

Annex D

Report of the Sub-Committee on the Revised Management Procedure (RMP)

Members: Bannister (Convenor), An, Acquarone, Brandão, Brandon, Butterworth, Childerhouse, Cipriano, Cooke, de la Mare, Donovan, Elvarsson, Gunnlaugsson, Hakamada, Hammond, Hatanaka, Hiruma, Honda, Kelly, Kishiro, Kitakado, Leaper, Lockyer, Miyashita, Murase, Øien, Pampoulie, Palka, Park, Pastene, Punt, Roel, Schweder, Skaug, Uoya, Vikingsson, Walløe, Witting.

1. INTRODUCTORY ITEMS

1.1 Convenor's opening remarks

As Convenor, Bannister welcomed the participants.

1.2 Election of Chair and appointment of rapporteurs

Bannister was elected Chair. Punt acted as rapporteur.

1.3 Adoption of Agenda

The adopted Agenda is shown in Appendix 1.

1.4 Available documents

The documents considered by the sub-committee were SC/63/RMP1-6, 19-20, 24-25, 30, Pike *et al.* (2010a; 2010b) and relevant extracts from past reports of the Scientific Committee.

2. REVISED MANAGEMENT PROCEDURE (RMP) – GENERAL ISSUES

2.1 Review MSY rates

The Scientific Committee has been discussing the maximum sustainable yield rate (MSYR) issue since 2007 (IWC, 2008) in the context of a general reconsideration of the plausible range to be used in population models used for testing the *Catch Limit Algorithm (CLA)* of the RMP. At present, this range is 1% to 7% when expressed in terms of the mature component of the population. As part of the review process, information on observed population growth rates at low population sizes is being considered. Cooke (2007) noted that in circumstances where variability and/or temporal autocorrelation in the effects of environmental variability on population growth rates is high, simple use of such observed population growth rates could lead to incorrect inferences being drawn concerning the lower end of the range of plausible values for MSYR. Last year, the Scientific Committee agreed a Bayesian approach (Punt, 2010) for calculating a probability distribution for the rate of increase for an 'unknown' stock in the limit of zero population size, r_0 , once the inputs needed to be applied to (rates of increase and associated sampling CVs, and values for the extent and temporal-auto-correlation in environmentally-driven factors (σ and ρ) on the growth rate) become available. The Scientific Committee also identified a work plan which focused on estimating the latter two factors using data on calving intervals and calving rates.

2.1.1 Progress on intersessional work

Butterworth summarised the progress made by the intersessional MSYR working group since the last Annual Meeting and noted that Kitakado, Brandon and Cooke had

developed methods for analysing data on calving intervals and calving rates. The results from these methods are needed to complete the MSYR review.

SC/63/RMP20 addressed item (11) of the sub-committee's work plan from last year (IWC, 2011b, p.97). A Bayesian meta-analysis was conducted using the time series of baleen whale calving rates and intervals that were supplied to the 3rd Scientific Committee Workshop on Baleen Whale MSYR (IWC, 2011c, p.402). Ten series of calf counts or calving proportions, and eight series of calving intervals were used in the analysis. These two sets were analysed separately, because for most stocks both types of series were available. The results were expressed as posterior probability distributions of the process variance and serial correlation coefficient for calving rates and intervals for a generic stock (a stock without stock-specific data). The results of the analyses of calf count/calving proportion series and calving interval series each showed that the data were consistent with almost the full possible range (-1,1) of serial correlation coefficients for a generic stock. The results from the calf count and calving proportion time series suggested that all values of inter-annual process variance, σ , in the range [0,1] were plausible, but with values near 1 being less likely. The calving interval series showed lower values of process variance, with values of $\sigma > 0.4$ being unlikely. To elucidate the relation between calving interval variance and calving rate variance probably requires explicit modelling of the calving cycle. Variance in mortality rates has not been considered.

SC/63/RMP30 presented two approaches for the analysis of selected data sets to estimate environmental variability and auto-correlation in reproductive rates of baleen whales. Both approaches recognised that for a given stock, the average calving interval is the reciprocal of the average proportion calving, and thus allow for the incorporation of both data types in a unified estimation framework for parameters of interest. For an unknown stock of baleen whales, the extent of environmental variability was (depending on the approach) estimated to be 0.347 and 0.396 (standard deviations in log-space), and the estimates of the auto-correlation parameter, ρ , were 0.614 and 0.288. The estimates of the hyper-parameters from this meta-analysis framework can be used in simulations to inform the lower end of the range for MSYR values. In general, the resulting parameter estimates appeared to be mostly consistent with those in SC/63/RMP20, which employed a different modelling framework and included more data on reproductive variability. Therefore, it was concluded that these results may provide some confidence in the robustness of available estimates, given different data sets and modelling assumptions.

The sub-committee noted that the approaches in SC/63/RMP20 and SC/63/RMP30 differed in several respects (statistical estimation paradigm, how inferences are drawn about the 'population' from which σ and ρ are drawn, whether the calving interval and calving rate data are analysed separately or simultaneously, and how observation error is taken into account). A small group was therefore

established to evaluate the three approaches. Based on analyses for comparable data sets (Appendix 2), the sub-committee **agreed** that the three approaches lead to similar estimates given common assumptions and data sets. Owing to its generality, the sub-committee **agreed** to use the estimates from the approach of SC/63/RMP20. Appendix 2 provides more details on how these distributions for σ and ρ are calculated and lists the percentiles for the posterior distributions for σ and ρ from each of the stocks included in the meta-analysis of calving rates and calf counts, as well as those for the posterior distributions for an unknown stock.

SC/63/RMP26 addressed item (1(2)) of last year's work plan, concerning the correlation between variability in reproductive rates and in survival rates. If the correlation is positive, these two sources of variability will compound each other with regard to the variability in net recruitment rate. A review of the literature found that the correlation was often negative in manipulation experiments, such as when eggs are removed from birds' nests to suppress reproduction, but that the correlation was usually positive when variability resulted from food limitation. The model presented last year was developed further to allow for both inter-annual and individual variability. For an individual, the relationship between survival and reproduction can be non-monotonic, if reproduction shuts down when body condition drops below a threshold, resulting in improved survival. However, when averaged over a population that includes variation between individuals, the relationship between survival and reproduction was monotonic and positive in all the cases examined. The paper concluded that the assumption of a constant survival rate would likely result in underestimation of the variability in net recruitment rate.

The sub-committee thanked Cooke for providing these results, which addressed two of the three tasks identified during last year's Annual Meeting related to the issue of the correlation between survival and reproductive rates. The third task, direct estimation of variability in survival rates, could not be addressed and in any case, data would only be available for two stocks, southwest Atlantic right whales and western gray whales, and it is unlikely that inferences based on those stocks would be sufficient to draw general conclusions regarding inter-annual variation in survival.

Witting questioned whether the model on which SC/63/RMP26 was based was sufficiently realistic to allow general conclusions to be drawn regarding the correlation between survival and reproductive rates. He noted that the model in SC/63/RMP26 considered an annual time-step whereas the processes which would lead to these correlations may operate on finer time-scales. De la Mare noted that one possible example of this would be females becoming pregnant in the breeding grounds if the conditions there were good, but failing to give birth if conditions on the feeding grounds were poor. The model of SC/63/RMP26 includes a non-linear relationship between survival/reproductive rate and environmental conditions. This, the sub-committee noted, generally leads to a monotonic relationship between survival and reproductive rate under the model of SC/63/RMP26. The exception to this occurs when individual variation is ignored when survival can be negatively correlated with reproductive rate. Survival can also increase moderately with moderately poor environmental conditions because of lower reproductive rate.

The sub-committee **agreed** that it should take account of a potential positive correlation between survival and reproductive rates (negative correlation between reproductive rate, f , and natural mortality, M). In the absence

of information to specify the magnitude of variation in survival, the sub-committee **agreed** that analyses should be conducted in which: (a) the correlation is zero; and (b) there is a perfect negative correlation between f and M , with variability in M comparable with that for f .

The sub-committee identified the steps in deriving a distribution for the ratio of expected rate of increase at low population size to the maximum possible of increase, r_0/r_{\max} , as follows.

- (1) Associate each stock for which a rate of increase is available with values for σ and ρ . This step is needed because the stocks included in the meta-analysis differed from those for which rates of increase are available.
- (2) Use an age-structured population dynamics model to select the values for the standard error of the log of fecundity and the inter-annual correlation in the log-fecundities so that the projected variation in fecundity matches the input values from step 2. This step is needed because annual fecundity is constrained to be less than 1 in the population dynamics model and because this model does not allow females to give birth in consecutive years.
- (3) Use the results from step 2 to infer the variance and correlation in the rate of increase at low population size.
- (4) Develop a relationship between the expected value for the rate of increase and its variance and the value for r_{\max} and $\chi = r_0/r_{\max}$ for each stock in the meta-analysis.
- (5) Use Bayesian methods to compute posterior distributions for the parameters of a beta distribution for $\chi = r_0/r_{\max}$ given uniform priors on the parameters of the beta distribution.
- (6) Create a posterior predictive distribution for the value of χ for an unknown stock, taking into account the uncertainty of the parameters of the beta distribution as well as the selection of a stock from the beta distribution.

Appendix 3 outlines a first application of the algorithm above. The sub-committee noted that Appendix 3 made several assumptions (e.g. how values for σ and ρ were assigned to stocks) which had not been discussed. Specifically, the approach in Appendix 3 of assigning the same values for σ and ρ to stocks within a species suggests that consideration should have been given to a hierarchical meta-analysis when analysing the calf count and calving rate data. The sub-committee also noted the importance of considering the assumption of the extent to which the stocks considered in the various meta-analyses are interchangeable.

The sub-committee established a Steering Group (Butterworth [Convenor], Brandon, Cooke, de la Mare, Kitakado, Punt, Schweder, Walløe and Witting) to guide the intersessional work. The Terms of Reference for the Steering Group are to review Appendix 3 and identify additional and alternative analyses, including how the correlation between M and f is to be modelled, in preparation for completing the MSYR review at next year's Annual Meeting. Alternative approaches, if fully-specified, could be presented to the Steering Group for consideration.

2.1.2 Other issues

SC/63/RMP25 explored some implications of estimating MSYR from the recovery trajectories of competing populations using simulation. This is a simple study to illustrate a class of issues that have not been given much attention to date in the work of the sub-committee. Estimating MSYR from the recovery of depleted populations makes strong assumptions about each population being isolated, stationary and recurrent. Possible competition undermines

the assumption that populations are isolated. The study used a model of intra-specific competition based on a two-species version of the Pella-Tomlinson model to derive yield curves under various conditions. In this class of model, the yield curves for one population depend on the abundance of the competing population. Both MSY and MSYR depend on the state of the competing populations. The MSYR of interest to management is the one where both species are maintained at their MSYL. This value of MSYR can be less than that applying to either species alone. Fitting a single species model to each recovery trajectory leads to estimates of MSYR that are close to the value applicable to each population alone. This is not surprising because the effects of competition are small when both populations are at low abundance. These estimates of MSYR are not estimates of the MSYR required for management when both species are maintained at higher levels of abundance. The general revision of MSYRs as contemplated by the Scientific Committee would have the effect of using the estimates in contexts other than those in which they were estimated.

Discussion on SC/63/RMP25 focused on two issues:

- (1) the realism of the population dynamics model on which the analyses were based; and
- (2) whether the RMP process would be able to appropriately use information on MSYR from syntheses of rates of increase at low population size given the possible implications of multi-species effects.

In relation to the first issue, Gunnlaugsson noted that the model on which SC/63/RMP25 was based did not account for the possibility that two stocks which are very similar biologically should behave similarly, while Witting noted there were several cases in which single-species models are predicting responses which are too fast at low stock size compared to an inertia model which predicts a delayed response, including gray whales (Punt *et al.*, 2004; Witting, 2003), Southern Hemisphere blue whales (Mori and Butterworth, 2004), and humpback whales (IWC, 2003). Witting argued that the even stronger immediate response that follows from the two-species model in SC/63/RMP25 occurs because it involves a density-regulation response from two rather than one species. De la Mare responded to these concerns, noting that the models in SC/63/RMP25 should not be considered definitive, or even necessarily very realistic, but that they provided insight on the likely impact of multi-species dynamics on perceptions of rates of increase and hence MSYR for managed stocks.

In relation to the second issue, Butterworth noted that the RMP process had considered multi-species effects on the performance of the *CLA* using operating models through, for example, time-varying carrying capacity and MSYR. He also emphasised that the *Implementation Review* process, a feature which was not envisaged during the development of the *CLA*, provided a way to address situations in which new information related to multi-species effects become available. He queried whether an implication of SC/63/RMP25 was a need for a 'meta-RMP' evaluation process in which the process of conducting *Implementation Reviews* would itself be simulated. De la Mare responded that while it was clearly necessary to consider the implications of the process for updating the range for MSYR, this would not necessarily involve simulations.

The sub-committee was informed that the Working Group on Ecosystem Modelling is planning to consider the RMP in the context of multi-species operating models. The sub-committee **agreed** that this would be an ideal way to

bring multi-species considerations into its deliberations and supports the idea of a joint session with the Working Group at next year's Annual Meeting.

2.1.3 Conclusion

The sub-committee noted that last year the Scientific Committee had agreed that it should complete the review this year on the basis of the data and analyses available, accepting that it was not appropriate to keep extending the time available for the review given its importance to finalising the approach for evaluating amendments to the *CLA* (IWC, 2011a, p.7). Although it was regrettable that the review had not been completed this year, it **stressed** that it has agreed an intersessional work plan such that it will not only complete the review, but will also allow the sub-committee to finalise the approach for evaluating amendments to the *CLA* at next year's meeting.

2.2 Finalise the approach for evaluating proposed amendments to the *CLA*

The Scientific Committee last discussed this issue in 2006. It agreed at that time the two steps which had to be completed were: (1) finalisation of the MSYR review; and (2) specification of additional trials for testing amendments to the *CLA*. The latter related to modelling the effects of possible environmental degradation in addition to, or possibly replacing, the trials in which *K*, perhaps with MSYR, varies over time. This is because the current changing *K* trials have questionable behaviour when modelling population sizes above *K*. The sub-committee re-established a Working Group under Allison (members: Butterworth, Cooke, Donovan, Punt and Walløe) to develop and run such trials for consideration at next year's meeting.

2.3 Evaluate the Norwegian proposal for amending the *CLA*

The sub-committee was unable to complete its evaluation of the Norwegian proposal as the MSYR review has yet to be completed. The sub-committee will complete this task at the next Annual Meeting if the MSYR review can be completed.

2.4 Relationship between phase-out rule and abundance estimates based on multi-year surveys

Last year the sub-committee recommended a number of changes to the RMP specifications and annotations (IWC, 2011b, p.102-03) which were endorsed by the Scientific Committee and the Commission. One of these was to extend, from five to six years, both the period for which catch limits are set, and the preferred interval between *Implementation Reviews*. In this context, the sub-committee placed in its work plan a reconsideration of the number of years since the last survey after which catch limits start to be phased out under the RMP specifications.

The eight-year phaseout rule can be problematic in cases such as the northeast Atlantic, where each survey of the management area is spread over a number of years. Assuming that a *Combination Area* is surveyed over a six-year period, that a Catch Limit Calculation is performed one year after the end of the survey, and that the calculated catch limit applies to the following six years, then the catch limit for a *Small Area* that is surveyed only in the first year of the multi-year survey will start to phase out in the third year of the six-year block of catch limits.

The sub-committee **agreed** that a change to the phaseout rule involves a change to the RMP specifications, and not merely to the annotations. According to the agreed protocol for changes to the RMP specifications (IWC, 1994, p.47),

a change requires that the Scientific Committee's agreed list of standard simulation trials be run for the proposed revision. The sub-committee recalled the trials that had previously been conducted, which showed that there was no degradation in risk-related performance when the inter-survey interval was extended to 10 years (IWC, 1993, p.58, p.94). The sub-committee **agreed** that a change of the start of the phaseout from eight to ten years could be recommended without further trials.

The sub-committee noted that this would ameliorate the problem with respect to multi-year surveys. It **recommended** that all references to eight years in section 3.4 of the RMP specification be amended to ten years. The sub-committee noted that if a larger change is sought, a revision proposal would need to be made, accompanied by results of the requisite set of trials.

The sub-committee **agreed** that it did not foresee any further amendments to RMP specifications in the near future and it **agreed** that the full RMP and its annotations should be published in the next Supplement of the *Journal of Cetacean Research and Management* and placed on the IWC website, along with the most recent versions of the Requirements and Guidelines for Surveys (see Item 2.6.2) and Guidelines for Data Collection and Analysis under the Revised Management Scheme (RMS) other than those required as direct input for the *Catch Limit Algorithm (CLA)*.

2.5 Modify the 'CatchLimit' program to allow variance-covariance matrices

The sub-committee noted that the 'CatchLimit' program was originally written by the Norwegian Computing Center, who should be tasked with making this modification. The sub-committee noted that there are likely to be costs associated with this work, which should be conducted in collaboration with Allison.

2.6 Update guidelines for conducting surveys and Implementations

2.6.1 Consideration of line transect methodology

SC/63/RMP2 noted that the last detection distance recorded for each sighting has been used consistently in abundance analyses of the Iceland/Faroese NASS shipboard data for large baleen whales. The common practice has been to use the first detection distance, which will be at a smaller angle to the trackline and with a smaller inclination angle to the horizon and therefore less precise. Random movement will introduce a positive bias when the first distance is used. It may also introduce a positive bias when the last distance is used if the last surfacing of an animal moving away from the track is more likely to be missed. As these surveys have not tracked all animals up to abeam (stopped when duplicated and primary sightings not tracked) there has been a potential for bias. The first and last detection distances were compared from T-NASS sightings and these sets showed little difference, so, if there was a bias, it is of similar magnitude with either method. Other advantages of using the last (or later) detection distance is that this will be more consistent when comparing sightings from different platforms and assigning duplicates in the case of dispersed aggregations. Tracking all sightings up to abeam is suggested in SC/63/RMP2 for future surveys to avoid such uncertainty about responsive movement. More consideration needs to be given to what constitutes a trial in methods that attempt estimation of the proportion of animals missed on the trackline.

The sub-committee **endorsed** the use of the last detection distance for analyses of data from the T-NASS surveys.

SC/63/RMP6 outlined how a hidden Markov model could be used to identify and define the density distribution of inter-breath intervals (IBI) as the observation state of two hidden diving processes (regular dives and deep dives). The method was applied to individual follows of minke whales from a land-based station at Flaxafloi Bay, Iceland. Regular dives were found to have a mean surfacing interval of 43 seconds (SD=44.8) and deep dives had a mean surfacing interval of 155 seconds (SD=115.1). The model estimated that minke whales perform regular dives during 62% and deep dives during 38% of the time. SC/63/RMP6 reported that the relative proportions spent in each dive type can be used as estimates of how much time a whale will be typically at the surface available to be detected during cue counting surveys. The proportion of time spent in deep dives decreased from 38% to 14% during interactions with whalewatching boats, while regular dives increased from 62% to 86%. SC/63/RMP6 noted that the estimated mean values of surfacing intervals are both less and greater than the average of 77 seconds from VHF-transmitter data for minke whales in North Atlantic.

Schweder and Øien noted that visual surfacing rates are likely to be more affected by measurement errors than data obtained from VHF-tagged animals because: (a) it is difficult to track an individual; (b) visual tracking can lead to matching a tracked animal with another animal; and (c) individual surfacings may be missed. They also noted that surfacing data for use when estimating abundance should ideally be obtained under conditions similar to those of the survey, that vessel-based observations in the open sea are preferable, also because the presence of a vessel may have an impact on estimated dive times and collected data should reflect this. Furthermore, the method used for abundance estimation treats the dive time data in two ways: (a) an approximate likelihood based on the survey data and on the observed surfacing rate is maximised; and (b) to correct for bias due to, among other things, minke whales having a rhythm of some 3-6 short dives between each long dive, the survey data are simulated from the fitted model, but then with dive time series sampled from the observed VHF data to correct the raw data for bias. A hidden Markov model for dive times, as suggested in SC/63/RMP6, would not address either of these two respects.

Lusseau responded to the comments from Schweder and Øien, noting that surfacing time and the number of breaths during each surface time cannot be fixed, but rather varies in time and space. The sub-committee noted there were situations in which visual-based observations will be useful, such as estimation of encounter rates with whalewatching vessels. However, it **endorsed** the Scientific Committee's previous conclusion that visual measures of dive time sequences should not be used in the abundance estimation for North Atlantic minke whales.

2.6.2 Updated guidelines

No additional changes to the guidelines were suggested at this year's meeting although the question of the acceptability of model-based estimates will be considered next year. As noted under Item 2.4, the updated guidelines, taking into account the modifications suggested last year (IWC, 2011b, p.92) will be published in the next issue [i.e. this issue] of the Supplement to the *Journal of Cetacean Research and Management*.

2.7 Work plan

The sub-committee **agreed** that its work plan before and during the 2012 Annual Meeting would be as follows.

- (1) Refine the data and assumptions on which the meta-analyses of environmental impacts on growth rate and of increase rates at low population size are based (Item 2.1.1).
- (2) Complete the MSYR review (Item 2.1.1).
- (3) Specify and run additional trials for testing amendments to the *CLA* (Item 2.2).
- (4) Finalise the approach for evaluating proposed amendments to the *CLA* (Item 2.2).
- (5) Evaluate the Norwegian proposal for amending the RMP (Item 2.3).
- (6) Modify the Norwegian 'CatchLimit' program to allow variance-covariance matrices to be specified for the abundance estimates. Compare the results from the modified program with those from the 'accurate' version of the Cooke program for some cases (Item 2.5).
- (7) Run the full set of revised results for the North Atlantic fin whales, the Western North Pacific Bryde's whales, and the North Atlantic minke whales using the Norwegian 'CatchLimit' program and place the results on the IWC website (this is a carryover from the 2010 work plan).

3. RMP – PREPARATIONS FOR IMPLEMENTATION

3.1 Western North Pacific Bryde's whales

3.1.1 Consideration of research proposal associated with variant 2

The Scientific Committee had agreed in 2007 (IWC, 2008) that three of the four RMP variants (1, 3 and 4) considered during the *Implementation* for the western North Pacific Bryde's whales performed acceptably from a conservation viewpoint and recommended that those variants could be implemented without a research programme. It also agreed that variant 2 (i.e. sub-area 2 is treated as a *Small Area*) was not 'acceptable without research' because conservation performance was 'unacceptable' on three 'medium' plausibility trials in which there were two stocks of Bryde's whales in the western North Pacific, one of which consisted of two sub-stocks (stock structure hypothesis 4).

Last year the Scientific Committee received a research proposal (see IWC, 2011b, pp.103-107) which revised an original research proposal (Pastene *et al.*, 2008) and recommended that it be revised further and, in particular, that the power analysis that assessed the use of genetic methods focus more clearly on the specific hypotheses for western North Pacific Bryde's whales.

Pastene advised the sub-committee that a revised proposal had not been written given that the Commission had not yet decided to implement the RMP for western North Pacific Bryde's whales. He informed the sub-committee that Japan will present new information related to stock structure during the *Implementation Review* for this group of whales that is scheduled for the 2013 Annual Meeting.

3.1.2 Summary of agreed abundance estimates

No new abundance estimates were presented to the sub-committee.

3.1.3 Recommendations and work plan

The sub-committee **agreed** that it will need to prepare for the 2013 *Implementation Review* for the western North Pacific Bryde's whales during next year's meeting.

3.2 North Atlantic fin whales

3.2.1 Consideration of research proposal associated with variant 2

The Scientific Committee agreed in 2009 (IWC, 2010) that if the RMP is implemented for North Atlantic fin whales, variants 1, 3, 4, 5 and 6 (see table 4 of IWC, 2010) could be implemented without a research programme. It also agreed that variant 2 (i.e. sub-area WI+EG is a *Small Area*) was not 'acceptable without research' because conservation performance was 'unacceptable' on a subset of the trials for stock structure hypothesis IV (four breeding stocks, but with no dispersal between the C sub-stocks). Re-analysis of the *Implementation Simulation Trials* using a different version of the *CLA* in 2010 indicated that variant 3 was also not 'acceptable without research' (IWC, 2011b). Last year, the Scientific Committee received a draft research proposal from Iceland which used biopsy sampling and satellite tagging late in the season to determine whether stock structure hypothesis IV should have been assigned 'low' plausibility. The Scientific Committee noted that the aim of any research proposal should be to assess the probability of hypothesis IV relative to the probabilities for the other stock structure hypotheses and that the *Implementation Simulation Trials* could be used to assess the effect sizes on which power analyses should be based.

SC/63/RMP19 was written in response to requests made by the Scientific Committee last year on a research proposal to accompany variant 2 (Gunnlaugsson *et al.*, 2010). *Implementation Simulation Trials* were used to determine that a mixing rate of 22% would allow variant 2 to perform 'acceptably' for stock structure hypothesis IV. The analysis goes further and determines the maximum likelihood estimate for the mixing rate to be 8% for all values of MSYR, rejecting a mixing rate of 5% for MSYR_{mat} of 1% with 95% confidence. The author noted that these results support the power analysis in Appendix 5 of Gunnlaugsson *et al.* (2010) and therefore no further power analysis is needed. The author raised concerns regarding the performance of the optimisation method used in the code that implements the *Implementation Simulation Trials* for the North Atlantic fin whales and requested further analysis to determine the effects of this on the results.

The sub-committee thanked the author of SC/63/RMP19 and noted that the results in SC/63/RMP19 provided a specific level of mixing which can be used in power analyses. The sub-committee **agreed** that results in SC/63/RMP19, combined with those of Gunnlaugsson *et al.* (2010), should provide an adequate basis to justify sample sizes and looked forward to seeing a revised version of the research proposal at next year's meeting.

Noting the evidence for a lack of convergence in SC/63/RMP19, the sub-committee requested Allison to examine whether and when the optimisation method should be used when conditioning fails to find the actual minimum of the objective function and any implications of this for previous results of *Implementation Simulation Trials*.

SC/63/RMP4 conducted analyses to explore the plausibility of stock structure hypothesis IV using Discovery Mark recoveries by *Small Areas*. Markings on the WI grounds are highly likely to be recovered the next season, but EG markings not so. The recoveries within the WI grounds then reduce quickly over time while recoveries from EG increase. This feature is impossible under Hypothesis IV, for which the profile of recoveries over time will be the same for all areas, while a dispersion model fits this pattern significantly better. The markings have been concentrated on the whaling

grounds and along the continental shelf in the EG area to the west of Iceland, while the sightings surveys show a continuous distribution over a much larger area. The sighting survey abundance estimates are fitted in the *Implementation Simulation Trials*, which therefore result in a poor fit to the Discovery Marks for any stock structure hypothesis. The dispersal model shows that these groups of around 2,000 animals in the marking areas are not isolated but disperse (6%) and the low survival estimate implies that there is a dispersal to other areas (or other parts of these areas) of around 10%. A parent-offspring relatedness study of animals within the WI grounds led to an estimate of abundance of around 5,000, so more than half the living relatives (parent or offspring) of animals visiting the grounds are not there. In conclusion, marked animals are likely found close to where they were the year before, but 10 years later have dispersed into/from a much wider area. They do not mix in the same fixed proportions each year as in Hypothesis IV and hence this hypothesis does not fit the data at hand and there is no need for an extensive sampling scheme, although research such as on relatedness will certainly continue.

The sub-committee **agreed** that while the results in SC/63/RMP4 were suggestive that hypothesis IV can be rejected given available information, the analyses were not conducted within the context of the *Implementation Simulation Trials*. It therefore **recommended** that the analysis of Discovery Mark data be integrated within the existing *Implementation Simulation Trials*. In making this recommendation, the sub-committee noted that SC/63/RMP4 had shown that the marking data are not comparable with the abundance estimates for the entire stock, which suggests that the component of the stock which is marked is much smaller than the whole population. This needs to be accounted for and will require that the *Implementation Simulation Trials* be modified accordingly for the analysis suggested.

Last year, in discussion of the draft research proposal in Gunnlaugsson *et al.* (2010), Cooke noted that the proposed genetic mark-recapture studies could be partially confounded by male-mediated genetic exchange between breeding stocks, as is known, for example, for humpback whales. Such genetic exchange would, however, reduce the power of genetic mark-recapture data to distinguish among the existing hypotheses.

In that context, SC/63/RMP5 reported that there is an apparently high proportion of female-female pairs in the potential parent-offspring matches from a relatedness study using catches of North Atlantic fin whales from the grounds west of Iceland (Gunnlaugsson *et al.*, 2010). This led to a postulated modification to hypothesis IV where the males would move between isolated female breeding stocks. The raw data were inspected and turned out to be sex-biased, in particular during the last year, leaving little signal of sex difference in the matches when this was taken into consideration. Recoveries from Discovery markings show more mobility of females among feeding grounds when the last year is ignored. This, and the lack of genetic difference between the breeding stocks which would be implied by this modification to the hypothesis, were found to be incompatible.

The sub-committee noted that the indications in SC/63/RMP5 were that male-mediated genetic exchange was unlikely. However, there was insufficient time to address this issue in detail and the sub-committee deferred discussion of this matter until next year's meeting when a revised research proposal should be available.

3.2.2 Abundance estimates for use in the CLA

No new abundance estimates were presented to the sub-committee. See also Item 4 for a discussion of abundance estimates for use in the RMP.

3.2.3 Other

SC/63/RMP1 presented the first analyses using data from the Icelandic DNA Registry for North Atlantic fin whales. Although it does not clarify the genetic structure of the North Atlantic fin whale, it nevertheless provides information on the feeding migration patterns for this species. SC/63/RMP1 found a highly significant match between a mother-fetus pair caught in 2009 and an alleged father caught in 2010 based on microsatellite loci. Although the sample size is small, this match nevertheless suggests that individuals occurring on the same mating ground are likely to exhibit similar timing and migration routes, and not roam across the Atlantic as has been suggested before.

The sub-committee welcomed this information and looked forward to seeing this type of information used to provide information pertinent to stock structure discussions.

The abundance of fin whales was estimated in European Atlantic waters from data collected during shipboard sightings surveys conducted in 2005 and 2007 (SC/63/RMP24). The estimates presented update those presented in Allison *et al.* (2010). Estimates for the Faroese block of TNASS have been presented elsewhere. Estimated abundance was 19,354 (CV 0.24) for identified sightings and 29,512 (CV 0.26) when adjusted to include a proportion of unidentified large whale abundance prorated by number of sightings. This adjustment was made because there were a large number of unidentified large whale sightings in one of the CODA survey blocks. A model-based estimate of identified fin whales was 19,751 (CV 0.17), very similar to, but more precise than, the design-based estimate.

SC/63/RMP24 accounted for whales that were unidentified to species using a simple pro-ratio technique (but did not necessarily recommend those estimates as 'best'). The sub-committee and the author of SC/63/RMP24 noted that an implicit (and untested) assumption of this approach is that all species have identical rates of identification. This is clearly not the case generally, but may be an adequate assumption for large baleen whales.

In discussion, it was noted that SC/63/RMP24 provided design-based and model-based estimates, with the latter being more precise and being better able to account for an inability to follow the original design. The sub-committee **agreed** that this matter, although of course relevant to the acceptability or otherwise of such estimates for use in the RMP, was of broader relevance to the work of the Scientific Committee. It therefore **referred** the issue to the Plenary to decide on the most appropriate way to handle discussions at next year's meeting.

3.2.4 Recommendations and work plan

The sub-committee **agreed** that it will review a revised research proposal and start preparing for the 2014 *Implementation Review* during next year's meeting.

3.3 North Atlantic minke whales

3.3.1 Review new abundance estimates

SC/63/RMP3 summarised a sighting survey conducted around Jan Mayen in the *Small Management Area CM* during summer 2010. This was the third year in the ongoing six-year survey program 2008-13 for minke whales in the northeast Atlantic. One vessel covered the area during the period 20 July to 31 August. The total survey area was

divided into three blocks which all were covered twice. The survey vessel was able to conduct 2,028 n.miles altogether in primary search mode in the designed survey blocks. During the primary search, the established sightings procedures, including double platform and tracking of minke whales, were followed as in previous surveys in which minke whales have been the primary target species. In addition, 569 n.miles with 'large whale effort' were surveyed under conditions beyond those acceptable in the survey protocol for minke whales and only the upper platform was on watch during these parts of the survey. The species most often observed during the survey were minke (34 groups from the primary platform), fin (31 groups), humpback (35 groups) and sperm (28 groups) whales. The Jan Mayen area was last surveyed in 2005. Norwegian surveys have covered this area (or parts of it) in 1988, 1995, 1997, 2005 and now in 2010. The sighting rates of *Lagenorhynchus* dolphins, killer whales and sperm whales seem to have increased over this period of surveys while the baleen whales have had a more variable occurrence in the area.

The sub-committee welcomed this information and noted that these data would be included in a future abundance estimate for the North Atlantic minke whales.

A re-analysis of combined data from surveys of shelf (2005) and offshore (2007) European Atlantic waters (SC/63/RMP24) resulted in an estimate of minke whale abundance of 30,410 (CV=0.34). The model-based estimate was less precise and considerably larger.

Pike *et al.* (2010b) presented a survey report from the 2009 aerial survey around Iceland, incorporating results from a partial survey conducted during 2008 and a comparison to earlier surveys. It examined sighting distances for *Lagenorhynchus* spp. dolphins and humpback whales to ascertain whether the exceptionally wide effective search half width found for minke whales in the 2009 survey was evident for other species. The comparison of perpendicular sighting distances for dolphins and humpback whales in 2009 to earlier surveys showed that they were quite similar, which suggests that the anomalous results for minke whales were not characteristic of other species. The minke whale uncorrected estimate for block 1 surveyed in the 2008 partial survey was 7,751 (95% CI 2,328, 20,472), which is similar to that estimated for 2001 and much higher than those estimated for 2007 and 2009.

Pike *et al.* (2010a) examined perception bias in the 2007 and 2009 aerial surveys. Pike *et al.* (2010a) used Mark-Recapture Distance Sampling (MRDS) techniques, using an independent observer configuration and assuming full independence, to estimate $p(0)$ for these surveys and applied the correction to the previously completed standard estimates. For the 2007 survey, using only data from the more effective observer, for which duplicate data were available, the best MR model included radial distance, platform and their interaction term, and resulted in an estimated $p(0)$ of 0.72 (CV=0.24) for the primary platform, and a corrected total estimate of 20,834 (95% CI 9,808, 37,042). The authors of Pike *et al.* (2010a) considered this the best estimate for 2007 because a lack of duplicated data for the less effective observer resulted in a larger variance when that observer was included. For the 2009 survey, the best MR model for the right side duplicate data included only radial distance as a covariate and resulted in an estimated $p(0)$ of 0.55 (CV=0.10) for the primary platform. The corrected total estimate was 9,588 (95% CI 5,274, 14,420). The best available estimate of abundance for 2007 was 48% of that for 2001. Abundance in 2009 remains the lowest yet seen in all areas, just 46% of

that observed in 2007 and 22% of that estimated in 2001. It is uncertain what part the wider detection distances realised during this survey had in this.

The sub-committee noted the abundance estimates and anticipated considering these estimates formally during the upcoming *Implementation Review*.

3.3.2 Recommendations and work plan

The sub-committee **agreed** that it will review the above as well as any new abundance estimates and start to prepare for the 2014 *Implementation Review*.

3.4 Work plan

The sub-committee **agreed** that its work plan before and during the 2012 Annual Meeting would be as follows.

- (1) Prepare for the 2013 *Implementation Review* for the western North Pacific Bryde's whales (Item 3.1).
- (2) Allison and Punt to examine whether and when the optimisation method used when conditioning trials fails to find the actual minimum of the objective function and any implications of this for previous results of *Implementation Simulation Trials* (Item 3.2.1).
- (3) Review a revised research proposal for North Atlantic fin whales for the 'variant with research' to be submitted to the 2012 meeting.
- (4) Prepare for the 2014 *Implementation Review* for North Atlantic minke whales¹.
- (5) Prepare for the 2014 *Implementation Review* for North Atlantic fin whales.
- (6) Review a proposal for a *pre-Implementation assessment* of North Atlantic sei whales.

4. OTHER BUSINESS

The sub-committee noted that abundance estimates are used in three ways in the RMP and the AWMP: (1) for use when conditioning *Implementation Simulation Trials*, i.e. when estimating the parameters of the operating model; (2) when applying the RMP within *Implementation Simulation Trials*; and (3) when applying the RMP in actuality. There is a need for a single list of all abundance estimates for stocks for which management advice is needed which need to be annotated by how they can be used (including 'do not use'). Donovan agreed to produce an initial list of abundance estimates and what their status is given past decisions by the Scientific Committee, which would then be checked, possibility modified, and approved by the respective sub-committees and Working Groups during next year's meeting.

At the start of the meeting Víkingsson had requested that the sub-committee discuss a proposal to initiate a *pre-Implementation* of North Atlantic sei whales, as there had not been time to discuss it during last year's meeting. However, this item was not included on the sub-committee's work plan for this year and there was insufficient time to discuss this issue at this meeting.

5. ADOPTION OF REPORT

The report was adopted at 11:00 on 8 June 2011. The sub-committee thanked Bannister for his excellent chairmanship and the rapporteur for his unstintingly dedicated work.

¹The Scientific Committee has agreed that as the original *Implementation* was undertaken in 1993 before the Requirements and Guidelines for *Implementations* were developed, a fuller *Implementation Review* than those completed in 2003 and 2008 was appropriate.

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Appendix 1

AGENDA

1. Introductory items
 - 1.1 Convenor's opening remarks
 - 1.2 Election of Chair, appointment of rapporteurs
 - 1.3 Adoption of agenda
 - 1.4 Available documents
2. Revised Management Procedure (RMP) – general issues
 - 2.1 Review MSY rates
 - 2.1.1 Progress on intersessional work
 - 2.1.2 Other issues
 - 2.1.3 Conclusion
 - 2.2 Finalise the approach for evaluating proposed amendments to the *CLA*
 - 2.3 Evaluate the Norwegian proposal for amending the *CLA*
 - 2.4 Relationship between phase-out rule and abundance estimates based on multi-year surveys
 - 2.5 Modify the 'CatchLimit' program to allow variance-covariance matrices
 - 2.6 Update guidelines for conducting surveys and *Implementations*
 - 2.6.1 Consideration of line transect methodology
 - 2.6.2 Updated guidelines
- 2.7 Work plan
3. RMP – Preparations for *Implementation*
 - 3.1 Western North Pacific Bryde's whales
 - 3.1.1 Consideration of research proposal associated with variant 2
 - 3.1.2 Summary of agreed abundance estimates
 - 3.1.3 Recommendations and work plan
 - 3.2 North Atlantic fin whales
 - 3.2.1 Consideration of research proposal associated with variant 2
 - 3.2.2 Abundance estimates for use in the *CLA*
 - 3.2.3 Other
 - 3.2.3 Recommendations and work plan
 - 3.3 North Atlantic minke whales
 - 3.3.1 Review new abundance estimates
 - 3.3.2 Recommendations and work plan
 - 3.4 Work plan
4. Other business
5. Adoption of report

Appendix 2

COMPARISON OF THREE APPROACHES FOR THE META-ANALYSIS OF ENVIRONMENTAL VARIABILITY AND AUTO-CORRELATION IN REPRODUCTIVE RATES OF BALEEN WHALES

J. R. Brandon, D.S. Butterworth, J.G. Cooke, T. Kitakado, J. Moore and A.E. Punt

A small working group, comprised of the authors, was assigned the task of evaluating the extent of agreement between the approaches presented in SC/63/RMP20 and SC/63/RMP30. Several differences between these approaches were noted as described under the discussions of the sub-committee.

Following this discussion, a reanalysis was requested by the sub-committee using only the subset of time series available for those stocks with estimates of annual calving rates. The comparative analysis also involved agreement between the likelihood functions as well as model structure between the different approaches. The goal of this reanalysis was to provide an assessment of the sensitivity of the resulting estimates to the apparent differences in the underlying hierarchical parameterisation (i.e. the approaches

taken to account for correlations between parameters shared across stocks) between the modeling approaches. The time series chosen for the comparative analysis are listed in Table 1.

Table 1
Stocks used for comparative runs of the three analysis methods (SC/63/RMP20 and SC/63/RMP30).

| Species | Stock | Likelihood | Start | End | Points |
|----------|-----------------------|------------|-------|------|--------|
| Humpback | Gulf of Maine | Binomial | 1979 | 2005 | 27 |
| Humpback | Gulf of St Lawrence | Binomial | 1983 | 2009 | 25 |
| Humpback | SE Alaska | Binomial | 1977 | 2008 | 32 |
| Gray | Eastern North Pacific | LogNormal | 1994 | 2007 | 6 |
| Right | NW Atlantic | Binomial | 1981 | 2009 | 29 |

Table 2
Stocks used for application of the method specified in SC/63/RMP20.

| Species | Stock | Type | Notes | Likelihood | Start | End | Points |
|----------|-----------------------|--------------------|---------------------------------|------------|-------|------|--------|
| Blue | Gulf of California | Calving proportion | For known rep. females | Binomial | 1986 | 2009 | 18 |
| Bowhead | B-C-B | Calving proportion | As fraction of total stock | Normal | 1985 | 2004 | 8 |
| Fin | Gulf of St Lawrence | Calf count | - | Poisson | 1983 | 2009 | 27 |
| Gray | Eastern North Pacific | Calf ratio | Ratio est. calves/est. 1+ stock | LogNormal | 1994 | 2007 | 6 |
| Humpback | Gulf of Maine | Calving proportion | For known rep. females | Binomial | 1979 | 2005 | 27 |
| Humpback | Gulf of St Lawrence | Calving proportion | For known rep. females | Binomial | 1983 | 2009 | 25 |
| Humpback | SE Alaska | Calving proportion | For known rep. females | Binomial | 1975 | 2008 | 34 |
| Right | SE Atlantic | Calf count | - | Poisson | 1979 | 2006 | 28 |
| Right | SW Atlantic | Calf count | - | Poisson | 1971 | 2008 | 38 |
| Right | N Atlantic | Calving proportion | For known rep. females | Binomial | 1981 | 2009 | 29 |

Table 3
Percentiles of the posterior distributions of σ and ρ .

| Parameter | Species | Stock | Percentiles | | | | | | | | | | |
|-----------|----------|-----------------------|-------------|--------|--------|--------|--------|--------|--------|-------|-------|-------|-------|
| | | | 1 | 2.5 | 5 | 10 | 25 | 50 | 75 | 80 | 95 | 97.5 | 99 |
| σ | Blue | Gulf of California | 0.020 | 0.037 | 0.056 | 0.093 | 0.188 | 0.380 | 0.607 | 0.857 | 1.028 | 1.183 | 1.386 |
| | Bowhead | B-C-B | 0.578 | 0.618 | 0.663 | 0.721 | 0.835 | 0.995 | 1.189 | 1.413 | 1.555 | 1.668 | 1.778 |
| | Fin | Gulf of St Lawrence | 0.034 | 0.069 | 0.125 | 0.235 | 0.455 | 0.765 | 1.088 | 1.363 | 1.532 | 1.662 | 1.800 |
| | Gray | Eastern North Pacific | 0.013 | 0.027 | 0.044 | 0.079 | 0.174 | 0.378 | 0.727 | 1.199 | 1.440 | 1.626 | 1.786 |
| | Humpback | Gulf of Maine | 0.044 | 0.072 | 0.094 | 0.117 | 0.161 | 0.209 | 0.264 | 0.330 | 0.379 | 0.423 | 0.515 |
| | Humpback | Gulf of St Lawrence | 0.020 | 0.037 | 0.060 | 0.092 | 0.175 | 0.294 | 0.427 | 0.566 | 0.668 | 0.748 | 0.869 |
| | Humpback | SE Alaska | 0.006 | 0.012 | 0.019 | 0.034 | 0.075 | 0.135 | 0.214 | 0.309 | 0.398 | 0.489 | 0.636 |
| | Right | SE Atlantic | 0.002 | 0.004 | 0.006 | 0.011 | 0.023 | 0.042 | 0.068 | 0.100 | 0.136 | 0.205 | 0.395 |
| | Right | SW Atlantic | 0.213 | 0.226 | 0.237 | 0.251 | 0.277 | 0.308 | 0.344 | 0.383 | 0.408 | 0.435 | 0.469 |
| | Right | N Atlantic | 0.143 | 0.179 | 0.208 | 0.241 | 0.298 | 0.366 | 0.444 | 0.532 | 0.599 | 0.667 | 0.761 |
| | Generic | | 0.010 | 0.027 | 0.045 | 0.077 | 0.179 | 0.371 | 0.710 | 1.100 | 1.340 | 1.561 | 1.737 |
| ρ | Blue | Gulf of California | -0.941 | -0.902 | -0.860 | -0.790 | -0.575 | -0.181 | 0.291 | 0.646 | 0.818 | 0.906 | 0.961 |
| | Bowhead | B-C-B | -0.672 | -0.566 | -0.472 | -0.373 | -0.167 | 0.065 | 0.309 | 0.509 | 0.602 | 0.672 | 0.748 |
| | Fin | Gulf of St Lawrence | -0.737 | -0.569 | -0.351 | -0.117 | 0.281 | 0.636 | 0.800 | 0.882 | 0.914 | 0.936 | 0.956 |
| | Gray | Eastern North Pacific | -0.934 | -0.862 | -0.772 | -0.627 | -0.312 | 0.093 | 0.458 | 0.714 | 0.838 | 0.925 | 0.971 |
| | Humpback | Gulf of Maine | -0.952 | -0.924 | -0.888 | -0.825 | -0.677 | -0.412 | -0.054 | 0.225 | 0.389 | 0.516 | 0.634 |
| | Humpback | Gulf of St Lawrence | -0.940 | -0.887 | -0.799 | -0.674 | -0.414 | -0.002 | 0.440 | 0.727 | 0.838 | 0.910 | 0.959 |
| | Humpback | SE Alaska | -0.943 | -0.861 | -0.702 | -0.473 | -0.119 | 0.320 | 0.729 | 0.904 | 0.948 | 0.972 | 0.986 |
| | Right | SE Atlantic | -0.895 | -0.783 | -0.642 | -0.481 | -0.169 | 0.169 | 0.575 | 0.898 | 0.966 | 0.990 | 0.998 |
| | Right | SW Atlantic | -0.546 | -0.478 | -0.417 | -0.339 | -0.220 | -0.074 | 0.074 | 0.222 | 0.315 | 0.396 | 0.514 |
| | Right | N Atlantic | -0.746 | -0.526 | -0.380 | -0.237 | -0.027 | 0.195 | 0.409 | 0.593 | 0.683 | 0.758 | 0.839 |
| | Generic | | -0.953 | -0.895 | -0.807 | -0.656 | -0.307 | 0.076 | 0.421 | 0.696 | 0.816 | 0.881 | 0.945 |

Upon re-analysis, the results of the alternative approaches were found to be in agreement and it was therefore concluded that the different approaches were all compatible for the purposes of this study. The framework developed in SC/63/RMP20 was most easily able to analyse the larger set of available data during the timeline of the meeting, and this approach was therefore adopted for that task.

The sub-committee agreed to utilise calving proportion data where available, and otherwise use raw calf counts. The sub-committee agreed not to use calving interval data because these would require an explicit model of the calving cycle in order to relate them at annual variability. Table 2 lists the time series used in the final analysis. The analysis

method of SC/63/RMP20 was applied. The purpose was to provide stock-specific and generic posterior distributions for σ and ρ for use in the analysis proposed in Appendix 3.

The exponential model for variability was used, because this corresponds to the definition of process variance σ that is used in the analysis proposed in Appendix 3.

The posterior distributions of inter-annual variability, σ , and the serial correlation coefficient, ρ , were generated for each of the stocks listed in Table 2, and also for a generic stock (i.e. stocks for which there are no stock-specific data) using the procedure described in SC/63/RMP20. Figs 1-2 a-k show the resulting posterior distributions for σ and ρ respectively. Table 3 lists some percentiles of the posterior distributions.

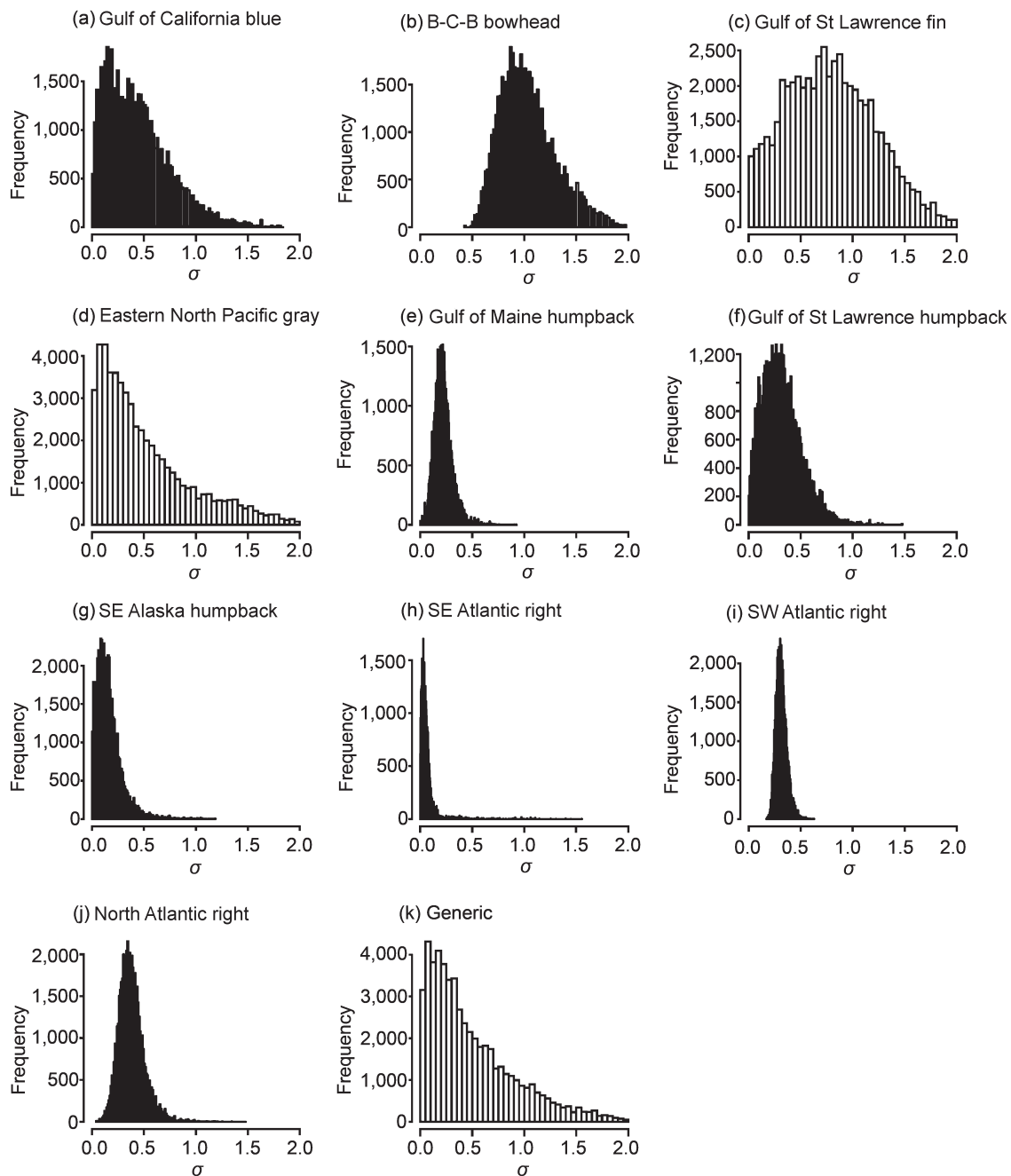
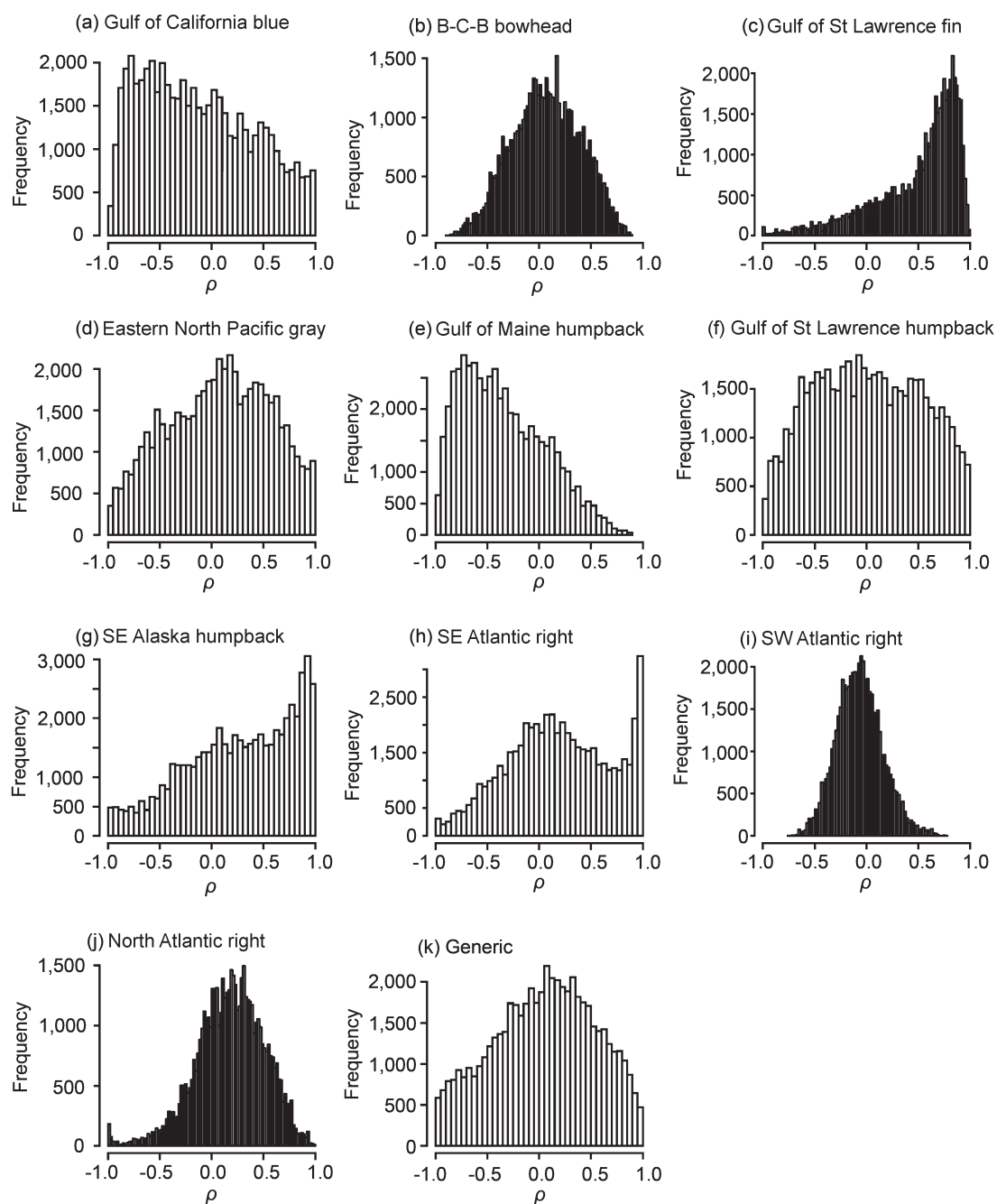


Fig. 1. Posteriors for σ .

Fig. 2. Posteriors for ρ .

Appendix 3

AN INITIAL ATTEMPT TO DERIVE A POSTERIOR FOR THE RATE OF THE INCREASE FOR AN UNKNOWN STOCK

André E. Punt

Specification of data

The data on which the meta-analysis calculations are based are listed in Table 1. There is no value for the number of years on which the rate of increase for Gulf of Maine humpbacks is based so it was set to the median across the stocks. Table 2 lists the values for the parameters of the population dynamics model (Adjunct A). Biological parameter values were not [immediately] available for all stocks and so values were shared among stocks. Similarly, values for $\tilde{\sigma}_f$ and $\tilde{\rho}^f$ were not available from the meta-analysis of calf counts and calving rates for all stocks. Where possible, values for $\tilde{\sigma}_f$ and $\tilde{\rho}^f$ were assigned to stocks based on values for these parameters for other species. The values for $\tilde{\sigma}_f$ and $\tilde{\rho}^f$ are the medians from the results of the meta-analysis.

Derivation of variation and temporal correlation in the intrinsic rate of growth

The distribution for the annual rate of increase is determined by projecting a population ahead in the absence of density-dependence and recording the mean, standard deviation, CV and lag-1 autocorrelation over years 200-2,000 for \tilde{r}_y . These four statistics are also recorded for the 'raw' calving rate $N_{y,0} / N_y^m$. Previous analyses have shown that the standard deviation and temporal auto-correlation in the raw calving rate will not match the pre-specified values for these quantities ($\tilde{\sigma}_f$ and $\tilde{\rho}^f$ in Table 2) if the values for σ_f and ρ^f are set to $\tilde{\sigma}_f$ and $\tilde{\rho}^f$. This occurs because of the constraints imposed by the population dynamics model (i.e. the calving rate for females which did not give birth the previous year cannot exceed 1, and females cannot give birth in consecutive years). Consequently, the values for σ_f and ρ^f are adjusted ('tuned') until the model-predicted standard deviation and temporal auto-correlation of the raw calving rates matches the pre-specified values.

Table 3 lists the values for σ_f and ρ^f derived from this analysis. It was not feasible to find values for σ_f and ρ^f which matched the values $\tilde{\sigma}_f$ and $\tilde{\rho}^f$ when natural mortality was perfectly negatively correlated with reproductive rate in several cases (Eqn A.4; Table 3). Therefore the remaining analyses of the document are based on the case in which survival is constant only.

Computation of a probability distribution for $r_0^{\text{true}}/r_{\text{max}}$

The algorithm for computing a probability distribution for $r_0^{\text{true}}/r_{\text{max}}$ is given in Adjunct B. The first step in the process is to compute a relationship between $E(r^{\text{real}})$ and $\text{Var}(r^{\text{real}})$ and r_{max} and $\chi = r_0^{\text{true}}/r_{\text{max}}$ based on the dynamics model underlying Cooke's earlier analyses (Equations B.1 and B.2). As expected, the r^2 for the fit was ~ 1 as it is primary a way to interpolate.

Given the relationships which account for environmental variation and the data in Table 1, the Bayesian meta-analysis leads to a posterior predictive distribution for the value of $r_0^{\text{true}}/r_{\text{max}}$ for an unknown stock (see Fig. 1). The lower percentiles for this distribution are:

| 1% | 2% | 5% | 10% | 25% | 50% |
|---------|---------|---------|---------|---------|---------|
| 0.36183 | 0.45395 | 0.59234 | 0.70183 | 0.84563 | 0.94107 |

Table 1

Estimates of r_0 selected by IWC (2010) and the associated time periods over which they were estimated.

| | r_0 (%) (95% CI) | SE | Time period | No. years |
|-----------------------------|--------------------|-------------------|-----------------|-----------------|
| Blue whale | | | | |
| Central N Atlantic | 9.0 (2.0, 17.0) | 3.83 ^a | 1987-2001 | 15 |
| S Hemisphere | 8.2 (1.6, 14.8) | 3.37 ^a | 1978/78-2003/04 | 26 |
| EN Pacific | 3.2 | 1.4 | 1991-2005 | 16 |
| Fin whale | | | | |
| N Norway | 5 (-13, 26) | 9.95 ^a | 1998-98 | 11 |
| EN Pacific | 4.8 (-1.6, 11.1) | 3.24 ^a | 1987-2003 | 15 |
| Humpback whale | | | | |
| W Australia | 10.1 (0.9, 19.3) | 4.69 ^a | 1982-94 | 13 |
| E Australia | 10.9 (10.5, 11.4) | 0.23 ^a | 1984-2007 | 24 |
| EN Pacific | 6.4 | 0.9 | 1992-2003 | 12 |
| Hawaii | 10 (3-16) | 3.32 ^a | 1993-2000 | 18 |
| Gulf of Maine | 6.3 | 1.2 | N/A | 18 ^c |
| Gray whale | | | | |
| Western | 2.9 (1.9, 4.0) | 0.54 ^b | 1994-2006 | 23 |
| Bowhead whale | | | | |
| B-C-B | 3.9 (2.2, 5.5) | 0.84 ^b | 1978-2001 | 24 |
| Southern right whale | | | | |
| SE Atlantic | 7.3 (6.6, 7.9) | 0.33 ^a | 1971-2003 | 33 |
| SW Atlantic | 6.8 (5.8, 7.8) | 0.51 ^a | 1971-2000 | 30 |
| SE Indian | 8.10 (4.48-11.83) | 1.88 ^a | 1993-2006 | 14 |

^acomputed from the 95% confidence interval by dividing by 3.92;

^bcomputed from the 90% confidence interval by dividing by 3.28; ^cmedian of the number of years for the other stocks.

Table 2

Values for the parameters of the population dynamics model.

$\tilde{\sigma}_f$ and $\tilde{\rho}^f$ are respectively the values for the standard deviation and temporal auto-correlation in the data type concerned.

| | S | a_{max} | r_{max} | $\tilde{\sigma}_f$ | $\tilde{\rho}^f$ |
|--------------------------------------|-------|----------------------|------------------|--------------------|------------------|
| Blue whale | | | | | |
| Central North Atlantic ¹ | 0.975 | 10 ^{&} | 0.07 | 0.380 | -0.181 |
| Southern Hemisphere ¹ | 0.975 | 10 ^{&} | 0.07 | 0.380 | -0.181 |
| Eastern North Pacific ¹ | 0.975 | 10 ^{&} | 0.07 | 0.380 | -0.181 |
| Fin whale | | | | | |
| North Norway ^{2,3} | 0.95 | 5 | 0.07 | 0.765 | 0.636 |
| Eastern North Pacific ^{2,3} | 0.95 | 5 | 0.07 | 0.765 | 0.636 |
| Humpback whale | | | | | |
| Western Australia ⁴ | 0.97 | 10 | 0.06 | 0.135 | 0.320 |
| Eastern Australia ⁴ | 0.97 | 10 | 0.06 | 0.135 | 0.320 |
| Eastern North Pacific | 0.98* | 12 | 0.06 | 0.135 | 0.320 |
| Hawaii ⁴ | 0.97 | 10 | 0.06 | 0.135 | 0.320 |
| Gulf of Maine | 0.955 | 7 | 0.065 | 0.209 | -0.412 |
| Gray whale | | | | | |
| Western ⁵ | 0.98 | 7 | 0.06 | 0.378 | 0.093 |
| Bowhead whale | | | | | |
| Bering-Chukchi-Beaufort | 0.99 | 22 | 0.04 | 0.995 | 0.065 |
| Southern right whale | | | | | |
| SE Atlantic | 0.99 | 8 ^{&} | 0.073 | 0.042 | 0.169 |
| SW Atlantic | 0.98 | 9.1 ^{&} | 0.068 | 0.308 | -0.074 |
| SE Indian ⁶ | 0.99 | 8 | 0.073 | 0.042 | 0.169 |

[&]Values given in Table 2 in SC/63/Rep2 for a_m were rounded to nearest whole age and those given as x^+ were to set to age x .

*Increased from 0.97 (see SC/63/RMP3).

¹Set to the parameter for California blue whales.

²Placeholder values.

³ $\tilde{\sigma}_f$ and $\tilde{\rho}^f$ set based on those for Gulf of St Lawrence fin whales.

⁴Roughly average humpback values.

⁵Set to those for eastern north Pacific gray whales.

⁶Set to SW Atlantic right whales.

Table 3

Values for the parameters which determine variation and correlation in fecundity and the resulting CV and correlation of the rate of increase. Results are shown for cases in which survival is constant and which it is perfectly correlated with fecundity. Cases in which failure to converge are indicated by ampersands.

| | No variation in survival | | | | Perfect correlation between M and f | | | |
|--------------------------------------|--------------------------|----------|---------|-----------|---|----------|---------|-----------|
| | σ^f | ρ^f | $CV(r)$ | $\rho(r)$ | σ_f | ρ_f | $CV(r)$ | $\rho(r)$ |
| Blue whale | | | | | | | | |
| Central North Atlantic ¹ | 0.575 | 0.612 | 0.538 | -0.227 | 0.398 ^{&} | -0.181 | | |
| Southern Hemisphere ¹ | 0.575 | 0.612 | 0.538 | -0.227 | 0.398 ^{&} | -0.181 | | |
| Eastern North Pacific ¹ | 0.575 | 0.612 | 0.538 | -0.227 | 0.398 ^{&} | -0.181 | | |
| Fin whale | | | | | | | | |
| North Norway ^{2,3} | 1.35 | 0.928 | 3.642 | 0.573 | 0.807 ^{&} | 0.675 | | |
| Eastern North Pacific ^{2,3} | 1.35 | 0.928 | 3.642 | 0.573 | 0.807 ^{&} | 0.675 | | |
| Humpback whale | | | | | | | | |
| Western Australia ⁴ | 0.200 | 0.841 | 0.177 | 0.097 | 0.234 | 0.86 | 0.609 | 0.696 |
| Eastern Australia ⁴ | 0.200 | 0.841 | 0.177 | 0.097 | 0.234 | 0.86 | 0.609 | 0.696 |
| Eastern North Pacific | 0.186 | 0.803 | 0.161 | 0.142 | 0.243 | 0.845 | 0.674 | 0.664 |
| Hawaii ⁴ | 0.200 | 0.841 | 0.177 | 0.097 | 0.234 | 0.86 | 0.609 | 0.696 |
| Gulf of Maine | 0.234 | 0.422 | 0.353 | -0.468 | 0.678 ^{&} | -0.485 | | |
| Gray whale | | | | | | | | |
| Western ⁵ | 0.416 | 0.473 | 0.482 | 0.015 | 0.32 ^{&} | 0.066 | | |
| Bowhead whale | | | | | | | | |
| Bering-Chukchi-Beaufort | 1.333 | 0.539 | 1.354 | 0.049 | 0.995 ^{&} | 0.065 | | |
| Southern right whale | | | | | | | | |
| SE Atlantic | 0.048 | 0.539 | 0.045 | 0.065 | 0.048 | 0.54 | 0.053 | 0.194 |
| SW Atlantic | 0.378 | 0.54 | 0.389 | -0.142 | 0.432 | -0.06 | -2.349 | -0.029 |
| SE Indian ⁶ | 0.048 | 0.539 | 0.045 | 0.065 | 0.048 | 0.54 | 0.053 | 0.194 |

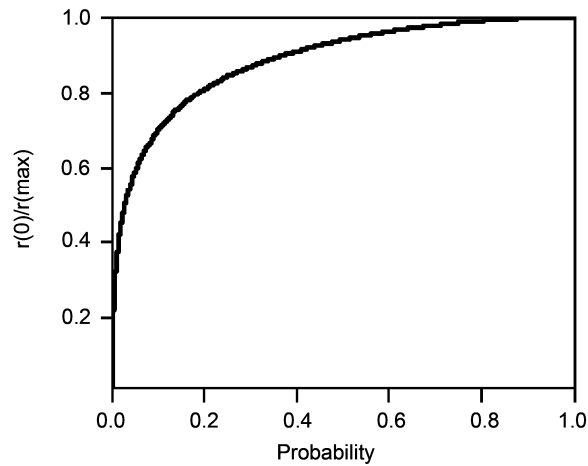


Fig. 1. Cumulative distribution for $r_0^{\text{true}}/r_{\text{max}}$ from the Bayesian meta-analysis.

REFERENCE

International Whaling Commission. 2010. Report of the Scientific Committee. Annex D. Report of the sub-committee on the Revised Management Procedure (RMP). *J. Cetacean Res. Manage (Suppl.)* 11(2): 114-34.

Adjunct A

Estimate the standard deviation and temporal autocorrelation in the rate of increase

The following population dynamics model forms the basis for the forecasts under different levels of variability in calving rate and survival:

$$N_{y,a} = \begin{cases} f_y (N_y^m - N_{y-1,0} S_{y-1}) & \text{if } a = 0 \\ N_{y-1,a-1} S_{y-1} & \text{if } 1 \leq a < x \\ (N_{y-1,x} + N_{y-1,x-1}) S_{y-1} & \text{if } a = x \end{cases} \quad (\text{A.1})$$

where $N_{y,a}$ is the number of animals of age a at the start of year y ,

N_y^m is the number of 'mature' females at the start of year y :

$$N_y^m = 0.5 \sum_{a=a_m}^x N_{y,a} \quad (\text{A.2})$$

f_y is the calving rate (number of calves per mature female which did not calf the previous year – this number of mature females is given by $N_y^m - N_{y-1}S_{y-1}$) during year y :

$$f_y = f e^{\varepsilon_y^f - \sigma_f^2/2} \quad \varepsilon_y^f = \rho^f \varepsilon_{y-1}^f + \sqrt{1 - (\rho^f)^2} \eta_y^f \quad \eta_y^f \sim N(0; \sigma_f^2)^1 \quad (\text{A.3})$$

f is the expected calving rate (in the absence of density-dependence),

ρ^f is the extent of auto-correlation in calving rate,

σ_f is the extent of variation in calving rate,

S_y is the survival rate during year y ($S_y = e^{-M_y}$):

$$M_y = \bar{M} - \varepsilon_y^f \quad (\text{A.4})$$

The population is projected ahead for 2,000 years, and the annual rate of increase, $\tilde{r}_y = \ln(N_y^m / N_{y-1}^m)$ is computed. The outcomes from this algorithm are the mean, standard deviation, CV and lag-1 autocorrelation over years 200-2,000 for \tilde{r}_y and the ‘raw’ calving rate $N_{y,0} / N_y^{m,2}$. The value for f in Equation A.3 is not pre-specified, but is rather chosen so that the deterministic rate of increase is equal to the pre-specified value for r_0 in Table 2.

Adjunct B

Estimating a posterior distribution for r_0 for an unknown stock

In the following \hat{r}_i is the estimate of the rate of increase for stock i , and σ_i is the (estimate of) the observation error standard deviation for \hat{r}_i . Let us first define $r_{0,i}^{true}$ as the expectation of the rate of increase for stock i at low stock size and $r_{\max,i}$ as the maximum demographically possible rate of increase for stock i (assumed to be known exactly). Now, $r_{0,i}^{true} / r_{\max,i} = \chi_i$ is assumed to be beta-distributed, i.e. $\chi_i \sim Be(\alpha, \beta)$,³ and \hat{r}_i is assumed to be distributed about a ‘realized’ rate of increase subject to observation error, i.e. $\hat{r}_i \sim r_i^{real} + v_i$ where $v_i \sim N(0; \sigma_i^2)$. The realised rate of increase is related to true rate of increase, accounting for process uncertainty caused by environmental variation, i.e. the distribution of $(1 + r_i^{real})^{n_i}$ is:

$$(1 + r_i^{real})^{n_i} = \prod_{y=1}^{n_i} \exp\{r_{\max,i} (1 - e^{-(\tau w_y - \tau^2/2)}) (1 - q_i)^z\} \quad (\text{B.1})$$

where n_i is the number of data points for stock i , $w_y = \rho w_{y-1} + \sqrt{1 - \rho^2} \varepsilon_y$, $\varepsilon_y \sim N(0; 1)$, ρ is the extent of auto-correlation in the environmental impact on r , and τ is the standard deviation for the environmental impact on r .

Now, given $q_i = (1 - (1 - \chi_i)^{1/z})$, z , ρ , and τ (assumed known) one can generate a distribution for $(1 + r_i^{real})^{n_i}$ numerically. For estimation purposes, the mean of r_i^{real} can be approximated using the formula:

$$E(r_i^{real}) = \alpha_1 r_{\max,i} + \alpha_2 \chi_i + \alpha_3 (r_{\max,i})^2 + \alpha_4 (\chi_i)^2 + \alpha_5 r_{\max,i} \chi_i + \alpha_6 (r_{\max,i})^2 \chi_i + \alpha_7 (\chi_i)^2 r_{\max,i} \quad (\text{B.2})$$

The standard deviation of r_i^{real} , $Var(r_i^{real})$ is approximated similarly.

The likelihood function is then:

$$L(D | \alpha, \beta) = \prod_i \int_0^1 \frac{\Gamma(\alpha, \beta)}{\Gamma(\alpha)\Gamma(\beta)} \chi_i^{\alpha-1} (1 - \chi_i)^{\beta-1} \frac{1}{\sqrt{2\pi\tilde{\sigma}_i}} e^{-[\hat{r}_i - E(r_i^{real})]^2 / (2\tilde{\sigma}_i^2)} d\chi_i \quad (\text{B.3})$$

where $\tilde{\sigma}_i^2 = \sigma_i^2 + Var(r_i^{real})$.

The integrals in Equation B.3 are evaluated numerically (in this case by applying the trapezoidal rule with 1,000 steps). The priors for α and β are assumed to be uniform, $U[0, 10]$.

¹Subject to the constraint that calving rate and annual survival cannot exceed 1 (if a generated value for the calving rate or survival exceeds 1, the value for η_y^f is generated again and this process repeated until the calving rate is less than 1).

²The raw calving rate was chosen for consistency with the approach used when analysing the data for the actual populations in Table 2.

³The beta distribution is selected here because it provides a flexible way to model bounded random variables.