Report of the Intersessional Workshop on MSYR for Baleen Whales

Contents

1. Introductory Items 2
1.1 Opening remarks 2
1.2 Election of Chair 2
1.3 Appointment of rapporteurs 2
1.4 Adoption of Agenda 2
1.5 Review of documents 2
2. Revision of tabulation of estimates for MSYR and abundance trends 2
2.1 Blue whale 2
2.2 Fin whale 3
2.5 Gray whale 3
2.6 Bowhead whale 4
2.7 Right whale 4
3. Meta-analysis of population trend information 9
4. Models of the effect of environmental variability on yield curves 9
5. Implications of information available on whale trajectories for deterministic density-dependent population models 14
6. Models to estimate MSYR and their limitations 15
6.1 Trends in abundance (as related to MSYR) 15
6.2 Population dynamics models and catch-at-age data 15
6.3 Changes in biological parameters 15
6.4 Maxima inferred from demographics 16
6.5 General limitations affecting more than one method 16
7. Progress for reviewing proposals to amend the RMP 16
8. Work Plan and Recommendations 17
8.1 Estimates of MSYR and Meta-analysis 17
8.2 Effects of environmental variability on yield curves 17
9. Adoption of report 17

The Workshop was held at the National Marine Mammal Laboratory, Alaska Fisheries Science Center, Seattle (6 February 2009), and at the School of Aquatic and Fishery Sciences, University of Washington Seattle (7-8 February 2009). The participants were Breiwick, Branch, Butterworth (convenor), Cooke, Donovan, Gunnlaugsson, Kitakado, Koski, Punt, Wade, and Walløe.

1. INTRODUCTORY ITEMS

1.1 Opening remarks

Butterworth (convenor) welcomed the participants. He noted that the primary aim of the Workshop was to continue progress made at the November 2007 Workshop and progress work such that decisions regarding MSYR for use in RMP trials can be made at the forthcoming Scientific Committee meeting.

1.2 Election of Chair

Donovan was elected as Chair.

1.3 Appointment of rapporteurs

Butterworth, Cooke and Punt acted as rapporteurs.

1.4 Adoption of Agenda

The adopted agenda is given as Annex A.

1.5 Review of documents

The documents available to the meeting were SC/F09/MSYR1-3, Cooke (2007) (SC/N07/MSYR1 revised), and relevant extracts from past reports (Annex B).

2. REVISION OF TABULATION OF ESTIMATES FOR MSYR AND ABUNDANCE TRENDS

The Workshop first reviewed the summary of information available relative to MSYR developed at the November 2007 Workshop (Table 1, International Whaling Commission, 2009), and revised this in the light of new information and further critical discussion.

Two broad changes were made to this Table:

It was agreed that the column related to reliability of estimates would refer only to the assumptions underlying treating the information concerned as providing an index of relative abundance, and not take account of the precision of the estimate. The different variances of the different estimates of trend are taken into account explicitly in the meta-analysis considered in item 3. Only estimates considered of high (H) reliability are used in this meta-analysis.

A column was added to the Table indicating whether estimates of trend referred to a period where the size of the population was considered "Low" (L), "Medium" (M) or "High" (H) relative to pre-exploitation abundance. These assignments were coarse, and were intended to indicate whether the population was below 0.33K, between 0.33K and 0.67K, or above 0.67K. The reason for this assignment was so that only trend information corresponding to populations at relatively low abundance (L) would be considered when making inferences about r_0, the population growth rate in the limit of population size approaching zero.

In making entries of trend estimates to the Table, no distinction was made between estimates of proportional increase over a year (conventionally denoted as λ-1) or instantaneous growth rates obtained from log-linear regressions against time (sometimes denoted as r). Strictly, the relationship between these two quantities is given by $e^r = \lambda - 1$ rather than $r = \lambda$, but for the small values concerned and the purpose of the overall exercise (bounding the plausible range for MSYR) the latter constituted an adequate approximation. Note further that some entries indicated Y in the column headed " If no, could they be?" refer to cases where data are available but have yet to be analysed to provide a numerical estimate. There are a number of such cases for the Northwest Pacific, but obtaining these trend estimates is not considered a high priority because they would have high variance because of small sample size.

Table 1 of this report incorporates all the adjustments and extensions agreed to the earlier table. These adjustments, with associated rationale where pertinent, are listed below.

2.1 Blue whale

North Atlantic – Central: The Pike *et al.* (2007) estimate was preferred for input to meta-analysis as it is based only on dedicated surveys, rather than on sightings collected during commercial whaling operations which might not provide an adequately random or systematic sample.

North Pacific – Eastern: Mark-recapture estimates of abundance are available for near-shore California from photo-identification studies. Calambokidis *et al.* (2007, table 5) provides estimates from a Jolly-Seber analysis for the years 1991-2005. A regression on the natural log of abundance (calculated at the workshop) results in an estimated rate of increase of 3.2% (SE 1.4%, 95%CI 0.2-6.1%). It was noted that higher estimates of abundance are available from mark-recapture and line-transect data from broader surveys for a much more limited number of years (Calambokidis and Barlow, 2004). The much longer time-series provides a more precise estimate of a rate of increase, but it was noted that these estimates refer only to whales using near-shore waters.

Southern Hemisphere – The Branch (2007) estimate was preferred for input to the meta-analysis because it is based only on dedicated surveys, without addition of sightings collected in conjunction with commercial operations. The CI differs from that reported earlier because of adjustments to incorporate additional variance.

2.2 Fin whale

Southern Hemisphere – Indian+Pacific: The JARPA survey results were designated of low reliability because these surveys covered only a limited portion of the latitudinal range of the population's austral summer distribution.

2.3 Bryde's whale

North Pacific – Western: The trend estimate given was replaced by that provided by Kitakado in SC/F09/MSYR2 based on improved methodology. This incorporated an increase rate parameter in the abundance estimation approach of (Kitakado *et al.*, 2008) based on surveys over the period 1988-2002 and incorporating additional variance.

2.4 Humpback whale

North Pacific – Eastern (California/Oregon/Washington feeding area):The eastern North Pacific stock migrates between Mexico/Central America in winter to California, Oregon, and Washington in summer. Mark-recapture estimates of abundance are available for near-shore California from photo-identification studies. Calambokidis *et al.* (2004, table 11) provides estimates from a Jolly-Seber analysis for the years for 1992-2002, using data from 1991-2003. A regression on the natural log of abundance (calculated at the workshop) results in an estimated rate of increase of 6.4% (SE 0.9%, 95%CI 4.3-8.4%). It was noted that these estimates refer only to whales using near-shore waters, but systematic surveys show that few humpback whales occur in offshore waters.

North Pacific – Hawaii: Mobley *et al.* (2001) estimated a trend of 7% per year (calculated as 6.6% with 95%CI -1.8%-15.1% at the workshop) for 1993-2000 using data from aerial surveys that were conducted in a consistent manner in four separate years across all of the Hawaiian Islands. Mizroch *et al.* (2004) estimated survival rates for Hawaiian humpback whales using mark-recapture methods, and a Pradel model fit to data from all islands of Hawaii for the years 1980-1996 resulted in an estimated rate of increase of 10% per year (95% C.I. of 3-16%). For shelf waters of the northern Gulf of Alaska, Zerbini *et al.* (2006) estimated an annual rate of increase for humpback whales from 1987-2003 of 6.6% (95% C.I. of 5.2-8.6%). All of these estimates are considered valid, but they refer areas that contain the same population of whales (two estimates are for Hawaii and the estimate for the Gulf of Alaska feeding area contains whales from Hawaii as well). Estimates from breeding areas were preferred given that the estimate for the Gulf of Alaska feeding area represents the trend of whales from multiple breeding areas (Hawaii, Revillagigedo, Mexico, and Asia). The estimate from Mizroch *et al.* (2004) is slightly more precise and is from an earlier period, so it was selected for use in the meta-analysis, and taken to refer to an Hawaii population.

Additional information comes from the SPLASH study in the North Pacific (2004-6). The abundance estimate for the total North Pacific represents an annual increase of 4.9% over the most complete estimate for the North Pacific from 1991-93. Similarly, comparisons of SPLASH abundance estimates for Hawaii to estimates from 1991-93 gave estimates of annual increase that ranged from 5.5 to 6.0% (Calambokidis *et al.*, 2008). No confidence limits were calculated for these rates of increase from SPLASH data.

Southern Hemisphere – BSA (Brazil): This estimate would not be used for further computations, pending a check of the appropriateness of the method used to calculate the associated confidence interval.

Southern Hemisphere – BSE (Eastern Australia): The original estimate was replaced by an update which took account of further surveys carried out using unchanged methodology (Noad *et al.*, 2008).

2.5 Gray whale

North Pacific – Western: Although an updated estimate is available, it was decided not to change the table entry as the newer estimate would need adjustment for human-related mortality.

North Pacific – Eastern: The eastern North Pacific population of gray whales has been monitored by a south-bound migration survey in central California since the late 1960s. Overall, the population showed an increasing trend for two decades and has since apparently fluctuated (Rugh *et al.*, 2005). It has been suggested that the population has approached its carrying capacity (Moore *et al.*, 2001), and analyses of the trend and catch data suggest the population is

currently above MSYL (Punt *et al.*, 2004; Wade, 2002). It was decided that the rate of increase from the first two decades of data would be appropriate to use, such as the estimate in Buckland *et al.* (1993). However, that estimate does not take account of the catches that occurred during that time period, and also does not include a parameter for additional variance, determined to be the appropriate way to analyze the data without over-estimating precision (Punt *et al.*, 2004; Wade, 2002). Therefore, the preferred analysis was an exponential model fit to the abundance data through 1988, including catches and a parameter for additional variance. This analysis was provided at the workshop (P. Wade, pers. commn), using methods documented in Wade (2002). The estimated annual rate of increase was 4.4% (SE 0.6%, 95% CI 3.1-5.6%).

2.6 Bowhead whale

Bering-Chukchi-Beaufort: The estimated rate of increase from censuses was adjusted to incorporate the impact of catches (Branch *et al.*, 2004)

2.7 Right whale

North Atlantic – Western: Fujiwara and Caswell (2001) provide an estimate of λ from photo-identification data for N. Atlantic right whales. The estimated lambda from Fujiwara and Caswell (2001) needs to be adjusted upwards for human-caused mortality. Knowlton and Kraus (2001) summarized mortality of North Atlantic right whales. From their Fig. 8, for the years 1985-99 there were 14 fatal mortalities and 9 possible fatal mortalities (as determined by observations of whales at sea that were struck by ships or entangled in fishing gear), for a total of possibly 23 whales that died from human causes. The minimum number of whales known to be alive was determined to be 263 in 1996 (IWC right whale workshop). Fujiwara and Caswell (2001) estimate a λ of 1.01 (1.00-1.02 95%CI) for the years 1985-1999. A population that grows at 1.01 with an abundance of 263 in 1996 will have an average population size of 253.3 for the years 1985-1999. 23 human-caused mortalities with an average population size of 253.3 results in a HCM rate of 0.60% per year. There were also 18 documented mortalities from natural or unknown causes during this time period. Knowlton and Kraus (2001) also calculate 84 presumed deaths during the time period from photo-identification data, using the criterion that a whale not seen for six years has died. This leads to a discovery rate of mortalities of 41/84=0.488, resulting in a multiplier of 2.05. Therefore, an observed human-caused mortality rate of 0.60% extrapolates to a rate of 1.23% per year, assuming an equal probability of discovery for whales that die from human or natural causes. This adjusts the estimated *r* from Fujiwara and Caswell (2001) up to 2.23% per year. Since 1999 calf production has increased in this population, and an abstract (by R. Pace) presented to the 2007 Marine Mammal Biennial contains an estimated annual rate of increase of 1.8% from the photo-identification data. It was noted that this estimate would be replaced once a manuscript is available for review a revised estimate.

Southern Hemisphere – South west Pacific: The original estimate was replaced by an update which took account of further surveys (Bannister, 2008).

Table 1 follows. Text continues on page 9.

Table 1

Summary of information available relative to MSYR discussions for stocks of baleen whales. A full discussion of stock structure was beyond the scope of the Workshop. The table below has followed Scientific Committee discussions where possible, although for some species/areas, stock structure has not been examined by the Scientific Committee for many years. For Southern Hemisphere baleen whales, where no recent Scientific Committee discussions/agreements have occurred, it was agreed to use ocean basins. Given problems of interpreting CPUE data as a simple index of abundance (IWC, 1989), uncritical analyses of such data to give trends are not included.

Species: 'Stock'	Trend information available	If no, could they be	Stock Status	Data available incl. time periods	Reliability of available estimates (see key)	References
Blue whale						
North Atlantic						
Western	N	Y		Photo-ID data available, but pertains to local population (in Gulf of St Lawrence)	(N/A)	Sears *et al.* (1990)
Central	5.2 (3.0,7.4)			1979-1988 (SPUE)	Sighting during whaling. Covers the season (M)	(Sigurjónsson and Gunnlaugsson, 1990))
	9.0 (2.0-17.0)		L	1987-2001 (DS)	(H)	(Pike *et al.*, 2007)
Eastern	N					
North Pacific						
Western	N	Y#		1998-present (DS)	(N/A)	Miyashita
Eastern	3.2 (0.2-6.1)		L	1991-2005 (MR)	(H)	Calambokidis *et al.* (2007)
Southern Hemisphere	7.3 (1.4-11.6)			1968//69-2001/02 (DS, SPUE,)	(M)	(Branch *et al.*, 2004)
	8.2 (1.6-14.8)		L	1978/79-2003/04 (DS)	(H)	(Branch, 2007)
Pacific	N					
Indian	N					
Atlantic	N					
Northern Indian Ocean						
Pygmy blue whale						
Various	N					
Fin whale						
North Atlantic						
Newfoundland-Labrador	N					
Nova Scotia	N					
East Greenland-Iceland	N					
Spain-Portugal-British Isles	N					
North Norway	5 (-13-+26)		L	1988-98 (DS)	(H)	(Vikingsson *et al.*, 2007)
North Pacific						
East China Sea	N					
Eastern	4.8(-1.6- +11.1)		L	1987-2003 (DS)	(U)	(Zerbini *et al.*, 2003) CI updated by Cooke.
Western	N	Y#		1998-present (DS)	(N/A)	Miyashita
Southern Hemisphere						
Pacific*	N					
Indian+Pacific* (Areas IV+V)	10.2 (4.8-15.6)		L	1995/96-2004/05 JARPA	Limited latitudinal coverage (L)	(Matsuoka *et al.*, 2006)
Atlantic	N					

Species: 'Stock'	Trend information available	If no, could they be	Stock Status	Data available incl. time periods	Reliability of available estimates (see key)	References
Sei whale						
North Atlantic	N					
Western (Nova Scotia)	N					
Central (Iceland-Denmark Strait)	N					
Eastern	N					
North Pacific						
Western	N	Y#		1998-present (DS)	(N/A)	Miyashita
Central	N					
Eastern						
Southern Hemisphere	N			1926/27-1977/78	(R)	(Horwood and Millward, 1987)
Pacific	N					
Indian	N					
Atlantic	N					
Bryde's whale						
North Atlantic	N					
Western	N					
Eastern	N					
North Pacific	N					
Western	4.1 (-3.0, 11.2)	Y	M	1988-2002 (DS)	(H)	Kitakado (2009)
East China Sea	N					
Eastern	N					
Southern Hemisphere						
South Atlantic	N					
South Indian Ocean	N					
South African inshore	N					
Solomon Islands	N					
Western South Pacific	N					
Eastern South Pacific	N					
Peruvian	N					
Northern Indian Ocean	N					
Antarctic minke whale						
Indian	N					
Pacific	N					
Common minke whale						
North Atlantic						
Northeastern	N					
Central	N					
Western	N					

Species: 'Stock'	Trend information available	If no, could they be	Stock Status	Data available incl. time periods	Reliability of available estimates (see key)	References
North Pacific						
Western NP ('inshore')	N					
'offshore'						
'J' Stock	N					
Eastern ('remainder')	N					
Southern Hemisphere (dwarf)	N					
Humpback whale						
*North Atlantic***						
Western North Atlantic (Caribbean BS)	3.1 (SE 0.5)		M/H	1979-93 (MR)	(H)	(Stevick *et al.*, 2003)
Eastern North Atlantic (?Cape Verde BS)	N					
North Pacific						
Eastern	6.4 (4.3-8.4)		L	1991-2003 (DS)	(H)	(Calambokidis and Barlow, 2004; Calambokidis *et al.*, 2004); Wade (pers. commn)
Hawaii	6.6 (-1.8, 15.1)			1993-2000 (DS)	(R)	(Mobley *et al.*, 2001) Wade (pers. commn)
	10.0 (3.0-16.0)		L	1980-1996 (MR)	(H)	Mizroch et al. (2004)
Western	N	Y[#]		1998-present	(N/A)	Miyashita
Southern Hemisphere						
BSA (Brazil)	7.4 (0.6-14.5)	Calculation to be checked	L	1995-1998 (SPUE)	Index based on SPUE (M)	(Ward *et al.*, 2006)
BSB (West Africa)	N					
BSC (East Africa)	12.1 (7.1-17.1)	Y	M/H	1988-2002 (DS)	(H)	(Findlay and Best, 2006)
BSD (Western Australia)	10.1 (0.9-19.3)		L	1982-1994 (DS)	(H)	(Bannister and Hedley, 2001)
BSE (Eastern Australia)	10.9 (10.5-11.4)		L	1984-2007 (DS)	(H)	(Noad *et al.*, 2006)
BSF (Oceania)	N					
BSG (Ecuador)	N					
Antarctic (feeding)	9.6 (5.8-13.4)			1978/79-2003/04 (IDCR/SOWER)	(H)	Branch (in press)
Northern Indian Ocean	N					
Gray whale						
North Pacific						
Western gray whale	2.9 (90% 1.9 -4.0)		L	1994-2006 (MR)	(H)	(Cooke *et al.*, 2007)

Species: 'Stock'	Trend information available	If no, could they be	Stock Status	Data available incl. time periods	Reliability of available estimates (see key)	References
Eastern gray whale	1.86 (SE 0.32)		M/H	1967/68 - 2001/02 (DS)	(H)	(Punt *et al.*, 2004; Rugh *et al.*, 2005)
	4.89 (SE 0.44)			1967/68 – 1987/88 (DS)	(H)	Buckland *et al.* (1993)a Includes effect of catches estimated at 1.6 (Branch *et al.,* 2004)
	4.4 (3.1-5.6)			1967/68 – 1987/88 (DS)	(H)	Wade (pers. commn)
Bowhead whale						
Bering-Chukchi-Beaufort	3.9 (2.2-5.5)		M	1978-2001 (census)	(H)	(Zeh and Punt, 2005) Includes effect of catches estimated at 0.5 (Branch *et al.,* 2004)
Spitzbergen	N					
Eastern Canada- W. Greenland	N					
Sea of Okhotsk	N					
North Atlantic right whale						
Western	2.23 (1.23-3.23)		L	1980-1995, photo-id	(H)	Fujiwara *and Caswell* (2001) Includes effect of human –effected mortalities estimated at 1.23 (Wade, pers commn) Pace
	1.8 (No CI)			1990-2003, photo-id	(R)	
Eastern	N					
North Pacific right whale						
Western	N	Y#		1998-present	(N/A)	Miyashita
Eastern	N					
Southern right whale						
SE Atlantic	7.3 (6.6-7.9)		L	1971-2003 (DS)	(H)	(Best *et al.*, 2005)
SW Atlantic	6.8 (5.8-7.8)		L	1971-2000 (MR)	(H)	(Cooke *et al.*, 2003)
SE Pacific	N					
SE Indian	8.10 (4.48-11.83)		L	1993-2006 (DS)	(H)	Bannister (2008)

***Key** Reliability of available estimates: H=high; M=medium; L=low; U=uninformative; R=reject Data: SPUE Sighting-per-unit-effort. # Low priority as CI will be large.

3. META-ANALYSIS OF POPULATION TREND INFORMATION

SC/F09/MSYR1 outlined a Bayesian approach for conducting a meta-analysis for the rate of increase in the limit of zero population size, r_0, with the latter expressed in terms of total population size. The approach leads to a distribution for the rate of increase for an "unknown stock" (a stock that is not included in the set of stocks used to the fit the model) as well as the distributions for the stocks included in the analysis. SC/F09/MSYR1 applied the approach to data for a subset of the stocks for which rates of increase are reported in Table 1 of IWC (2009a).

It was noted that SC/F09/MSYR1 adopted a Bayesian approach to meta-analysis and that alternative approaches could also be used to estimate the population mean and between-population standard deviation for r_0. Annex C summarizes the results of the application of a linear mixed effects model to the data on which the analyses of SC/F09/MSYR1 were based. The Workshop **agreed** that the results in Annex C were sufficiently similar to those in (Cooke, 2007)that the analyses to be discussed at the 2009 meeting of the Scientific Committee could be based on the approach of Cooke (2007) only.

A key assumption of the meta-analysis approach in SC/F09/MSYR1 and Annex C is that the stocks are interchangable, i.e. they are a random subset of stocks. Best (1993) examined 44 stocks which were severely depleted and found that was not feasible to monitor 18 of them, and another 16 were not being monitored. Best (1993) stated that the reasons for not monitoring these 16 stocks did not seem to be related to population size, but may reflect practical difficulties obtaining representative samples due to temporal or spatial segregation in relation to the study area. However, there are other reasons why the stocks included in SC/F09/MSYR1 may be unrepresentative. For example, it was noted that stocks which are generally found in low densities even at high stock size should *a priori* exhibit low productivity, essentially because the extent to which prey could be released due to a reduction in stock size is likely to be low for such stocks. However, it was also noted the same stocks may be in low densities at some times of the year / life, but be quite concentrated at others. The Workshop **agreed** that while it was likely that there are many ways in which the assumption of interchangability might be violated, it was hard to decide how and when based simply on biological considerations. It therefore **agreed** that the sensitivity of the results from the meta-analysis to ignoring the data for each species should be examined once the data are finalized as this would provide one manner in which to examine the impact of violation of the assumption of interchangability.

The effects of non-representativeness by stock within species could be addressed by implementing a two-level hierarchical model. It was noted that the number of stocks for each species is low which could lead to numerical stability problems for the Bayesian approach. Moreover, results in Annex C indicate that the data support a model in which there is a stock effect only over a model with a stock and species effect. The Workshop **agreed** that the meta-analysis should be based on a model in which there is between-stock variation in the rate of increase, but not between-species variation.

An implicit assumption of including a stock in the meta-analysis is that it was at a low fraction of its carrying capacity during most of the period when the data on which the estimate of r_0 is based were collected. The Workshop therefore **agreed** that only stocks which are roughly depleted to below 0.33K would be considered in future meta-analyses (see the annotations to Table 1).

Annex D summarizes the results of applying the Bayesian meta-analysis to the current estimates of increase rate.

4. MODELS OF THE EFFECT OF ENVIRONMENTAL VARIABILITY ON YIELD CURVES

Cooke (2007, revised) described a framework for incorporating environmental variability into models of the net recruitment rate and yield curves. The model distinguishes between r_{max}, the maximum rate of increase that a whale population can exhibit under good conditions, and r_0 the expected rate at which a real population in a given habitat increases at low population levels. r_{max} is assumed to be determined by biological factors such as the breeding cycle of the species. For stocks in good habitats at population levels well below K, the population increase rate is expected to be close to r_{max} most of the time and variability will be low. In lower quality habitats, or at stocks sizes close to K, growth rates are expected to be lower and more variable. Under the model, both K and r are related to habitat quality and are correlated. Also, the MSYL is predicted to be closer to 0.5K in low quality habitats even if a higher value is assumed for higher quality habitats. The model was used as the operating model to generate simulated scenarios of populations recovering from exploitation, to generate data to which the standard deterministic density-dependent model was fitted. Estimates of K and MSYR were generated for each replicate of each scenario. The results showed that estimates of MSYR tend to be positively biased especially for low true MSY rates in scenarios with high environmental variability. The main changes compared with the original previous version of the paper presented at the previous workshop were:

(1) Estimation of MSYL was abandoned because this parameter was not well estimated in any scenario; instead it was fixed at 0.6K when fitting the standard model.

(2) The model was fitted in each of two ways: (i) estimating the initial population level relative to K; (ii) assuming the population was at K at the start of the period with catches and using the historic catches. The positive bias in

estimates of MSYR tended to be smaller in the latter case. Simulations involving model selection showed that the positive bias in MSYR was greater when the model fitted (i.e. estimate N_0 vs. assume $N_0 = K$) was selected using AIC, than when $P_0 = K$ was assumed regardless of the data.

(3) The fitting process included an exhaustive grid search over r, K and N_0/K to identify possible multiple maxima in the likelihood, a phenomenon to which Butterworth and De Decker had drawn attention in correspondence. Because multiple maxima do indeed occur in some replicates, the model was fitted in two ways in each case using (a) the global maximum of the likelihood; and (b) the local maximum at the lowest value of r. The latter approach produced slightly lower median estimates of r and hence MSYR.

In discussion, it was noted that there was some positive bias in MSYR even in scenarios with only observation error, but that this might be expected in a non-linear model especially given the asymmetry of the fitted model: the fitted population trend can only be concave, because growth is assumed to slow as the population increases, while the observed data can show either a concave or a convex trend, simply due to random variation in the data. The greater bias when the initial population level is estimated could be explained by the fact that the observed data can by chance show a levelling off in population growth well below the true K.

Some of the bias was thought to be due to mismatch between the true and assumed MSYL. The MSYL in the estimation was fixed at 0.6K although the true value ranged from 0.5K to 0.6K depending on habitat quality. Kitakado presented some simulation results from a similar model which showed that the positive bias in MSYR was less when the true model always had MSYL=0.6K regardless of habitat quality, so that there was no mismatch between the true and assumed MSYL.

The Workshop **agreed** that scenarios should be examined where the true and assumed MSYL coincide, to eliminate the effect of this factor. However, fixing MSYL=0.6K required setting a low r_{max} (0.02) in low quality habitats. Such a low r_{max} was considered biologically unlikely and greatly restricted the scope for variability. The Workshop **agreed** to address the MSYL mismatch question by looking at the following scenarios:

(i) set both the true and assumed MSYL to 0.5K. In this case the yield curve is symmetrical and the MSYL is independent of habitat quality;

(ii) let MSYL depend on habitat quality as before, but provide the estimator with the true value for MSYL in each case.

There were some further differences between the results of the Kitakado and Cooke implementations, which the workshop could not resolve in the time available, in particular a difference in the distributions for the estimates of K. The Workshop **recommended** that the authors to try to resolve these in correspondence.

The Workshop examined some further runs where the population was depleted to 0.05K instead of 0.25K as used in Cooke (2007) (Annex E). The median bias was lower in this case for the 1%-*MSYR* scenarios compared with the 0.25K case, but higher for the 4% scenarios. The Workshop **agreed** to include this case in the standard list of scenarios in Table 2.

The Workshop examined some sample plots of trajectories resulting from the model (Figs 1 and 2). It was noted that a lack of fit to the deterministic model was evident in many simulations. The simulation results suggested that the bias in MSYR estimates was less when the model fit assuming $N_0=K$ was accepted regardless of lack of fit, but the Workshop considered it unrealistic that fits of the Pella-Tomlinson would be accepted that were at complete variance with the data, as for example in the case of eastern gray whales. Examination of the plots (e.g. Figs. 1 and 2) suggested that it would tend to be the fits with low estimates of MSYR that would be rejected. The Workshop **agreed** that examination of trajectories was important for understanding the properties of the model and estimators, and requested authors to bring model output to the 2009 Scientific Committee meeting so that plots such as Fig. 1 could be produced.

Plots of median recovery trajectories suggested that the effective true MSYR in the stochastic operating model might be higher than the nominal deterministic value (e.g. Fig. 1), and that this might account for some of the apparent bias. A definition of the true effective MSYR for the stochastic case had been developed in Punt (2008): the MSYR was defined as the constant fishing mortality rate that gave the highest long-term average yield. The Workshop **agreed** with this definition, and **recommended** that it should be computed for each scenario listed in Table 2.

Table 2 and Figs 1 and 2 follow. Text continues on page 13 .

Table 2
List of scenarios for testing MSYR estimation with environmental stochasticity

Scenario	Years of Catches	Gap years	Data years	Survey interval	CV	Depletion	Habitat quality	Env. var. Sigma	Env. corr. Rho	Calving interval	True MSYR	True Z	True MSYL	Assumed MSYL	Remarks
A1	50	0	30	5	0	0.25	0.1	0		1	0.011	2.39	0.509	0.6	Deterministic
A2	50	0	30	5	0	0.25	0.4	0		1	0.039	2.39	0.538	0.6	case
A3	50	0	30	5	0	0.25	0.9	0		1	0.067	2.39	0.589	0.6	
B1	50	0	30	5	0.2	0.25	0.1	0.5	0.5	1	0.011	2.39	0.509	0.6	Reference
B2	50	0	30	5	0.2	0.25	0.4	0.5	0.5	1	0.039	2.39	0.538	0.6	case
B3	50	0	30	5	0.2	0.25	0.9	0.5	0.5	1	0.067	2.39	0.589	0.6	
C1	50	0	30	2	0.2	0.25	0.1	0.5	0.5	1	0.011	2.39	0.509	0.6	Data rich
C2	50	0	30	2	0.2	0.25	0.4	0.5	0.5	1	0.039	2.39	0.538	0.6	(15 surveys)
C3	50	0	30	2	0.2	0.25	0.9	0.5	0.5	1	0.067	2.39	0.589	0.6	
D1	50	20	10	2	0.2	0.25	0.1	0.5	0.5	1	0.011	2.39	0.509	0.6	Data poor
D2	50	20	10	2	0.2	0.25	0.4	0.5	0.5	1	0.039	2.39	0.538	0.6	(20-year gap)
D3	50	20	10	2	0.2	0.25	0.9	0.5	0.5	1	0.067	2.39	0.589	0.6	
E1	50	0	30	5	0.2	0.05	0.1	0.5	0.5	1	0.011	2.39	0.509	0.6	Depletion
E2	50	0	30	5	0.2	0.05	0.4	0.5	0.5	1	0.039	2.39	0.538	0.6	to 0.05*K;*
E3	50	0	30	5	0.2	0.05	0.9	0.5	0.5	1	0.067	2.39	0.589	0.6	standard data
F1	50	0	30	2	0.2	0.05	0.1	0.5	0.5	1	0.011	2.39	0.509	0.6	Depletion
F2	50	0	30	2	0.2	0.05	0.4	0.5	0.5	1	0.039	2.39	0.538	0.6	to 0.05*K;*
F3	50	0	30	2	0.2	0.05	0.9	0.5	0.5	1	0.067	2.39	0.589	0.6	data rich
G1	50	20	10	2	0.2	0.05	0.1	0.5	0.5	1	0.011	2.39	0.509	0.6	Depletion
G2	50	20	10	2	0.2	0.05	0.4	0.5	0.5	1	0.039	2.39	0.538	0.6	to 0.05*K;*
G3	50	20	30	2	0.2	0.05	0.9	0.5	0.5	1	0.067	2.39	0.589	0.6	data poor
H1	50	0	30	5	0.2	0.25	0.2	0.5	0.5	1	0.010	1	0.500	0.5	MSYL=0.5K
H2	50	0	30	5	0.2	0.25	0.8	0.5	0.5	1	0.040	1	0.500	0.5	symmetrical
J1	50	0	30	5	0.2	0.05	0.1	0.5	0.5	1	0.011	2.39	0.509	0.509	MSYL
J2	50	0	30	5	0.2	0.05	0.4	0.5	0.5	1	0.039	2.39	0.538	0.538	known
J3	50	0	30	5	0.2	0.05	0.9	0.5	0.5	1	0.067	2.39	0.589	0.589	
K1	50	0	30	5	0.2	0.25	0.1	0.0		1	0.011	2.39	0.509	0.6	No
K2	50	0	30	5	0.2	0.25	0.4	0.0		1	0.039	2.39	0.538	0.6	environmental
K3	50	0	30	5	0.2	0.25	0.9	0.0		1	0.067	2.39	0.589	0.6	variability
L1	50	0	30	5	0.2	0.05	0.1	1.0	0.5	1	0.011	2.39	0.509	0.509	High
L2	50	0	30	5	0.2	0.05	0.4	1.0	0.5	1	0.039	2.39	0.538	0.538	environmental
L3	50	0	30	5	0.2	0.05	0.9	1.0	0.5	1	0.067	2.39	0.589	0.589	variability
M1	50	0	30	5	0.2	0.25	0.1	0.5	0.9	1	0.011	2.39	0.509	0.6	High
M2	50	0	30	5	0.2	0.25	0.4	0.5	0.9	1	0.039	2.39	0.538	0.6	environmental
M3	50	0	30	5	0.2	0.25	0.9	0.5	0.9	1	0.067	2.39	0.589	0.6	correlation
N1	50	0	30	5	0.2	0.25	0.1	1.0	0.9	1	0.011	2.39	0.509	0.6	High variability
N2	50	0	30	5	0.2	0.25	0.4	1.0	0.9	1	0.039	2.39	0.538	0.6	and
N3	50	0	30	5	0.2	0.25	0.9	1.0	0.9	1	0.067	2.39	0.589	0.6	correlation
O1	50	0	30	5	0.2	0.25	0.1	0.5	0.5	3+	0.011	2.39	0.509	0.6	Explicit
O2	50	0	30	5	0.2	0.25	0.4	0.5	0.5	3+	0.039	2.39	0.538	0.6	calving
O3	50	0	30	5	0.2	0.25	0.9	0.5	0.5	3+	0.067	2.39	0.589	0.6	intervals

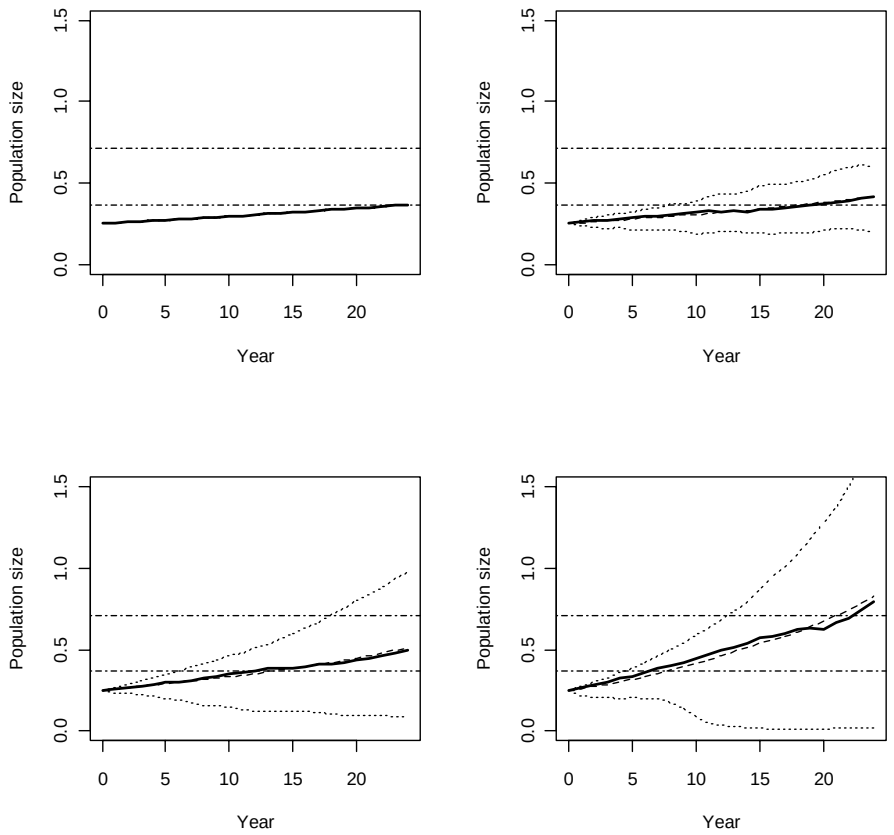

Fig. 1. Median (solid line), mean (dashed line) and 90% intervals (dotted lines) for the true population trajectory underlying the simulated data sets. The horizontal lines indicate the population size to which a population initially depleted to 0.25*K* would recover if MSYR=1.2% and 3.9% respectively.

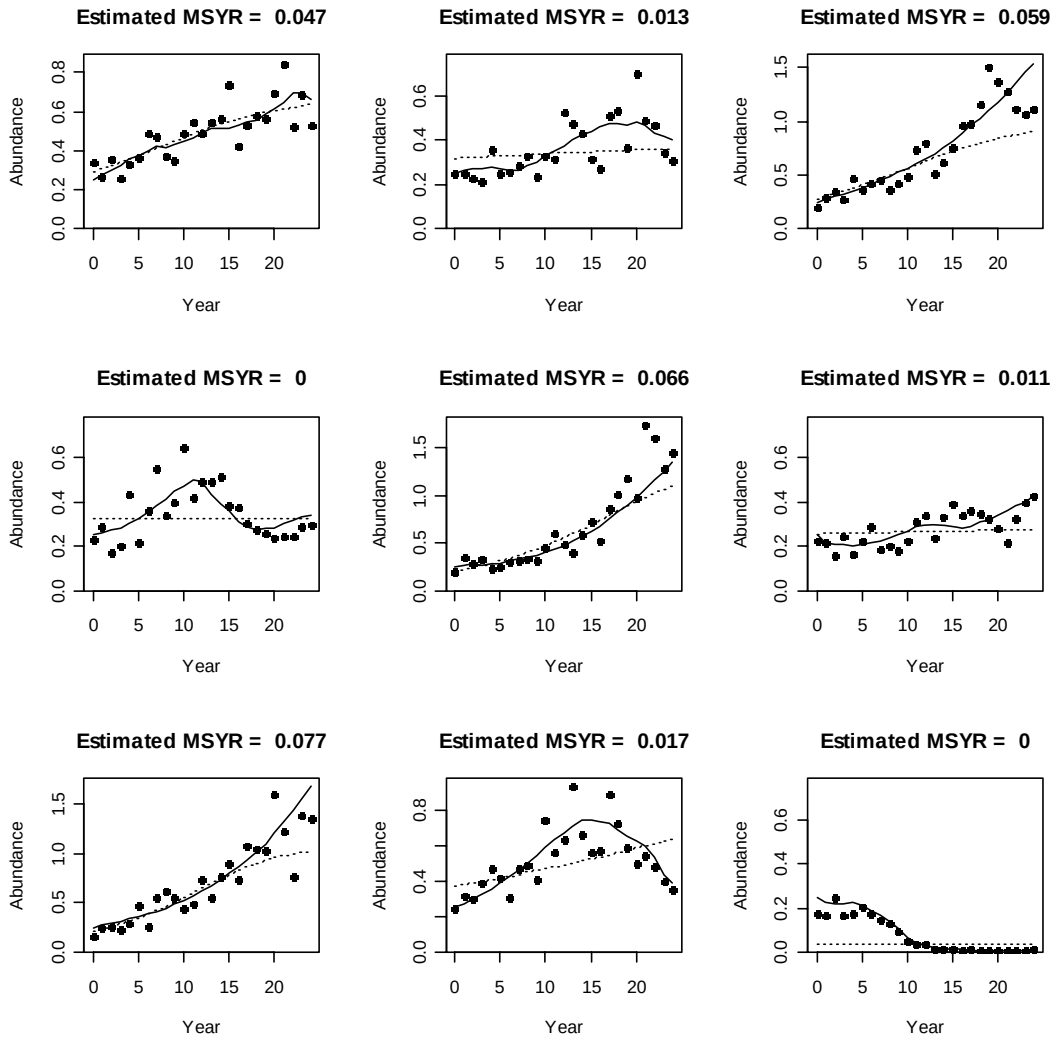

Fig. 2. Simulation results for nine simulated data sets. The solid lines are the true population trajectories, the dashed lines are the estimates thereof and the dots indicate the data generated by the operating model and used by the estimation model. Similar plots, but sorted by estimated MSYR, were also examined during the Workshop. These plots showed the four simulations closest to the lower 10th, median and upper 90% percentiles of the estimated MSYR values.

There was some discussion about what levels of environmental variability and correlation were realistic in the context of what is known about whales and other species. Data on right and bowhead whales show variability in calf production. The appropriate way to interpret these data is not from the raw calf counts, because a high calf year tends to be followed by a low calf year, because mothers of these species do not calve in successive years. The approach used by Leaper *et al.* (2006) is preferable: the annual deviation in calving probability, from the level that would be expected from the number of mothers that are ready to reproduce, is estimated; these deviations are then correlated with environmental factors. The Workshop **recommended** that all available data sets with information on recruitment variability in whales be analysed with respect to values of σ (environmental variability) and ρ (serial correlation).

The Workshop noted that while variability can be detected in some parameters, such as calving interval or calf production, variation in other parameters such as adult survival is harder to detect. The true extent of variance in net recruitment may be underestimated if it is assumed that only those parameters whose variation can be detected vary.

The conventional wisdom (e.g. (Eberhardt, 1985)) is that reproduction failure occurs when whales nutritionally stressed, but adults do not die. However, there is little evidential basis for this assumption, and recent experience, e.g. with eastern gray whales, suggests that there can also be mass mortalities of adults when food is scarce.

It was noted that some whale populations tend to increase at steady rates for relatively long periods, interspersed by sudden severe reductions, probably caused by two or more consecutive years of bad environmental conditions. The

Workshop noted that several abrupt declines in population size have only been observed at high population levels in whales. No case has been observed where a population at low levels has dropped substantially However, abrupt population reductions at low population levels may be more likely to go undetected.

The theoretical model of Cooke (2007) predicts that in high quality habitats, major reduction in population size will only occur at high population levels, but that in lower quality habitats such reductions can occur at any population level. Analyses of otariid populations (Gerber and Hilborn, 2001) has shown that the annual probability of a >50% decline in population size was less than 2%. In the case of whales a population is less likely to decline substanatially in a single year.

The Workshop **agreed** that the realism of scenarios be examined by recording the frequency of cases where the population declines by more than 50% in 5 years for different ranges of population size relative to *K*.

With regard to realistic values for the serial correlation in environmental conditions, it was suggested that the serial correlation in the abundance prey species such as krill and capelin be examined. The Workshop **agreed** that the values of 0.0, 0.5 and 1.0 for the environmental variability (σ) and 0.0, 0.5, and 0.9 for the serial correlation (ρ) be retained until more information on typical levels is available.

The Workshop further **agreed** that it would be useful to examine a case with an explicit multi-year calving cycle, such as 3+ years as for bowhead and right whales, to examine how the assumed levels of environmental variability would relate to variability in calf production. The calving probability could be assumed, for example, to depend on the stored energy accumulated since the previous calving.

It was also suggested that some alternative formulations to those used in Cooke (2007, revised) for modelling the relationship between environmental variability and net recruitment should be tried, such as mixed models but no specific proposals were made.

The Workshop **agreed** that the models developed in Cooke (2007) should be examined further, and compiled a list of scenarios (Table 2) for which results should be obtained before the next meeting.

5. IMPLICATIONS OF INFORMATION AVAILABLE ON WHALE TRAJECTORIES FOR DETERMINISTIC DENSITY-DEPENDENT POPULATION MODELS

SC/F09/MSYR3 examined the question of under what circumstances could the standard deterministic density-dependent model be tested using observations of recovering stocks. A test is possible only for stocks which have (i) been substantially reduced by past catches; (ii) have recovered to a high fraction of *K*; and (iii) are subject to regular monitoring. Few stocks meet these criteria: most are either still at low levels, or were never depleted much. Only 2-3 stocks (or stock complexes) were identified which met these criteria currently: eastern North Pacific gray whales, North Atlantic humpbacks, and possibly North Atlantic fin whales, although the latter case is complicated by stock structure ambiguities. For both of these two stocks, the data have proven not to be compatible with standard density-dependent models, as has been found by several published analyses (Butterworth *et al.*, 2002; Punt *et al.*, 2006; Wade and Perryman, 2002).

Further stocks are expected to meet the criteria in the near future, particularly Southern Hemisphere humpbacks, especially the SW Pacific (E. Australian) stock which is predicted to reach a high fraction of *K* within the next 10 years. Bowhead whales are increasing more slower, but are also believed to have reached MSYL and a slowdown in growth rate would be expected in the near future.

The test of the standard model is one-sided, in the sense that if a stock recovers less than predicted by the model, this can be fitted with a lower *r* and/or *K* value, and no model misspecification will be evident. Only for stocks which recover more than expected will the model be rejected.

The simulation framework developed in Cooke (2007) was used to examine how likely it is that the standard density-dependent model would be rejected by the data. This was done by recording those cases where the constant-*K* model was rejected in favour of a model with a trend in *K* at the 95% significance level based on a likelihood test. The results showed that the probability of rejecting the model can be high, approaching 80% in some scenarios, in the presence of environmental variability. The distribution of MSYR estimates was generated for each of the two options: (i) the constant *K* model is used regardless of any lack of fit; (ii) the constant *K* model is replaced by a trend in *K* whenever the former is rejected by the data. The results show that the positive bias in MSYR estimates is larger when the trend in *K* is allowed than when the constant *K* model is used regardless of lack of fit.

The author of SC/F09/MSYR3 drew two conclusions: (i) the results suggest that cases such as gray and humpback whales where the standard model cannot be fitted should perhaps not be regarded as anomalies, but as in accordance with expectation; (ii) fitting a trend in *K* to "repair" a lack of fit by the standard model can make estimates of MSYR poorer, not better.

In discussion the Workshop **agreed** that, even when the simulations suggested that the assumption of constant *K* reduced the bias in MSYR estimates, it would be unrealistic to expect the Scientific Committee to accept assessments that were so clearly rejected by the data as in the case of eastern gray whales and North Atlantic humpbacks.

Attention was drawn to work in progress (Reeves *et al*. in prep) to examine an alternative hypothesis to explain the gray and humpback cases, namely that the early whaling may have focussed on mothers and calves in the breeding ground, and caused a greater effect on the population than the catch figures alone would suggest, due to disruption of reproduction.

Gunnlaugsson reported that the 2007 NASS survey suggested that the increase in humpback whales in the northern North Atlantic noted in previous surveys had not continued. Analyses will be tabled soon.

The Workshop **agreed** that the following analyses should be undertaken to explore this question for the eastern North Pacific gray whaless and North Atlantic humpback whales:

(1) Determine the size of effects needed to explain the observed trend using the breeding disruption hypothesis of Reeves *et al* (in prep).

(2) Determine the level of environmental variability that is required to fit the trends in gray and humpback whales using the aggregated stochastic model of Cooke (2007). For this purpose the serial correlation coefficient ρ should be fixed at different values (e.g. 0.0, 0.5 and 0.9) and σ estimated because it would clearly be impossible to estimate both.

(3) Repeat task 2 for an age-structured stochastic model, such as that used in Punt (In press).

6. MODELS TO ESTIMATE MSYR AND THEIR LIMITATIONS

6.1 Trends in abundance (as related to MSYR)

The Scientific Committee has discussed the relationship between the rate of increase in the limit of zero population size and MSYR extensively in the past. Two main views have emerged. One view, based on Butterworth and Best (1990), argues that estimates for $MSYR_{1+}$ can be inferred from estimates of r_0 given the bound $MSYR_{1+} \geq r_0/2$. This view arises from the assumptions that the relationship between the per capita growth rate and population size is smooth and convex so that $MSYL_{1+} > 0.5$, as suggested by, for example, Fowler and Baker (1991) that most large mammals exhibit density-dependence at high fractions of their carrying capacities. The counter view is based on the arguments that: a) the per capita growth rate may be high at low population size, but drop quickly thereafter (the 'basin model' and 'supercompensation' arguments – (1985)), b) the data analysed by Fowler and Baker (1991) do not enable any conclusions to be drawn that recruitment surveys have negative second derivative (de la Mare, 1994), and c) the impact of stochasticity in the population dynamics which leads to positively biased estimates of r_0 (e.g. SC/F09/MSYR3) and higher realized growth rates at low stock size than the average such growth rate, will reduce (or eliminate) the difference between $MSYR_{1+}$ and r_0 for some stocks.

The Workshop **agreed** that while both views remained, the fact that there is no evidence for a reduction in the growth rates for the right (and particularly) humpback whales that have been monitored regularly over the past two decades (some humpback stocks are now in the region of 0.3K) implies that the "supercompensation"/"basin model" argument is not as plausible as it was in the past.

6.2 Population dynamics models and catch-at-age data

The November 2007 Workshop discussed the use of population dynamics models and catch-at-age data when estimating MSYR. The current Workshop did not identify further issues pertinent to the estimation of MSYR. However, it noted that estimates of MSYR had been obtained using population models for four stocks (North Atlantic fin whales, North Atlantic minke whales, Eastern North Pacific gray whales, and Bering-Chukchi-Beaufort Seas bowhead whales). The Workshop assigned the estimates of MSYR for the first three of these stocks as "medium" reliability and those for the other as "high" reliability in terms of the data used and the appropriateness of the assumptions underlying the assessment. Catch-at-age data formed a key basis for estimates of MSYR for two stocks (minke whales in the Indian and Pacific Oceans); both of these estimates were assigned "low" reliability (Table1).

6.3 Changes in biological parameters

The Workshop **agreed** that the changes in biological parameters could not be used to define the range of values of MSYR for use in RMP simulation trials.

6.4 Maxima inferred from demographics

The major aim of the MSYR review is to define a lower bound for MSYR for use in RMP simulation trials. The Workshop **agreed** that maximum rates of increase based on demographics do not provide any information which could be used to estimate such lower bounds.

6.5 General limitations affecting more than one method

The November 2007 Workshop discussed the impact of environmental variation on the ability to estimate MSYR and MSYL under this item. This topic was discussed at the present Workshop under items 4 and 5 above.

Table 3

As for Table 1, except that the table is restricted to cases for which information is available on MSYR

Species: 'Stock'	MSYR values	Data available incl. time periods	Reliability of available estimates (see key to Table 1)	References
Fin whale				
North Atlantic				
East Greenland-Iceland	1.7 (1.0-2.9)* ($MSYR_{1+}$)	Very complicated; depends on model specifications, including multiple stocks. CI intervals approximate; high MSYR values from earlier single-stock models	(M)	(Branch and Butterworth, 2006)
Sei whale				
Southern Hemisphere	3.0 (no CI)	1926/27-1977/78	(R)	(Horwood and Millward, 1987)
Antarctic minke whale				
Indian	5.5; 5.4 (SE 0.5)	1978/79 – 2004/05	Possibly confounded by changing K & uncertainty about CAA data) (L)	(Mori *et al.*, 2007); (Punt and Polacheck, 2007)
Pacific	3.6; 2.6	1978/79 – 2004/05		(Mori *et al.*, 2007); (Punt and Polacheck, 2007)
Common minke whale				
North Atlantic				
Northeastern	1.90 (<0.10-3.84)	1953-2005	Uses CPUE data (M)	(Butterworth *et al.*, 2007)
Gray whale				
North Pacific				
Eastern gray whale	7.0 (90%4.8-9.2)	1967/68 - 2001/02 (DS)	No process error accounted for Impact of priors on MSYR and K) (M)	Punt *et al*. (2004)
Bowhead whale				
Bering-Chukchi-Beaufort	3.3 (90%1.9-4.8)	1978-2005 (census+catches)	(H)	(Brandon and Wade, 2006);

7. PROGRESS FOR REVIEWING PROPOSALS TO AMEND THE RMP

IWC (1994, p.47) specified the protocol for evaluating proposed amendments to the RMP. In reviewing the protocol in 2006, the Committee agreed (IWC, 2007) that three factors needed to be considered further:

(1) the appropriate range of MSYRs to be used in trials;

(2) development of an appropriate set of simulation trials;

(3) definition of an appropriate set of performance statistics.

The present Workshop is focussing on (1). Aside from the issue of MSYR, the Committee agreed on a number of trials and performance statistics (IWC, 2006) pending completion of the work on MSYR, noting that once that work had been completed, it would be in a better position to consider whether further trials incorporating environmental variation were required. Last year (IWC, 2009b) the Scientific Committee noted that Norway had completed the required work for the trials developed thus far evaluating proposed amendments.

The Workshop **agreed** that in finalising the trial specifications for proposals to amend the RMP, the Scientific Committee should take into account:

(1) the additional work regarding the appropriate range of MSYRs recommended under Item 9; and

(2) the approach used in Cooke (2007, revised) as a possible basis for further robustness trials with respect to environmental variability.

Any new trials should also be applied to the existing *CLA*.

8. WORK PLAN AND RECOMMENDATIONS

The Workshop **agreed** that as the ultimate use of the analyses was to determine the appropriate range of MSYR values to be used in the RMP, then it was essential that any computer programs used in the process must be validated by the Secretariat.

8.1 Estimates of MSYR and Meta-analysis

(1) Revision of the estimates of the rate of increase for humpbacks off Brazil (Zerbini and Ward) and for the eastern North Pacific gray whales (Breiwick) by the 2009 SC meeting (item 2.4).

(2) Punt will supply the software used to conduct the Bayesian hierarchical meta-analysis should be provided to the Secretariat for validation.

8.2 Effects of environmental variability on yield curves

(1) Punt to explore definitions of 'abrupt reduction in population size' and identify how often they occur in the simulations and distribution relevant plot to the Steering Group (item 4).

(2) Through the Steering Group chaired by Butterworth, summarise data on calf and population counts to estimate plausible ranges for the extent and correlation of environmental variation in birth and survival rates (item 2). Potential case studies are SW Atlantic right (Cook), BCB bowheads (Koski), Eastern North Pacific gray whales (Brandon), (North Atlantic rights (Krauss through Donovan), SE Atlantic (Best through Butterworth)

(3) Revise the analyses of Cooke (2007, revised) based on suggestions in item 4 and Table 2. Cooke should supply the Secretariat with the software for generating the data sets for validation. Any software used to estimate MSYR should be provided to the Secretariat for validation at the 2009 Annual Meeting. Once the operating model has been validated, the Secretariat should provide interested analysts with standard data sets.

(4) Kitakado and Cooke to examine reasons for the differences in the distributions for the estimates of *K*.

   (a) In relation in eastern North Pacific gray whales and North Atlantic humpack whales:

   (b) Determine the size of effects needed to explain the observed trend using the breeding disruption hypothesis of Reeves et al (in prep).

   (c) determine the level of environmental variability that is required to fit the trends using the aggregated stochastic model of Cooke (2007) (Butterworth and Cooke). For this purpose the serial correlation coefficient ρ should be fixed at different values (e.g. 0.0, 0.5 and 0.9) and σ estimated because it would clearly be impossible to estimate both.

   (d) Repeat task b for an age-structured stochastic model, such as that used in Punt (in press) (Butterworth, Brandon and Cooke).

9. ADOPTION OF REPORT

The report was adopted at 1442hrs on 8 February 2009.

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Annex A

Agenda

1. INTRODUCTORY ITEMS
    - 1.1 Opening remarks
    - 1.2 Election of Chair
    - 1.3 Appointment of rapporteurs
    - 1.4 Adoption of agenda
    - 1.5 Review of documents
2. REVISION OF TABULATION OF ESTIMATES FOR MSYR AND ABUNDANCE TRENDS
    - 2.1 Blue whale
    - 2.2 Fin whale
    - 2.3 Bryde's whale
    - 2.4 Humpback whale
    - 2.5 Gray whale
    - 2.6 Bowhead whale
    - 2.7 Right whale
3. META-ANALYSES OF POPULATION TREND INFORMATION
4. MODELS OF THE EFFECT OF ENVIRONMENTAL VARIABILITY OF YIELD CURVES
5. IMPLICATIONS OF INFORMATION AVAILABLE ON WHALE TRAJECTORIES FOR DETERMINISTIC DENSITY-DEPENDENT POPULATION MODELS
6. MODELS TO ESTIMATE MSYR AND THEIR LIMITATIONS
    - 6.1 Trends in abundance (as related to MSYR)
    - 6.2 Population dynamics models and catch-at-age data
    - 6.3 Changes in biological parameters
    - 6.4 Maxima inferred from demographics
    - 6.5 General limitations affecting more than one method
7. PROCESS FOR REVIEWING PROPOSALS TO AMEND THE RMP
8. WORK PLAN AND RECOMMENDATIONS
9. ADOPTION OF THE REPORT

Annex B

Documents

SC/F07/MSYR1. Punt, A.E. Constructing a posterior distribution for the rate of increase of whale stocks at low population size

SC/F09/MSYR2. Kitakado, T. Estimation of an annual rate of increase in population size for western North Pacific Bryde's whales

SC/F09/MSYR3. Cooke, J.G. A note on the interpretation of historical trends in baleen whale populations in the context of environmentally-induced variability in population dynamics, with implications for the estimation of MSY rates

Annex C
MSYR meta-analysis: Random Effect Models

JUSTIN G. COOKE

Input data

Stock	Species	r_0	SE	Weight	Estimate**
1	Blue	9.00	3.83	0.07	7.35
2	Blue	8.20	2.22	0.20	7.53
3	Fin	5.00	9.95	0.01	6.38
4	Fin	4.80	3.24	0.10	5.77
5	Fin	1.70	2.76	0.13	4.08
6	Humpback	3.10	0.50	4.00	3.21
7	Humpback	7.40	3.55	0.08	6.83
8	Humpback	12.10	2.55	0.15	9.53
9	Humpback	10.10	4.69	0.05	7.42
10	Humpback	10.60	0.26	15.37	10.57
11	Gray	2.90	0.54	3.48	3.03
12	Right	7.30	0.33	9.09	7.29
13	Right	6.80	0.51	3.84	6.79
14	Right	8.30	1.61	0.39	7.84
15	Bowhead	3.40	0.84	1.41	3.66

Model fits

Model	MMIC	Parameter	estimate	SE
Const	335.63	Const	7.61	0.16
Const + (Species)	193.37	Const	5.73	1.19
		(Species)	2.69	1.18
Const + (Stock)*	23.01	Const	6.48	0.89
		(Stock)	2.77	1.01
Const + (Species) + (Stock)	23.39	Const	6.35	1.22
		(Species)	1.13	1.38
		(Stock)	2.63	1.07

Random effect terms (in parenthesis). Estimates are random effect sigmas

* preferred model based on MMIC (Mixed Model Information Criterion)

** estimated for each stock from preferred model

Annex D

Revised outcomes from the Bayesian meta-analysis

ANDRE E. PUNT

The Bayesian meta-analysis of SC/F07/MSYR1 was applied to the data in Table 1 based on 5,000,000 cycles, excluding the first 2,000,000 as a burn-in and selecting a thinning rate such that the final sample from the posterior was based on 10,000 draws. This number of cycles is sufficient that the extent of auto-correlation between subsequent samples is negligible ($|\rho|<0.02$). Fig.1 shows the posterior distributions for μ and σ (the population mean value of r_0 and the between-population standard deviation for r_0), and Fig. 2 that for the rate of increase for an 'unknown' stock. Table 2 lists the 1st, 2nd, 5th and 10th percentiles of the posterior distribution for the rate of increase for an 'unknown' stock.

Fig.3 summarises the extent to which the analyses update the original point estimates of r_0 and their standard deviations by stock (Table 1), taking account of the information provided on the rate of increase from the population mean.

Table 1

Estimates of r_0 used in the meta-analyses.

Stock	r_0 (%)	SE
Blue		
Central North Atlantic	9.0 (2.0, 17.0)	3.83[a]
Southern Hemisphere	8.2 (1.6, 14.8)	3.37[a]
Eastern North Pacific	3.2	1.4
Fin		
North Norway	5 (-13, 26)	9.95[a]
Eastern North Pacific	4.8 (-1.6, 11.1)	3.24[a]
Humpback		
Western Australia	10.1 (0.9, 19.3)	4.69[a]
Eastern Australia	10.9 (10.5, 11.4)	0.23[a]
Eastern North Pacific	6.4	0.9
Hawaii	10 (3-16)	3.32[a]
Gray		
Western	2.9 (1.9, 4.0)	0.54[b]
Eastern	4.4	0.6
Bowhead		
Bering-Chukchi-Beaufort	3.9 (2.2, 5.5)	0.84[b]
North Atlantic Right		
Western	2.23 (1.23, 3.23)	0.51[a]
Southern Right		
SE Atlantic	7.3 (6.6 ,7.9)	0.33[a]
SW Atlantic	6.8 (5.8 ,7.8)	0.51[a]
SE Indian	8.10 (4.48-11.83)	1.88[a]

a – computed from the 95% confidence interval by dividing by 3.92

b – computed from the 90% confidence interval by dividing by 3.28

Table 2

Lower percentiles of the posterior distribution for the rate of increase for an unknown stock

Percentage	r_0 (%)
1	-1.088
2	-0.073
5	1.312
10	2.436

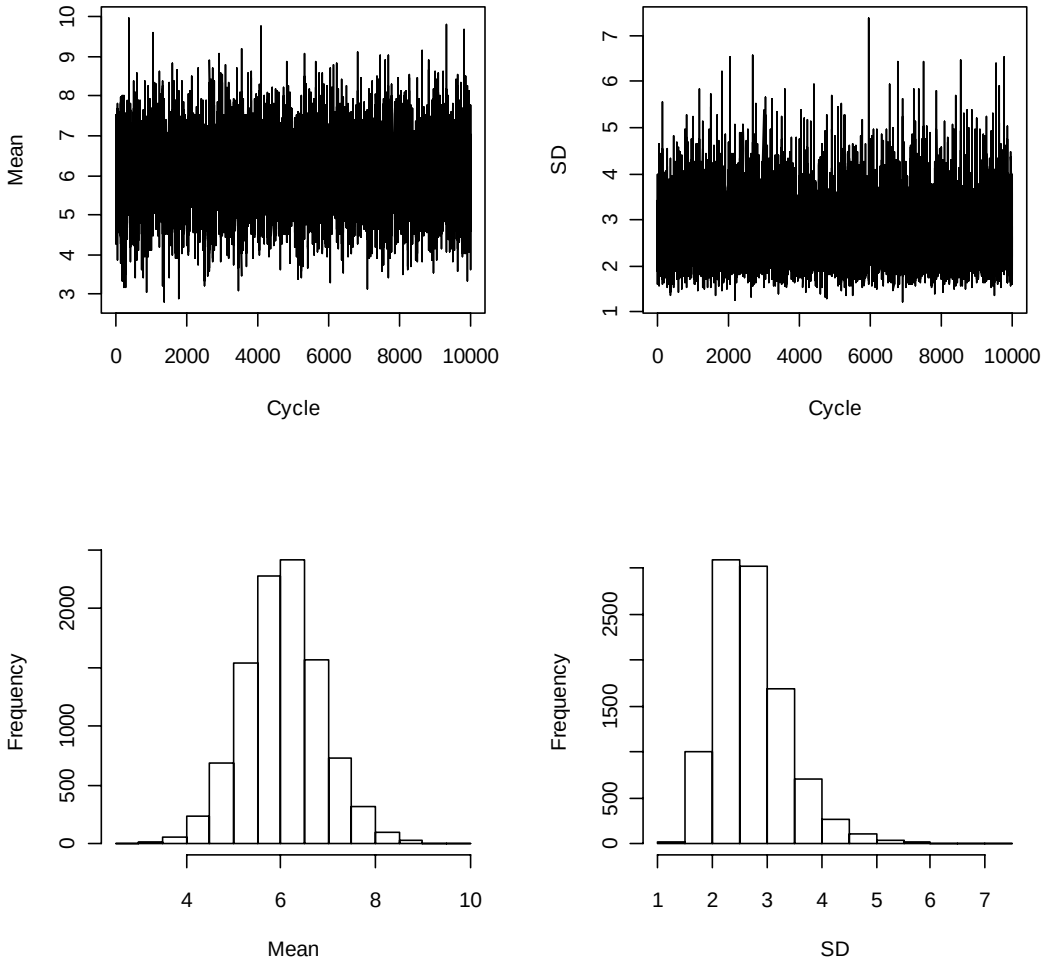

Fig. 1. Posterior distribution for the population mean values for the rate of increase (expressed as percentage) in the limit of zero population size, r0, and the between-population standard deviation for the rate of increase. The upper plots are traces and provide no indication of lack of convergence. The means and standard deviations of the hyper-distributions for the population mean and standard deviation are respectively 6.04/0.84 and 2.63/0.66.

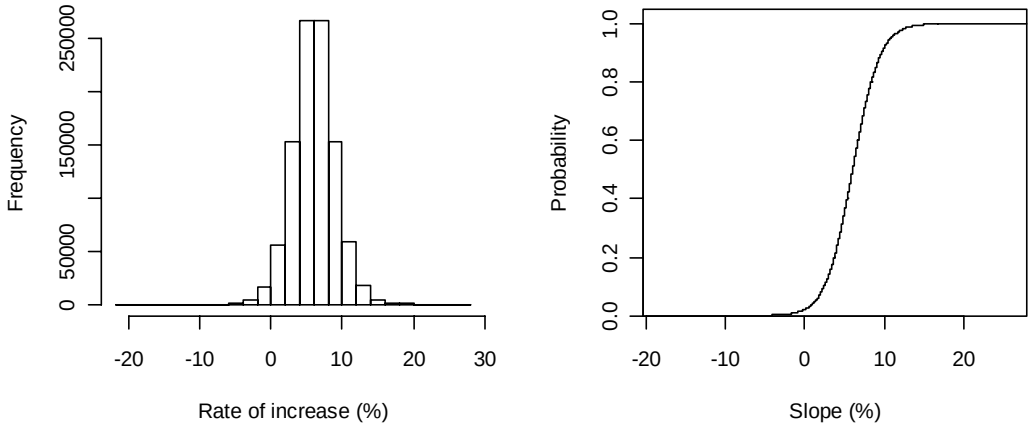

Fig. 2. Posterior distribution for r_0 for an "unknown" stock. The mean and standard deviation of this distribution are respectively 6.04 and 2.93.

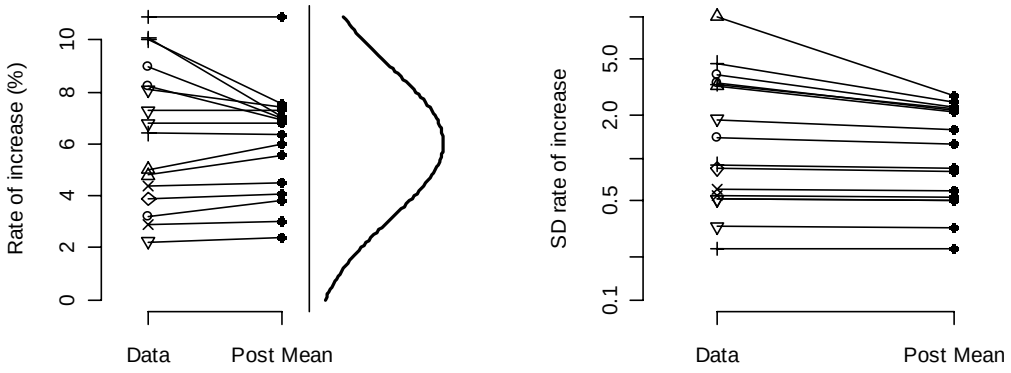

Fig. 3. Left Panel - estimates of stock-specific r_0 from Table 1 and the corresponding posterior means; the distribution for the rate of increase for an unknown stock (assumed to be normal) in the limit of zero population size is appended to the left panel. Right panel – estimates of the standard deviations for r_0 based on the observation error standard errors ("data") and the means of the stock-specific posteriors ("post means"). The y-axis is expressed in log-space for ease of presentation.

Annex E

Simulation runs with alternative depletions

JUSTIN G. COOKE

	Depletion to 0.05*K*						Depletion to 0.25*K* (SC/N07/MSYR1 (revised))					
	(a) Estimating initial *N*/*K*			(b) assuming *No*/*K*			(a) Estimating initial *N*/*K*			(b) assuming *No*/*K*		
	Percentiles (global minimum)			Percentiles (global minimum)			Percentiles (global minimum)			Percentiles (global minimum)		
Scenario	5th	Median	95th	5th	Median	95th	5th	Median	95th	5th	Median	95th
A1	0.015	0.015	0.015	0.015	0.015	0.015	0.013	0.013	0.013	0.012	0.012	0.012
A2	0.049	0.049	0.049	0.047	0.047	0.047	0.042	0.042	0.042	0.039	0.039	0.039
A3	0.073	0.073	0.073	0.075	0.075	0.075	0.070	0.070	0.070	0.070	0.070	0.070
B1	0.000	0.019	0.051	0.008	0.017	0.033	0.003	0.027	0.114	0.000	0.017	0.092
B2	0.040	0.053	0.073	0.037	0.048	0.056	0.027	0.044	0.089	0.022	0.041	0.103
B3	0.066	0.074	0.086	0.060	0.068	0.079	0.049	0.071	0.098	0.044	0.068	0.102
C1	0.010	0.018	0.034	0.010	0.015	0.022	0.007	0.018	0.114	0.005	0.012	0.114
C2	0.042	0.051	0.065	0.040	0.047	0.055	0.029	0.043	0.069	0.029	0.040	0.090
C3	0.065	0.074	0.087	0.060	0.067	0.079	0.050	0.071	0.095	0.048	0.071	0.091
D1	0.000	0.023	0.062	0.006	0.019	0.044	0.004	0.034	0.114	0.000	0.019	0.078
D2	0.033	0.055	0.076	0.030	0.048	0.062	0.019	0.049	0.103	0.012	0.040	0.081
D3	0.066	0.074	0.087	0.060	0.067	0.079	0.048	0.071	0.103	0.037	0.065	0.105
E1	0.000	0.019	0.067	0.009	0.017	0.047	0.004	0.059	0.114	0.000	0.016	0.109
E2	0.025	0.056	0.098	0.020	0.048	0.077	0.014	0.066	0.114	0.000	0.041	0.094
E3	0.050	0.079	0.114	0.044	0.063	0.090	0.044	0.085	0.114	0.040	0.071	0.109
F1	0.000	0.020	0.046	0.007	0.016	0.028	0.004	0.022	0.114	0.000	0.015	0.088
F2	0.039	0.049	0.059	0.038	0.045	0.054	0.023	0.042	0.067	0.021	0.038	0.079
F3	0.065	0.072	0.080	0.062	0.069	0.078	0.048	0.070	0.096	0.044	0.070	0.100
G1	0.000	0.019	0.046	0.010	0.017	0.032	0.003	0.027	0.114	0.000	0.016	0.089
G2	0.040	0.051	0.060	0.039	0.048	0.055	0.026	0.043	0.068	0.023	0.040	0.061
G3	0.072	0.073	0.074	0.062	0.068	0.078	0.060	0.071	0.083	0.053	0.068	0.090
H1	0.000	0.020	0.114	0.002	0.014	0.038	0.004	0.040	0.114	0.000	0.015	0.096
H2	0.032	0.056	0.103	0.031	0.046	0.064	0.021	0.053	0.114	0.014	0.041	0.114
H3	0.057	0.076	0.114	0.053	0.066	0.090	0.035	0.074	0.114	0.030	0.069	0.114
J1	0.000	0.023	0.075	0.008	0.018	0.037	0.003	0.030	0.114	0.000	0.019	0.072
J2	0.036	0.053	0.074	0.034	0.049	0.060	0.022	0.048	0.102	0.015	0.041	0.090
J3	0.066	0.073	0.088	0.059	0.067	0.083	0.044	0.072	0.107	0.036	0.066	0.114
K1	0.000	0.038	0.080	0.006	0.029	0.064	0.004	0.046	0.114	0.000	0.020	0.066
K2	0.013	0.059	0.078	0.017	0.054	0.070	0.011	0.057	0.114	0.000	0.041	0.080
K3	0.065	0.075	0.088	0.059	0.066	0.079	0.047	0.073	0.114	0.030	0.063	0.114
L1	0.000	0.018	0.053	0.008	0.016	0.032	0.004	0.028	0.114	0.000	0.014	0.059
L2	0.038	0.051	0.069	0.032	0.043	0.055	0.025	0.044	0.082	0.022	0.039	0.060
L3	0.065	0.075	0.087	0.042	0.051	0.078	0.048	0.071	0.097	0.044	0.055	0.078