to two and catch up to one bowhead whale from the Davis Strait/Baffin Bay stock in the summer of 1998. This planned hunt follows the initiation of legal hunting on the Hudson Bay/Foxe Basin stock in 1996. An estimate of 270 (CI 210-331) for the northern Foxe Basin part of the Hudson Bay/Foxe Basin stock's summer range in August 1994 has been published (Cosens *et al.*, 1997). In addition, Innes referred to an estimate of 59 (CI 20-120) for the northwest Hudson Bay part of this stock's range in August 1995 (Cosens and Innes, In press). Both estimates are from systematic aerial survey and are unadjusted to account for detection bias, i.e. for animals not at the surface during the overpass or at the surface but missed by observers.

No recent information on absolute abundance or trend is available for the Davis Strait/Baffin Bay stock. The statement in IWC (1997, p.90) that the DS/BB and HB/FB stocks have been conservatively estimated at 450 whales *each*, citing Zeh *et al.* (1993), is incorrect. Zeh *et al.* (1993) estimated that there were at least 450 whales in the two stocks, *combined*. Of this total, about 350 were estimated for Davis Strait/Baffin Bay and 100 for Hudson Bay/Foxe Basin.

Finley presented SC/50/AS15. Observations of bowheads at Isabella Bay, northeastern Baffin Island, were made in 11 autumn seasons (310 field days) between 1983 and 1997. Except for 1983, bowheads were observed most days, averaging 23.5 (± SD 20.35) in 80 daily scans.

This study indicates that up to 99 bowheads can be present in Isabella Bay, northeastern Baffin Island, at one time during the autumn. The 11-year time series of scan samples from a shore observation site at Isabella Bay has not been fully analysed, but preliminary analyses suggest no evidence of a trend in this component of the Davis Strait/Baffin Bay stock between 1983 and 1997. The recovery of Davis Strait/Baffin Bay bowheads may be limited by predation by killer whales. At Isabella Bay, up to one third of adult bowhead whales have been scarred by killer whale attacks, and there are anecdotal and direct observations of killer whales attacking and killing bowhead whales.

According to Innes, a recent series of interviews with hunters carried out by the Nunavut Wildlife Management Board revealed the hunters' firm belief that bowheads have increased substantially throughout the eastern Canadian Arctic since the end of commercial whaling 75-80 years ago (Hay, 1995).

For both of these stocks the sub-committee expressed its appreciation for the recent studies on abundance and distribution, using traditional knowledge, sighting surveys, photography and biopsy samples, and encouraged additional work along these lines. Given the apparent interest in continuing harvests from these two stocks that were depleted by commercial whaling, additional knowledge of their status is crucially needed.

The sub-committee remains concerned for the viability of the Hudson Bay/Foxe Basin stock because of its small size, especially in light of the aboriginal harvest of one whale in 1996 (IWC, 1998a, p.92).

The sub-committee also expressed concern about the approval for up to two strikes of whales in 1998 from the Davis Strait stock because of its small size and possible lack of increase.

5.2.2 Okhotsk Sea stock

Only one paper was available that presented information on this stock. The results contained in SC/50/AS11 were documented earlier in this report. Previously reported estimates for this population are 250-300 whales but no quantitative data are available. SC/50/AS11 suggested that the population size could be estimated using a genetic mark-recapture study.

5.2.3 Other stocks

The sub-committee remains concerned about the status and apparent low abundance of the Spitzbergen stock, about which little is known (Burns *et al.*, 1993). It encouraged additional studies on abundance and distribution to be undertaken.

6. GRAY WHALES

6.1 Eastern Pacific Stock

One paper was presented regarding this stock of gray whales (SC/50/AS13). The author reported on the results of observation studies in Mechigmenskiy Zaliv and adjacent waters from 1984-96. He noted that most sightings of gray whales in this area occurred between June and November, with peak numbers occurring in August or September in most non-El Niño years. During the years influenced by El Niño, peak usage occurred in June.

It was also reported that in 1997, the Russian State Committee on Environment issued an allowance to the Chukotka Autonomous Okrug for the harvest of 140 gray whales, which is within the limits of the aboriginal quota set by the IWC for the needs of the small native populations of the region. In accordance with the requests it received, the Okrug Administration distributed an allowance of 101 whales between nine settlements. During the 1997 hunting season, 79 whales were harvested: 48 males and 31 females.

Hunting was conducted from whaling boats and sea kayaks under the direct control of fishing inspectors from the Chukotka Regional Fisheries Inspection Agency. In the majority of settlements, rifles were used during the hunt. In 1997, 20 darting guns with exploding bombs, received as humanitarian aid from Alaskan Eskimos, were used for the first time in the gray whale harvest. Using the darting guns, 17 shots resulted in 16 catches (i.e., one animal was shot twice with the darting gun). The time required for catches, where dart guns were not used, was between 30 and 120 minutes (average time per whale: 77 minutes); whereas, the time required for catches, where dart guns were used, was about half as long (average time per whale: 36 minutes).

In regard to last year's recommendation, the sub-committee was informed (SC/50/ProgRep Mexico) that studies in the gray whales' breeding lagoons had continued and expanded to include most of the wintering range of this species (stock) in Mexican waters. Systematic boat surveys were conducted at the lagoons (Ojo de Liebre, or Scammon's, San Ignacio and Magdalena Bay). Also, aerial surveys were conducted over the Baja California coastline and the lagoons. Among the objectives of this season's research was to evaluate the impact of ENSO on the distribution and use of the lagoons. Although no detailed information was presented to this meeting, due to the short period in between the end of the field season and this meeting, preliminary information suggests that whales were present in fewer numbers in the southernmost breeding lagoon in Baja California (Magdalena Bay) and further, that they left this location earlier than they had been observed to in previous years.

Regarding advice to the Commission concerning management, the sub-committee has no changes to the recommendations made during last years meeting of the Scientific Committee.

6.2 Western Pacific Stock

One paper (SC/50/AS5) was presented regarding this stock. Zhu summarised the location and year of sightings, strandings, and catches of gray whales in Chinese coastal waters. He noted that five sightings of gray whales that were not related to catching operations were reported between 1953 and 1979. In addition, seven gray whales were reported stranded between 1933 and 1996, and 13 gray whales were reported caught by fishermen between 1916 and 1958.

The sub-committee thanked the author for his efforts to summarise this information. Given the severely deplete d nature of this stock, the information presented in SC/50/AS5 is very important in establishing base lines for sightings and stranding studies that may be used to infer trends in abundance for this stock in the future.

Zhu stated that reports in early 1998 of five stranded gray whales along the southern Chinese coast were an error. The animals turned out to be false killer whales.

7. MINKE WHALES OFF GREENLAND

There were no papers presented during the meeting on the two stocks of minke whales that occur off Greenland. Born reported that in 1997 a total of 146 minke whales (99 females, 42 males and 5 with sex undetermined) were landed from the West Greenland stock. Additionally, two whales were struck and lost. A total of 65 biopsy samples were collected from the catch (see SC/50/ProgRep Denmark).

Born also reported that eleven minke whales (10 females, 1 male) were landed from the eastern Greenland stock in 1997. Three whales were struck and lost. The question of management advice is discussed under Item 10.

8. FIN WHALES OFF GREENLAND

There were no papers presented during the meeting on this stock. Born reported that in 1997 eleven fin whales (5 females, 5 males and 1 of undetermined sex) were landed from this stock. In addition, two whales were struck and lost. Four biopsy samples were collected from the catch (see SC/50/ProgRep Denmark). The question of management advice is discussed under Item 10.

9. HUMPBACK WHALES OFF ST VINCENT AND THE GRENADINES

On 26 February 1998, two humpback whales were taken and landed at the whaling station on Petit Nevis. The whales were landed after 1700hrs. As the Fishery Officer did not receive word immediately, he did not arrive until the following day, after the smaller whale had been butchered and distributed. It was described to him by the fishermen to have been a male of 4-6m in length. He measured, photographed and examined the remaining whale, which was in the process of being cut up. It was a non-lactating female 15.3m in length. Information regarding other data and samples that may have been collected will be released at a later date.

Regarding advice to the Commission concerning management, the sub-committee has no changes to the Committee recommendations made during last year's meeting. The sub-committee draws attention to the Scientific Committee's intention to undertake a Comprehensive Assessment of North Atlantic humpback whales at its meeting in 2000. Furthermore, additional information on the status of humpback whales in the North Atlantic can be found in Annex E.

10. LONGER TERM PRIORITIES

The sub-committee noted the actions taken by the Commission last year, of approving five-year aboriginal catch limits for Bering-Chukchi-Beaufort Seas bowheads before the Committee had completed a new assessment, and of approving coincident five-year aboriginal catch limits for both bowheads and eastern Pacific gray whales, West and East Greenland minke whales and West Greenland fin whales. Furthermore, the time required to complete a new assessment for a stock, precludes doing more than one during an Annual Meeting. The sub-committee therefore agreed that it did not appear necessary, and was not in any event feasible, to match the time between assessments with the time period of catch limits.

Recognising the usual Commission request that the Committee keep the stocks under annual review in any event, and that developing aboriginal whaling management procedure intervals between assessments of up to six years are being considered, the sub-committee suggests the Committee give attention to the more important of the stocks subject to aboriginal harvest every six years. The sub-committee also noted that the sub-committee on Other Great Whales has proposed undertaking a Comprehensive Assessment of North Atlantic humpback whales in the year 2000. Furthermore, the sub-committee noted its own concerns arising during this meeting about other stocks of bowhead whales. Finally, the sub-committee encouraged that suggestions for future work to improve the Bering-Chukchi-Beaufort bowhead assessment models be pursued.

Greenland stocks

The sub-committee noted that it has never been able to provide satisfactory scientific advice on either the fin or minke whales off West Greenland. This is a matter of great concern, given that the provision of management advice on stocks subject to whaling is a high priority task assigned to the Committee by the Commission. The reason that satisfactory advice cannot be given is the lack of requisite data, particularly on stock structure and abundance. The Chairman of the sub-committee on Aboriginal Whaling Management Procedures indicated that even at this stage in the development process, it was clear that developing a *Strike Limit Algorithm* for the Greenland Fisheries that would fulfil all the Commission's objectives would be an extremely difficult, if not impossible task, given the available data.

The sub-committee recognised that the logistical difficulties of obtaining the necessary information are enormous, both in terms of the physical environment (including weather conditions) and the level of resources required. The sub-committee believed that it was unacceptable to merely continue to provide less than satisfactory advice and make general recommendations for further work.

It therefore recommends that the Committee establishes a Working Group, in collaboration with Greenlandic scientists, to determine a costed research programme that will enable the Committee to provide satisfactory advice to the Commission as soon as possible. At a minimum this programme will address questions of stock identity and abundance. The programme should take into account the work of the Aboriginal Whaling Management Procedures sub-committee, where the important relationship between data requirements and management procedures has already been stressed.

Born supported that idea of developing such a research proposal. He commented that research directed at better understanding of the stock structure using a variety of techniques has been initiated this year. This study would be done in cooperation with Norwegian scientists. Furthermore, Born noted that within the next five years, a survey for the purpose of estimating abundance of cetacean stocks off Greenland was planned. The sub-committee welcomed the Greenland research initiative.

Based on these developments, the sub-committee recommended, that while keeping all stocks subject to aboriginal whaling under review annually, primary attention be given to continuing work on the aboriginal whaling management procedure and to intensive assessments of stocks in future meetings as outlined in Table 2.

Table 2

Timetable for stock assessment consideration at future Annual Meetings.

Year	Stock to be considered
1999	Bowhead whales other than the Bering-Chukchi-Beaufort stock
2000	North Atlantic humpback whales
2001	Fin whales off Greenland
2002	Minke whales off Greenland
2003	Eastern and western Pacific gray whales
2004	Bering-Chukchi-Beaufort Seas bowhead whales

11. ADOPTION OF REPORT

The report was adopted on 2 May 1998 and the final text for Item 10 was circulated to sub-committee members on 3 May 1998.

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Appendix 1

AGENDA

1. Convenor's opening remarks
2. Election of Chairperson and rapporteurs
3. Adoption of the Agenda
4. Review of documents
5. Bowhead whales
   - 5.1 Comprehensive Assessment of the Bering-Chukchi-Bowhead Seas stock
     - 5.1.1 Biology, genetics and distribution
     - 5.1.2 Catch related data
     - 5.1.3 Data gathering methodology
     - 5.1.4 Assessment methodology
     - 5.1.5 Stock abundance and trends
     - 5.1.6 Assessment and management advice
   - 5.2 Other stocks
     - 5.2.1 Baffin Bay – Davis Strait stock and Hudson Bay stock
     - 5.2.2 Okhotsk Sea stock
     - 5.2.3 Other stocks
6. Gray whales
   - 6.1 Eastern Pacific stock
   - 6.2 Western Pacific stock
7. Minke whales off Greenland
8. Fin whales off Greenland
9. Humpback whales off St Vincent and the Grenadines
10. Longer-term priorities
11. Adoption of report

Appendix 2

AD-HOC BOWHEAD ASSESSMENT GROUP (E-MAIL CORRESPONDENCE GROUP)

The *ad-hoc* Bowhead Assessment Group ('bag'), chaired by Steve Buckland, has corresponded via e-mail since the 1997 Scientific Committee meeting in Bournemouth (IWC, 1998, appendix 2). More than 40 messages to the list have been archived on a NOAA computer in Seattle (URL *http://nmml01.afsc.noaa.gov/iwc-bag/iwc-bag.htm*). In addition to archived e-mail messages, the web-site also contains a link to the revised Bering-Chukchi-Beaufort Seas bowhead whale catch table, 1848-1997, used in current assessments (Appendix 3, table 1). The standard data required for 'reference set' assessment runs are also given at the web site. Topics discussed by the group include: replacement yield calculations; ROI statistics; abundance estimates; the 'reference' prior distributions; and the need for an intersessional meeting of the group. The e-mail correspondence group proved to be a quick and effective means of communication amongst the group members and aided the work of those carrying out Bering-Chukchi-Beaufort Seas bowhead whale stock assessments for this meeting. It was agreed that no intersessional meeting was required, and the tasks undertaken by members of the group are reported in SC/50/AS1, 2, 6, 7 and 8.

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Appendix 3

DATA USED IN THE BOWHEAD WHALE ASSESSMENT

Table 1

Bering-Chukchi-Beaufort Seas bowhead whale kill, 1848-1997.

Year	Total kill	Year	Total kill	Year	Total kill	Year	Total kill
1848	18	1886	168	1924	41	1962	20
1849	573	1887	240	1925	53	1963	15
1850	2,067	1888	160	1926	35	1964	24
1851	898	1889	127	1927	14	1965	14
1852	2,709	1890	136	1928	30	1966	24
1853	807	1891	284	1929	30	1967	12
1854	166	1892	346	1930	17	1968	27
1855	2	1893	180	1931	32	1969	32
1856	0	1894	234	1932	27	1970	48
1857	78	1895	117	1933	21	1971	25
1858	461	1896	118	1934	21	1972	44
1859	372	1897	130	1935	15	1973	51
1860	221	1898	309	1936	24	1974	42
1861	306	1899	234	1937	53	1975	32
1862	157	1900	148	1938	36	1976	74
1863	303	1901	55	1939	18	1977	72
1864	434	1902	162	1940	20	1978	17
1865	590	1903	116	1941	38	1979	23
1866	554	1904	86	1942	26	1980	38
1867	599	1905	105	1943	14	1981	26
1868	516	1906	69	1944	8	1982	14
1869	382	1907	96	1945	23	1983	16
1870	637	1908	123	1946	20	1984	16
1871	138	1909	61	1947	21	1985	14
1872	200	1910	37	1948	8	1986	22
1873	147	1911	48	1949	11	1987	29
1874	95	1912	39	1950	23	1988	28
1875	200	1913	23	1951	23	1989	25
1876	76	1914	61	1952	11	1990	41
1877	270	1915	23	1953	41	1991	47
1878	80	1916	23	1954	9	1992	46
1879	266	1917	35	1955	36	1993	51
1880	480	1918	27	1956	11	1994	38
1881	435	1919	33	1957	5	1995	57
1882	242	1920	33	1958	5	1996	45
1883	42	1921	9	1959	2	1997	62
1884	160	1922	39	1960	33	**Total**	**22,3877**
1885	377	1923	12	1961	17		

Sources: 1848-1972: IWC, (1995).
1973-1993: Suydam *et al.* (1995a); Soviet shore kills for 1973-75, see IWC (1995).
1994: Suydam *et al.* (1995b).
1995: 1996: Suydam *et al.* (1997).
1997: George *et al.* (1998).

Notes: These are recorded catches; the presence of zero can equally refer to no information as to no catch. The assignment of 'struck and lost' to the shore kill follows the methodology of Breiwick *et al.* (1982) which was 1848-1969, 100%; 1970-1977, 50%; 1978-1980, 75%, and a poor chance of survival or probably died for 1981-1996 (Suydam *et al.*, 1995a).

Since 1981, struck and lost whales have been assigned a chance of survival by whaling captains: 'excellent', 'fair', 'poor', 'died', and 'unknown'. The number of struck and lost estimated to have subsequently died is equal to the number of whales in the categories 'poor' and 'died' plus the number of whales in the category 'unknown' which were assumed to have died. The number of 'unknown' assumed to have died was equal to the number in that category times the fraction of whales in 'known' categories assigned to 'poor' and 'died' (cf. Suydam *et al.*, 1995a).

The table includes all available past soviet catches including the period 1972-75 when 8 bowheads were taken (see Soviet Union progress report, Anonymous, 1979, p.131). No bowheads are known to have been taken by Chukotkan natives since 1975.

Includes one bowhead taken by Canada in 1991 and one in 1996.

Table 2

Data used in the construction of an index of abundance for the Bering-Chukchi-Beaufort Seas stock of bowhead whales. Source: Zeh *et al.*, (1993). The N_4/P_4 estimates are based on the analyses conducted by Zeh *et al.* (1993).

	N_4		P_4		N_4/P_4	
Year	Estimate	SE	Estimate	SE	Estimate	CV
1978	3,383	289	N/A		5,019	0.294
1980	2,737	488	N/A		4,061	0.336
1981	3,231	716	0.750	0.108	4,308	0.266
1982	4,612	798	N/A		6,843	0.333
1983	4,399	839	N/A		6,527	0.343
1985	3,134	583	0.519	0.131	6,039	0.317
1986	4,006	574	0.518	0.062	7,734	0.187
1987	3,615	534	N/A		5,364	0.320
1988	4,862	436	0.739	0.053	6,579	0.115
1993	7,249	505	0.933	0.013	7,770	0.071

Table 3

Estimates, CVs (actually standard errors of the logarithms) and the correlation matrix for the indices of abundance for the Bering-Chukchi-Beaufort Seas bowhead stock. The values are based on the estimation procedure described in Appendix 1 of SC/50/AS1 (Punt and Butterworth, 1999).

Year	Estimate	CV	Correlation matrix									
1978	4,820	0.273	1.000									
1980	3,900	0.314	0.166	1.000								
1981	4,389	0.253	0.054	0.047	1.000							
1982	6,572	0.311	0.168	0.146	0.047	1.000						
1983	6,268	0.321	0.163	0.141	0.046	0.143	1.000					
1985	5,132	0.269	0.126	0.109	0.025	0.110	0.107	1.000				
1986	7,251	0.186	0.080	0.070	0.012	0.070	0.068	0.108	1.000			
1987	5,151	0.298	0.175	0.152	0.049	0.154	0.149	0.115	0.074	1.000		
1988	6,609	0.113	0.038	0.033	0.012	0.033	0.032	0.018	0.009	0.035	1.000	
1993	7,778	0.071	0.002	0.001	0.001	0.001	0.001	-0.002	-0.002	0.001	0.001	1.000

Table 4

Parameters for bowhead assessment.

Parameter	Value
$MSYL_{1+}$	U[0.4, 0.8][1]
$MSYR_{1+}$	U[0.01, 0.07][2]
a	DU[1,9][3]
ASM	Grouped $N(20,3^2)$, truncated at 13.5 and 26.5[4]
k	$\log(k) \sim U[\log(7{,}000), \log(31{,}000)]$[5]
s (adult)	$N(0.99,0.02^2)$ truncated at 0.995[6] with maximum age = 100 or, N(0.99, 0.022 truncated at 1 with no constraint on maximum age
s (immature)	Constrained by population dynamics equation to be less than s (adult)[7]
$f$max	$1/f\text{max} \sim U[2.5, 4]$ ($1/f$max = minimum average calving interval)[8]

[1] The prior specified in IWC (1995, p.148) for $MSYL_{mat}$ was considered to be appropriate for $MSYL_{1+}$ for reasons given in Annex F.

[2] Justification is based on the reported estimates of current rate of increase (ROI) (Appendix 3, Table 5) and the functional relationships defining $MSYR_{1+}$ (see IWC, 1994b, p.182), where the upper confidence interval for several ROIs exceeded 9% per year, which supports the upper range of 7% for $MSYR_{1+}$, while the lower confidence interval for at least one ROI is in the 2-3% per year range, which supports the lower limit of $MSYR_{1+}$. Further, the Working Group noted that its choice for a lower bound of 1% for the $MSYR_{1+}$ range was consistent with the recommendation for $MSYR_{1+}$ values used in the development of an Aboriginal Whaling Management Plan (IWC, 1994a, annex I).

[3] As in IWC (1995, p.148).

[4] As in IWC (1995, p.148).

[5] It was believed that a prior in which log(K) is uniform would be less informative (on key quantities of interest, such as RY) and more justifiable than one in which K is uniform. The upper and lower limits of log(31,000) and log(7,000), respectively, were proposed for computational convenience, as experience with these types of models has shown there is virtually a zero likelihood for log(K) values outside this range.

[6] As in IWC (1995, p.148), except that the upper truncation point was reduced from 1 to 0.995. Support for the 0.995 value was based on the belief that the expected longevity of a reproductively active bowhead whale would be unacceptably high were the upper value of the range set above 0.995. Using the 0.995 value in combination with a maximum age of 100 in the model should produce average longevities in the range of 60-90 years. Although new data (Whitcher *et al.*, 1996) was available since the choice of prior in IWC (1995, p.148) it did not increase the precision of the previous evidence.

[7] It was considered that juvenile survival should merely be constrained to be less than adult survival, since there was no independent knowledge on which a plausible prior could be based.

[8] It was considered more appropriate to set a uniform prior on the minimum possible average calving interval rather than the maximum historic ratio of calves to mature females. The limits on the latter in IWC (1995, p.148) transform to (2,4); as 2 was considered impossible for bowheads, it was revised to 2.5.

Table 5

Estimated annual rates of increase (with 95% confidence intervals) for several severely depleted stocks of baleen whales. Source: Best, (1993).

Stock	Point estimate	95% CI
South African right whale	0.068	[0.048, 0.086]
Argentine right whale	0.073	[0.038, 0.108]
West Australian right whale	0.127	[0.076, 0.178]
Northwest Atlantic humpback whale	0.094	[-0.12, 0.30]
West Australian humpback whale	0.088	[0.030, 0.146]
East Australian humpback whale	0.097	[0.06, 0.13]
Northeast Atlantic blue whale	0.051	[0.026, 0.076]

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Appendix 4

RESULTS FOR TWO SELECTED ASSESSMENTS OF THE BERING-CHUKCHI-BEAUFORT SEAS STOCK OF BOWHEAD WHALES

André E. Punt

Tables 1 and 2 present post-model-pre-data and posterior distributions for 15 management-related quantities for two assumptions about w (the age at which mortality is assumed to be infinite) and S_{max} (the maximum survival rate for adults). These two sets of assumptions are: (a) $w = 100$, $S_{max} = 1$ and (b) $w = \infty$, $S_{max} = 0.995$. Two sets of posterior distributions are shown for each assumption about w and S_{max}. The first '(1+ abundance data)' assumes that the N_4/P_4 and BEB estimates are absolute indices of 1+ abundance whereas the other '(0+ abundance data)' assumes that these estimates are absolute indices of 0+ abundance (i.e. calves are assumed to be counted during the surveys at Point Barrow).

The data included in the likelihood function are the percentages of calves and mature animals from 1985–92 and the abundance indices. The contribution of the abundance indices follows equation (3) of SC/50/AS1, except that:

(a) the BEB estimates for 1993 are assumed to be independent of the other estimates and normally rather than log-normally distributed, and

(b) the N_4/P_4 estimates for 1978–1988 are multiplied by 8,200/7,778 to account for the difference between the N_4/P_4 and BEB likelihoods for 1993. This is equivalent to the limit of equation (7) of SC/50/AS1 as $\sigma_b \rightarrow 0$

The 15 management-related quantities in Tables 1 and 2 are:

- K_{1+} - the pre-exploitation size of the 1+ component of the population.
- RY (1998) - the replacement yield for 1998.
- Q_0 (1998) - the value of the quantity Q_0 (see Wade and Givens (1997) for details) for 1998.
- P^{1+}_{1998}/K_{1+} - the ratio (expressed as percentage) of the size of the 1+ component of the population at the start of 1998 to K_{1+}.
- P^{f}_{1998}/K^{f} - the ratio (expressed as percentage) of the size of the mature female component of the population at the start of 1998 to the corresponding pre-exploitation size.
- $P^{1+}_{1998}/MSYL_{1+}$ - the ratio (expressed as percentage) of the size of the 1+ component of the population at the start of 1998 to *MSYL*.

$MSYR_{1+}$ - *MSYR* for uniform selectivity harvesting of the 1+ component of the population, expressed as percentage.
Slope - the annual rate of increase of the 1+ population from 1978 to 1993, expressed as a percentage.
S_{juv} - the survival rate for juveniles.
S_{adult} - the survival rate for adults.
a_m - the age-at-maturity.
f_{max} - the maximum fecundity rate.
P_{1993} - the size of the 1+ component of the population at the start of 1993.
$MSYL/K_{1+}$ - the *MSYL* of the population (in terms of the 1+ component).
λ_{max} - the maximum rate of increase (at low population size).

A posterior for the current (1998) calving interval was estimated as part of these analyses. The results indicate a posterior median of 4.2–4.3 with a posterior 90% interval of roughly [3–7].

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Table 1

Estimates of eight management-related quantities for the Bering-Chukchi-Beaufort Seas stock of bowhead whales based on the 'backwards' approach. The point estimates given are posterior medians, followed by posterior means in round parentheses. Posterior 90% probability intervals are given in square parentheses. Results are shown in this Table for the case w=100, S_{max}=1. In addition to those for the post-model-pre-data distribution, results are shown for analyses that assume that the N_4/P_4 and BEB estimates are absolute indices of 1+ and 0+ abundance.

	Estimation procedure					
Quantity	Post-model-pre-data		Posterior (1+ abundance data)		Posterior (0+ abundance data)	
K_{1+}	14,834 (14,750)	[11,065.8, 18,422.7]	12,872 (13,098)	[10,687.0, 17,056.8]	12,845 (13,123)	[10,788.6, 17,125.2]
RY (1998)	160 (164)	[95.4, 263.8]	208 (203)	[123.4, 275.9]	210 (204)	[117.1, 282.4]
Q_0 (1998)	154 (162)	[92.1, 273.7]	205 (203)	[119.5, 290.4]	204 (200)	[113.6, 286.9]
P^{1+}_{1998}/K_{1+}	56.5 (58.2)	[38.1, 89.1]	68.0 (68.0)	[48.2, 91.0]	64.5 (64.5)	[45.5, 87.7]
P^{f}_{1998}/K^{f}	39.9 (40.7)	[27.7, 60.0]	43.5 (44.0)	[35.7, 56.1]	40.8 (41.3)	[33.7, 53.4]
$P^{1+}_{1998}/\mathrm{MSYL}_{1+}$	84.9 (85.5)	[55.1, 124.3]	96.4 (96.0)	[70.4, 122.6]	92.1 (91.5)	[66.0, 119.4]
MSYR_{1+}	1.78 (1.96)	[1.07, 3.75]	2.49 (2.53)	[1.35, 4.06]	2.51 (2.51)	[1.31, 4.02]
Slope	1.68 (1.84)	[0.92, 3.67]	2.43 (2.45)	[1.23, 3.91]	2.47 (2.47)	[1.20, 3.92]
MSYL/K_{1+}	0.70 (0.68)	[0.53, 0.80]	0.71 (0.71)	[0.60, 0.80]	0.71 (0.71)	[0.60, 0.80]
S_{juv}	0.904 (0.883)	[0.703, 0.984]	0.928 (0.918)	[0.817, 0.987]	0.929 (0.918)	[0.811, 0.988]
S_{adult}	0.988 (0.987)	[0.971, 0.999]	0.990 (0.989)	[0.974, 1.000]	0.990 (0.989)	[0.974, 0.999]
A_m	20 (20)	[16.0, 26.0]	20 (20)	[16.0, 26.0]	20 (20)	[16.0, 25.0]
f_{max}	0.32 (0.32)	[0.26, 0.40]	0.31 (0.31)	[0.26, 0.39]	0.31 (0.31)	[0.26, 0.39]
λ_{max}	4.24 (4.43)	[2.91, 6.93]	5.02 (5.08)	[3.42, 7.32]	5.05 (5.09)	[3.40, 7.33]
P_{1993}	7,812 (7,812)	[5,657.9, 10,328.7]	7,957 (7,948)	[7,175.1, 8,829.8]	7,500 (7,527)	[6,806.8, 8,405.9]

(Table 2 on following page)

Table 2

Estimates of eight management-related quantities for the Bering-Chukchi-Beaufort Seas stock of bowhead whales based on the 'backwards' approach. The point estimates given are posterior medians, followed by posterior means in round parentheses. Posterior 90% probability intervals are given in square parentheses. Results are shown in this Table for the case w=∞, S_{max}=0.995. In addition to those for the post-model-pre-data distribution, results are shown for analyses that assume that the N_4/P_4 and BEB estimates are absolute indices of 1+ and 0+ abundance.

	Estimation procedure					
Quantity	'Backwards' reference analysis		Preferred - y_1=1848		Preferred - y_1=1950	
K_{1+}	14,337 (14,249)	[10,740.5, 17,709.1]	12,410 (12,657)	[10,225.3, 16,660.6]	12,307 (12,626)	[10,329.3, 16,680.8]
RY (1998)	144 (150)	[91.8, 240.5]	186 (184)	[117.6, 248.0]	191 (187)	[112.6, 258.5]
Q_0 (1998)	144 (151)	[89.7, 255.0]	190 (189)	[114.9, 270.0]	190 (188)	[109.7, 263.3]
P^{1+}_{1998} / K_{1+}	58.0 (59.7)	[39.3, 91.0]	69.7 (69.4)	[49.2, 91.5]	66.3 (66.1)	[46.5, 88.6]
P^{f}_{1998} / K^{f}	38.3 (39.3)	[26.9, 58.6]	41.2 (41.7)	[34.0, 53.4]	38.4 (39.1)	[31.9, 50.8]
$P^{1+}_{1998} / \mathrm{MSYL}_{1+}$	87.7 (88.5)	[57.0, 126.3]	98.7 (97.9)	[71.9, 123.3]	94.2 (93.6)	[67.6, 121.7]
MSYR_{1+}	1.73 (1.89)	[1.06, 3.63]	2.40 (2.44)	[1.31, 3.97]	2.43 (2.44)	[1.29, 3.91]
Slope	1.53 (1.69)	[0.88, 3.37]	2.26 (2.28)	[1.18, 3.67]	2.34 (2.32)	[1.15, 3.73]
MSYL/K_{1+}	0.69 (0.68)	[0.53, 0.79]	0.72 (0.71)	[0.60, 0.80]	0.71 (0.71)	[0.59, 0.79]
S_{juv}	0.905 (0.883)	[0.707, 0.981]	0.929 (0.918)	[0.813, 0.983]	0.927 (0.917)	[0.816, 0.983]
S_{adult}	0.986 (0.984)	[0.970, 0.995]	0.986 (0.985)	[0.972, 0.995]	0.987 (0.986)	[0.973, 0.995]
A_m	20 (20)	[16.0, 26.0]	20 (20)	[16.0, 25.0]	20 (20)	[16.0, 25.0]
f_{max}	0.32 (0.32)	[0.26, 0.39]	0.31 (0.32)	[0.26, 0.39]	0.31 (0.31)	[0.26, 0.39]
λ_{max}	4.12 (4.26)	[2.74, 6.55]	4.82 (4.87)	[3.33, 7.01]	4.86 (4.89)	[3.26, 7.07]
P_{1993}	7,823 (7,818)	[5,664.1, 10,442.9]	7,926 (7,909)	[7,159.9, 8,741.6]	7,455 (7,481)	[6,764.5, 8,360.3]