Report of the AWMP Intersessional Workshop on Developing *SLA*s for the Greenland Hunts

Greenland Representation, Copenhagen, 8-11 January 2014

Contents

1. INTRODUCTORY ITEMS

1.1 Convenors' opening remarks

The Committee has identified completion of the development of long-term *SLAs* for these hunts as high priority work. In order to meet the proposed timeframe, this intersessional Workshop was required. The focus of the proposed Workshop is to:

(1) review the results from the developers of SLAs for humpback whales and bowhead whales;
(2) finalise the modelling framework/trial structure for these hunts;
(3) develop a workplan to try to enable completion of work on SLAs for these two hunts at the 2014 Annual Meeting; and
(4) consider initial possible input (e.g. using AWMP/RMP-lite) for the joint AWMP/RMP workshop on North Atlantic common minke whale stock structure that will be held in 14-17 April 2014.

Donovan, on behalf of the participants, thanked the Greenland Representation for hosting the meeting and particularly Mads-Peter Heide-Jørgensen for organising the excellent facilities.

Election of Chair
Donovan was elected Chair.

Appointment of rapporteurs
Allison, Butterworth, Donovan, Givens and Punt served as rapporteurs.

Adoption of Agenda
The agenda given in Annex B was adopted.

Documents available
The documents available to the meeting were SC/J14/AWMP1 together with extracts from previous workshops and meetings of the Scientific Committee.

2. GENERAL ISSUES (BOWHEAD AND HUMPBACK WHALES)

2.1 Progress on intersessional work

The Scientific Committee workplan for the intersessional period related to the development of *SLA*s for bowhead and humpback whales was to:

(1) finalise the trials for the West Greenland humpback and bowhead whales;
(2) finalise removals series, including consideration of human-induced mortality outside the West Greenland area; and
(3) continue initial exploration of potential *SLA*s for the Greenland humpback and bowhead whale hunts.

Certain aspects of the work under (1) are generic and these are discussed here. Items specific to either species are dealt with under Items 3 and 4. The Workshop was informed that Brandão and Witting had reviewed the draft input files and thanked them for this work.

2.1.1 Environmental-driven variability on population dynamics

At the 2013 Annual Meeting, the Scientific Committee agreed that trials based on the environmental variability model for population dynamics of Cooke (2007) should be developed in addition to the previously agreed *Evaluation* and *Robustness Trials* that assume deterministic dynamics. The effect of environmental variability on whale population dynamics is not symmetric because the growth rate is demographically bound. The Committee, noting that conditioning of trials involving environmental stochasticity may prove problematic, had agreed that environmental variation would be invoked only for future projections.

During the intersessional period, Punt and Witting had developed mathematical specifications for an extension to the current population dynamics model which includes environmental variability in fecundity and has the property, in common with the approach of Cooke (2007), that there is no effect of environmental variability in the limit of zero population size, with the effect increasing with increasing population size (Appendix 1 of Annex D). The Workshop thanked Punt and Witting for developing this model formulation. It **agreed** that the proposed approach satisfied the requirements for modelling the effects of environmental variation on fecundity.

In terms of implementing the approach, the Workshop noted that there are no direct data on West Greenland humpback and bowhead whales to parameterise the environmental model. It therefore **agreed** that data on variability in calving rates for other populations of the same species (Eastern North Pacific humpbacks and Bering-Chuckchi-Beaufort Seas bowhead whales, respectively) should be used to parameterise this model. The extent of variation in calving rates for these stocks was compiled during the review of MSY rates (IWC, 2014a).

It is necessary to assign a depletion level for the two stocks with data to parameterise the environmental variability model. However, no model-based assessment exists for the ENP humpback whales while the population size of the B-C-B bowheads changed markedly during the full period over which the data on calving rates were collected. The Workshop noted that estimates of abundance for these two stocks show no evidence for a reduction in growth rate (IWC, 2014a) which would be expected if they were approaching a high fraction of carrying capacity. The Workshop also noted that during the MSYR review the Scientific Committee had included only stocks which were at 'low' abundance, and that 'low' abundance was no more than about 30% of carrying capacity (IWC, 2014b). The Workshop therefore **agreed** that the *Evaluation Trials* based on the environmental model assume that the ENP humpback whales and B-C-B bowheads were 30% of their carrying capacities and consider sensitivity to values of 15% and 60% as *Robustness Trials* given the uncertainty in depletion level. (This is not to imply that a view that the current depletion levels of B-C-B bowheads and Eastern North Pacific humpbacks are both 0.3.)

The Workshop noted that MSYR for a stochastic model is less than for a deterministic model, given the same parameter values for maximum fecundity, survival and age-at-maturity. Thus, trials with environmental variation in calving rates are effectively testing both the effects of lower MSYR and environmental variation, unless the MSYR is adjusted so average productivity is the same for the stochastic and equivalent deterministic trials. The Workshop therefore developed an approach to adjust MSYR (see Appendix 1 of Annex D) so that the environmental variation trials are testing only the impact of environmental variation.

2.2 Trial structure

The trial structure was modified as necessary in the light of the above discussion (see Annex D).

3. *SLA* DEVELOPMENT FOR BOWHEAD WHALES

3.1 Abundance estimates

Heide-Jørgensen (in press) reported on the application of two methods to estimate the abundance of bowhead whales (*Balaena mysticetus*) in West Greenland: (1) double platform visual aerial survey, corrected for missed sightings and the time the whales are available at the surface; and (2) a genetic mark-recapture approach based on a 14 year-long biopsy sampling programme in Disko Bay.

The aerial survey covered about 39,000 km^2 and resulted in 58 sightings, yielding an abundance of 744 whales (CV=0.34, 95% CI: 357-1,461). The estimate included a correction for the time-in-view using a Hidden-Markov model of the availability bias (Borchers *et al.,* 2013). If the survey data are processed following the same analytical approach as used for the 2006 estimate, which includes the same availability bias, but excludes the time-in-view correction, the abundance estimate is 829 individuals (CV=0.35; 95% CI 425 –1,618). The point estimate is about one-third lower than the 2006 abundance estimate of 1,229 (CV=0.47; 95% CI: 495-2,939; Heide-Jørgensen *et al.,* 2007), but the two estimates are not significantly different.

The genetic methods (assuming a closed population) relied on determining sex and mitochondrial haplotypes as well as genotyping nine microsatellite markers. A total of 427 individuals catalogued in 2013, which included 11 recaptures from whales identified in earlier years, led to an estimate of 1,538 whales (CV=0.24; 95% CI: 827-2,249). The possibility of a multi-year cyclical pattern linked to female reproduction, in which the females may not visit Disko Bay annually, was considered by applying a resampling interval that covers the female cycle of four years (2010-2013), with the earlier years (2000-2009) being considered as the initial sampling period. This provided a lower but more precise abundance estimate of 1,274 individuals (CV=0.12; 95% CI: 967-1,581). While the aerial survey is a 'snapshot' of the local spring aggregation in Disko Bay, the genetic approach estimates the abundance of the source of this aggregation. The latter method yields higher estimates, as the aggregation consists mainly of adult females which may not visit Disko Bay annually. However, neither approach indicates a continuation of the increase in bowhead whale abundance in Disko Bay that had been detected in previous studies.

In discussion, the Workshop **agreed** that the second, more precise mark-recapture abundance estimate above of 1,274 (CV=0.12) constituted the best available estimate of abundance for the number of whales visiting West Greenland. The Workshop suggested the following additional analyses for the future:

a) consideration of the use of an open population model (e.g. using program MARK) which would also provide an estimate of rate of change; and
b) input of the mark-recapture data themselves in fitting an integrated model of the population's dynamics (e.g. Johnston and Butterworth, 2009).

The Workshop noted that the immediate objective is progress to finalise the development of an *SLA* for West Greenland bowheads at the 2014 Annual Meeting. The work to date towards that end has assumed sighting survey estimates of abundance as the primary input into the population models which are fitted to provide conditioned operating models for *SLA* testing, and also for the *SLA* itself. Changing that at this stage to a mark-recapture based approach would compromise the possibility of completing this *SLA* development work during the 2014 Annual Meeting. The Workshop reiterated its view that work to incorporate mark-recapture estimates should be undertaken in the future, recognising that this would be a substantial exercise.

Accordingly, the Workshop **agreed** the retain the current approach of basing the operating models and *SLA* on sighting survey estimates of abundance, noting that the facts of a higher value and better precision for the 2012 mark-recapture compared to the sighting survey estimate of abundance would mean that the consequent *SLA* to be accepted would be more conservative (resource risk averse) than if an approach to incorporate mark-recapture estimates had been developed.

The Workshop **agreed** to base the conditioning of the operating model on (a) the fully-corrected 2012 sighting survey abundance estimate of 744 (CV=0.34, 95% CI: 357-1,461); and (b) a comparable estimate for the 2006 survey. The Workshop **agreed** to achieve this by assuming the same time-in view correction and associated CV as in 2012 to apply to the 2006 estimate (Annex E). While this results in a covariance between these final 2006 and 2012 estimates, in order to facilitate timely SLA development, the Workshop agreed that since CV (2012) and CV (2012 adjusted) are virtually the same, it would assume for simplicity that CV (2006 adjusted) is the same as CV (2006) although, in fact, the former should be larger. The time-in-view correction factor (the ratio of the adjusted to unadjusted estimates for 2012) is 744/829 = 0.8975. Multiplying the unadjusted 2006 estimate of !,229 (CV=0.47) by this factor yields an adjusted estimate of 1,103 (CV=0.47). SLA developers have the option to use this artificial CV (2006 adjusted) in any way they wish, if at all.

While agreeing to use the fully-corrected 2012 aerial survey abundance estimate, the Workshop noted that a number of the alternative models examined in [reflected AIC values only marginally worse than that for the best model. The Workshop **requests** Heide-Jørgensen to approach Borchers to evaluate the abundance estimates corresponding to these other models. Should any of those estimates be found to differ appreciably from 744, Donovan will consult with the intersessional steering group to add appropriate further trials to those agreed at the meeting.

3.2 Catches

The recent catches of bowhead whales in the North Atlantic since 1940 are listed in Annex F (Table 1). The numbers are summarised by area in Table 1 below. It was noted that most of the catches by Canada are taken from July-September, whereas those off West Greenland are taken in April-May (the only time the whales are present there). A catch limit of three bowhead whales was established by Canada for 2013.

Table 1.

Summary of the catches by bowhead whales since 1940.

Year	West Greenland	W. Davis Strait	W. Baffin Bay	Prince Regent Inlet	Foxe Basin	Hudson Bay	Hudson Strait	Area unknown	Total
Total	12	4	2	7	15	5	3	12	60
Number known by sex	1M : 6F	2M	2M	1M : 2F	3M : 4F	1M : 2F	1M : 6F		

The *SLA* must be robust to assumptions made regarding Canadian catches, which should encompass all plausible scenarios. The Workshop **agreed** that it is unrealistic to include all Canadian catches in the catch series (this had been the case in the specifications developed earlier) whilst using the abundance estimates for the West Greenland component of the stock only, for the following reasons:

(1) the abundance estimate from the Prince Regent area of Canada in 2002 is appreciably larger than for West Greenland;
(2) whilst telemetry data have shown that some whales tagged off West Greenland do move to the east of Baffin Island (Heide-Jørgensen, 2003; pers. comm.;), none of the x whales tagged in Canada (from settlements where whaling occurs) in summer have subsequently been seen in West Greenland in spring (e.g. Ferguson et al. 2010); and
(3) the sex ratio in the Canadian catches has been close to equal (Table 1) whereas the percentage of females off West Greenland is 80%.

The Workshop **agreed** that the following options for future catches by Canada will be tested[1]:

A: 5 constant over 100 years
B: 2-> 8 over 100 years
D: 2 constant over 100 years

The initial value of 2 for catch scenarios B and D is set to be equivalent to a current annual take of three bowheads in Canada, with Scenario B used to test a different form of the catch progression over time ~~and~~ while scenario D is retained to provide extra information on need satisfaction in the trials. If future catches by Canada are outside this range this will trigger an *Implementation Review* (and any possible need to develop a new *SLA*). While there is insufficient information at present to allow a robust estimate of the number of Canadian catches which might be from the West Greenland component of the stock to be calculated, the Workshop **agreed** that inclusion of scenario A in the *Evaluation Trials* should encompass any likely catches by Canada in the foreseeable future.

The historical catch series to be used in the trials is listed in Annex D, Table 1a and includes all the historical catches by Canada.

Noting the large number of genetically identified whales from the West Greenland area (N=xxx), the Workshop **recommends** that Canadian and Greenlandic scientists co-operate in comparing samples from the Canadian catch to the Greenlandic database. This may allow a direct measure of 'Greenlandic' animals in the Canadian catch.

3.3 Need envelopes

Witting advised the Workshop that the West Greenland managers recommended that the previous need envelope C (strikes increase to 15 over the 100-year period) was currently considered unrealistic by Greenland, and the Workshop **agreed** to drop it from further consideration. The Workshop noted that an *Implementation Review* could deal with need envelope C, or other need envelopes, if the requested number of strikes should exceed those tested during the current implementation process.

3.4 Trial structure

Workshop reviewed the trials structure developed during the 2013 meeting of the Scientific Committee and made a number of minor modifications (Annex D).

4. *SLA* DEVELOPMENT FOR HUMPBACK WHALES

4.1 Catches

Catches of humpback whales off West Greenland since 1960 (both direct and incidental) are given in Tables 2 and 3 of Annex F. In addition, Annex F includes a summary of incidental catches off Canada. The meeting reviewed the assumptions made in compiling these tables and confirmed that:

(1) whales killed for humanitarian reasons that were expected to die from non-anthropomorphic causes (e.g. whales trapped in ice) be excluded;
(2) any whales which collide with skiffs be excluded as no visible injury was seen;
(3) any whales injured by hunters but not killed be included as this is the most conservative assumption; and
(4) bycatches whose fate is unknown or which escaped towing gear be included as this is the most conservative assumption.

Witting presented SC/J14/AWMP1 which provided information on movement and mortality of humpback whales photographed off West Greenland, based upon the West Greenlandic humpback whale catalogue (managed by the Greenland Institute for Natural Resources) and the North Atlantic humpback whale catalogue (managed by Allied Whale). GINR submit all Greenlandic photo IDs to both catalogues. A total of 413 whales has been identified in the West Greenlandic catalogue. Many of these have been photographed at several locations within West Greenland and in a number of years. Two whales have also been sighted on Silver Bank, and one at St-Pierre et Miquelon, Newfoundland. The North Atlantic catalogue includes 501 humpback whales photographed in Greenland. These include pictures provided by GINR, plus pictures obtained from several other sources. None of the whales photographed off Greenland have been sighted in Icelandic waters or further east. Twenty of the 2,908 individuals identified in east Canadian waters have also been sighted in West Greenland. In the Gulf of Maine (the Bay of Fundy and the Scotia Shelf) only one of the reported 1598 individuals has also been sighted in West Greenland. Of the 329 whales identified in Bermuda, six were also sighted in West Greenland, as were 85 of the 2608 whales identified in the West Indies. The only information on mortality of whales photographed off Greenland is from deaths due to hunts or by-catch off West Greenland. Post-mortem identification pictures have been taken of five whales caught as part of the strike limit allocated, and two as by-catch in fishing gear. Of these

[1] Old scenario 'C' has been deleted as implausibly high at this time; should circumstances exceed the current scenarios this will trigger an *Implementation Review.*

seven, five were previously photographed while still alive. There is no information on mortality outside Greenlandic waters.

In discussion the Workshop **agreed** that this information did not require any change to the approach previously adopted for taking account of bycatches off eastern Canada, and further that resightings in the Gulf of Maine were so few as to negate any need to take explicit account of them. The Workshop also **emphasized** the importance of adding dead whales to photographic catalogues.

The resulting catch series to be used in the trials is listed in Annex D.

4.2 Trial structure

Workshop reviewed the trials structure developed during the 2013 meeting of the Scientific Committee and made a number of minor modifications (Annex D).

5. *SLA* DEVELOPMENT FOR COMMON MINKE WHALES

5.1 Preparations for joint AWMP/RMP workshop on stock structure

The Scientific Committee has previously noted the need for consistency in stock structure hypotheses with the RMP *Implementation* when developing *SLA*(s) for the West and East Greenland hunts. At the 2013 Annual Meeting, the Committee agreed to hold a joint AWMP/RMP workshop on the stock structure of common minke whales in the North Atlantic; from the AWMP perspective, the focus is on ensuring consistency with the RMP with respect to stock structure hypotheses relevant to developing *SLA*(s) for the West Greenland and East Greenland hunts. Palsbøll, the convenor for the joint workshop, advised that the workshop would be held in Copenhagen from 14-17 April 2014. The draft agenda for the workshop is given as Annex G. Several of the attendees at the present workshop will also attend the joint workshop.

6. *SLA* DEVELOPMENT FOR FIN WHALES

The Scientific Committee has previously noted the need for consistency in stock structure hypotheses with the RMP *Implementation* when developing an *SLA* for the West Greenland hunt (an RMP I*mplementation* for North Atlantic fin whales has been scheduled for the 2014 Annual Meeting). The present Workshop was informed of the progress made at the RMP fin whale workshop that had been held immediately prior to the present workshop (SC/65b/Rep. X). While considerable progress had been made, the work was not yet at the stage where there were implications for the development of an *SLA* for the West Greenland fin whale hunt. The Workshop noted that workplan developed at that prior workshop enabled relevant information on stock structure/operating models to be available at the 2014 Annual Meeting for discussion by the SWG on the AWMP.

7. WORKPLAN

7.1 Bowhead and humpback whales

The workplan for the 2014 Annual Meeting is as follows:

(1) estimate the CV for the revised 2006 bowhead abundance estimates (Givens and Butterworth) (item 3.1);
(2) distribute the final trials specifications to the Steering group (Punt, 24 January 2014) (items 3.4 and 4.2);
(3) complete operating model code provided to Brandão and Witting (Punt) (items 3.2 and 4.1);
(4) provide final catch series to Brandão and Witting (Allison) (items 3.4 and 4.2);
(5) develop input files (Brandão and Witting) (items 3.4 and 4.2);
(6) provide alternative bowhead abundance estimates obtained from other models which had fitted the data well to the Steering group (Heide-Jørgensen) (item 3.1);
(7) validate the operating model (Allison, before SC65b) (items 3.4 and 4.2); and
(8) develop and evaluate alternative SLAs (Brandão and Witting).

7.2 Other

The Workshop noted that Greenlandic aboriginal need is expressed in terms of weight of consumable product, not strikes, and that the hunt is typically distributed among several species. This implies, in principle that the allocation of removals among stocks may change over time. To address this possibility, it may be necessary to develop multi-species need envelopes that limit total strikes while allowing flexibility about the allocation among species. The Workshop **agreed** to consider this issue after further development of single-species *SLA*s.

8. ADOPTION OF REPORT

The Report was adopted at 16:43 on 10 January 2014. The Chair thanked the participants for their co-operative and productive attitude during the meeting, ensuring that sufficient progress should be achieved before the 2014 Annual Meeting to meet the proposed workplan for *SLA* development for humpback and bowhead whales off West Greenland. The Workshop thanked the Chair for his usual efficient and good humoured handling of the

meeting. All participants thanked Jette Donovan Jensen for arranging the accommodation and excellent dinner recommendations.

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Annex A
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Annex B
Agenda

1. INTRODUCTORY ITEMS
1.1 Convenors' opening remarks
1.2 Election of Chair
1.3 Appointment of rapporteurs
1.4 Adoption of Agenda
1.5 Documents available

2. GENERAL ISSUES (BOWHEAD AND HUMPBACK WHALES)
2.1 Progress on intersessional work
2.1.1 Environmental-driven variability on population dynamics
2.2 Trial structure

3. *SLA* DEVELOPMENT FOR BOWHEAD WHALES
3.1 Abundance estimates
3.2 Catches
3.3 Need envelopes
3.4 Trial structure

4. *SLA* DEVELOPMENT FOR HUMPBACK WHALES
4.1 Catches
4.2 Trial structure

***5. SLA* DEVELOPMENT FOR COMMON MINKE WHALES**
5.1 Preparations for joint AWMP/RMP workshop on stock structure
***6. SLA* DEVELOPMENT FOR FIN WHALES**

7. WORKPLAN
7.1 Bowhead and humpback whales
7.2 Other

8. ADOPTION OF REPORT

Annex C

Documents

SC/J14/AWMP1. Simon, M. and T. Boye. What can we learn about mortality of Greenlandic humpback whales from photo ID data?

Annex D

TRIAL SPECIFICATIONS FOR HUMPBACK AND BOWHEAD WHALES OFF WEST GREENLAND

A. The population dynamics model
The underlying dynamics model is deterministic, age- and sex-structured, and based on the Baleen II model (Punt, 1999).

A.1 Basic dynamics
Equations A1.1 provide the underlying 1+ dynamics.

$$\begin{aligned} R^{m/f}_{t+1,a+1} &= (R^{m/f}_{t,a} - C^{m/f}_{t,a})\,S_a + U^{m/f}_{t,a}\,S_a\,\delta_{a+1} && 0 \le a \le x-2 \\ R^{m/f}_{t+1,x} &= (R^{m/f}_{t,x} - C^{m/f}_{t,x})\,S_x + (R^{m/f}_{t,x-1} - C^{m/f}_{t,x-1})\,S_{x-1} && \\ U^{m/f}_{t+1,a+1} &= U^{m/f}_{t,a}\,S_a\,(1-\delta_{a+1}) && 0 \le a \le x-2 \end{aligned} \qquad \text{(A1.1)}$$

$R^{m/f}_{t,a}$ is the number of recruited males/females of age *a* at the start of year *t*;

$U^{m/f}_{t,a}$ is the number of unrecruited males/females of age *a* at the start of year *t*;

$C^{m/f}_{t,a}$ is the catch of males/females of age *a* during year *t* (whaling is assumed to take place in a pulse at the start of each year);

δ_a is the fraction of unrecruited animals of age *a*-1 which recruit at age *a* (assumed to be independent of sex and time);

S_a is the annual survival rate of animals of age *a*:

$$S_a = \begin{cases} S_J S_{1+} & \text{if } a = 0 \\ S_J & \text{if } 1 \le a \le a_T \\ S_{1+} & \text{if } a > a_T \end{cases} \qquad \text{(A1.2)}$$

S_J is the juvenile survival rate (note that for calves, *a*=0, the assumption made above is that if the mother dies, the calf dies too);

S_{1+} is the survival rate for animals older than age a_T;

a_T is the age at which survival rate changes from juvenile to adult.

x is the maximum (lumped) age-class (all animals in this and the *x*-1 class are assumed to be recruited and to have reached the age of first parturition). *x* is taken to be 15 for humpback whales and 35 for bowhead whales for these trials.

A.2 Births
The number of births at the start of year *t*+1, B_{t+1}, is given by Equation A2.1:

$$B_{t+1} = b_{t+1} N^f_{t+1} \qquad \text{(A2.1)}$$

N^f_t is the number of mature females at the start of year *t*:

$$N^f_t = \sum_{a=a_m}^{x} (R^f_{t,a} + U^f_{t,a}) \qquad \text{(A2.2)}$$

a_m is the age-at-maturity (the standard IWC convention of referring to the mature population is used here, although this actually refers to animals that have reached the age of first parturition);

b_{t+1} is the probability of birth/calf survival for mature females:

$$b_{t+1} = \max(0, b_K\{1 + A(1 - [N^{1+}_{t+1}/K^{1+}]^z)\}) \qquad \text{(A2.3)}$$

$$N^{1+}_t = \sum_{a=1}^{x} (R^f_{t,a} + U^f_{t,a} + R^m_{t,a} + U^m_{t,a}) \qquad \text{(A2.4)}$$

$$K^{1+} = \sum_{a=1}^{x} (R^f_{-\infty,a} + U^f_{-\infty,a} + R^m_{-\infty,a} + U^m_{-\infty,a})$$

b_K is the average number of live births per year per mature female at carrying capacity;

A is the resilience parameter; and

z is the degree of compensation.

The number of female births, B^f_t, is computed from the total number of the births during year *t* using Equation A2.5:

$$B^f_t = 0.5 \quad B_t \qquad \text{(A2.5)}$$

The numbers of recruited/unrecruited calves is given by:

$$R_{t,0}^{f} = \alpha_0 \, B_t^{f} \qquad R_{t,0}^{m} = \alpha_0 \, (B_t - B_t^{f})$$
$$U_{t,0}^{f} = (1-\alpha_0)\, B_t^{f} \qquad U_{t,0}^{m} = (1-\alpha_0)(B_t - B_t^{f}) \tag{A2.6}$$

α_0 is the proportion of animals of age 0 which are recruited (0 for these trials).

A.3 Removals

The historical (t<2013) removals are taken to be equal to the total reported removals (including struck and lost, by-catch, ship strikes etc.) (Table 1). The sex-ratio of future aboriginal catches is assumed to be 80:20 F:M (bowheads) and 50:50 F:M (humpbacks) while the sex ratio of by catches, ship strikes and Canadian catches is assumed to be 50:50 F:M. Catches are taken uniformly from the recruited component of the population:

$$C_{t,a}^{m} = C_t^{m} \, R_{t,a}^{m} / \sum_{a'} R_{t,a'}^{m} \; ; \qquad C_{t,a}^{f} = C_t^{f} \, R_{t,a}^{f} / \sum_{a'} R_{t,a'}^{f} \tag{A3.1}$$

$C_t^{m/f}$ is the number of males/females removed from the population during year t. The total removal in a given future year is the sum of (a) the minimum of the need for that year, Q_t , and the corresponding strike limit, (b) bycatches in fisheries, (c) ship strikes and (d) aboriginal catches in Canada (applies only for bowheads).

The total bycatch during future year y is computed by applying the average bycatch exploitation rate during 2007-2011 to the number of 1+ animals in year t, i.e.:

$$\tilde{C}_t = \tilde{F} \, N_t^{1+} \tag{A3.2}$$

$\tilde{F}$ is the average exploitation rate due to by-catch during 2007-2011:

$$\tilde{F} = \sum_{t=2007}^{2011} (\tilde{C}_t^{f} + \tilde{C}_t^{m}) / \sum_{t=2007}^{2011} N_t^{1+} \tag{A3.3}$$

A.4 Recruitment

The proportion of animals of age a that would be recruited if the population was pristine is a knife-edged function of age at age a_r , i.e.:

$$\alpha_a = \begin{cases} 0 & \text{if } \; 0 \le a < a_r \\ 1 & \text{otherwise} \end{cases} \tag{A4.1}$$

a_r is the age-at-recruitment (assumed to be 1 for humpbacks and 5 for bowhead whales).

The (expected) number of unrecruited animals of age a that survive to age a+1 is $U_{t,a}^{m/f} S_a$. The fraction of these that then recruit is:

$$\delta_{a+1} = \begin{cases} [\alpha_{a+1} - \alpha_a]/[1-\alpha_a] & \text{if } 0 \le \alpha_a < 1 \\ 1 & \text{otherwise} \end{cases} \tag{A4.2}$$

A.5 Maturity

Maturity is assumed to be a knife-edged function of age at age a_m.

A.6 Initialising the population vector

The numbers at age in the pristine population are given by:

$$R_{-\infty,a}^{m/f} = 0.5 \;\; N_{-\infty,0} \;\; \alpha_a \prod_{a'=0}^{a-1} S_{a'} \qquad \text{if} \;\; 0 \le a < x$$
$$U_{-\infty,a}^{m/f} = 0.5 \;\; N_{-\infty,0} \;\; (1-\alpha_a) \prod_{a'=0}^{a-1} S_{a'} \qquad \text{if} \;\; 0 \le a < x \tag{A6.1}$$
$$R_{-\infty,x}^{m/f} = 0.5 \;\; N_{-\infty,0} \prod_{a'=0}^{x-1} \frac{S_{a'}}{(1-S_x)} \qquad \text{if} \;\; a = x$$

$R_{-\infty,a}^{m/f}$ is the number of animals of age a that would be recruited in the pristine population;

$U_{-\infty,a}^{m/f}$ is the number of animals of age a that would be unrecruited in the pristine population; and

$N_{-\infty,0}$ is the total number of animals of age 0 in the pristine population.

The value for $N_{-\infty,0}$ is determined from the value for the pre-exploitation size of the 1+ component of the population using the equation:

$$N_{-\infty,0} = K^{1+} / \left(\sum_{a=1}^{x-1} \left(\prod_{a'=0}^{a-1} S_{a'} \right) + \frac{1}{1-S_x} \prod_{a'=0}^{x-1} S_{a'} \right) \tag{A6.2}$$

In common with the trials for the Eastern North Pacific gray whales (IWC, 2013), these trials are based on the assumption that the age-structure at the start of year τ is stable rather than that the population was at its pre-exploitation equilibrium size at the start of (say) 1600, the first year for which catch estimates are available. The determination of the age-structure at the start of year τ involves specifying the effective 'rate of increase', γ, that applies to each age-class. There are two components contributing to γ, one relating to the overall population rate of increase

(γ^+) and the other to the exploitation rate. Under the assumption of knife-edge recruitment to the fishery at age a_r, only the γ^+ component (assumed to be zero following Punt and Butterworth [2002]) applies to ages a of a_r or less. The number of animals of age a at the start of year τ relative to the number of calves at that time, $N^*_{\tau,0}$, is therefore given by the equation:

$$N^*_{\tau,a} = \begin{cases} 1 & \text{if } a = 0 \\ N^*_{\tau,a-1} S_{a-1} & \text{if } 1 \le a \le a_r \\ N^*_{\tau,a-1} S_{a-1}(1-\gamma^+) & \text{if } a_r < a < x \\ N^*_{\tau,x-1} S_{x-1}(1-\gamma^+)/(1-S_x(1-\gamma^+)) & \text{if } a = x \end{cases} \tag{A6.3}$$

B_τ is the number of calves in year τ and is derived directly from equations A2.1 and A2.3 (for further details see Punt, 1999):

$$B_\tau = \left(1 - \left[1/(N^f_\tau b_K) - 1\right]/A\right)^{1/z} \frac{K^{1+}}{N^{1+,*}_\tau} \tag{A6.4}$$

The effective rate of increase, γ, is selected so that if the population dynamics model is projected from year τ to a year Ψ, the size of the 1+ component of the population in a reference year Ψ equals a value, P_Ψ which is drawn from a prior (see Table 2).

A.7 z and A

A, z and S_0, are obtained by solving the system of equations that relate *MSYL*, *MSYR*, S_0, S_{1+}, f_{max} a_m, a_T,, *A* and *z,* where f_{max} is the maximum possible pregnancy rate (Punt, 1999).

A.8 Conditioning

The method for conditioning the trials (i.e. selecting the 100 sets of values for the parameters a_m, a_T, S_0, S_{1+}, K^{1+}, *A* and *z*) is based on a Bayesian assessment. The algorithm for conducting the Bayesian assessment is as follows.

(a) Draw values for the parameters S_{1+}, f_{max}, a_m, a_T, $MSYR_{1+}$, $MSYL_{1+}$, K^{1+}, P_Ψ, CV_{add} (the additional variance for the estimates of 1+ abundance in year Ψ), CV_{add2} (the additional variance for the relative estimates of abundance) from the priors in Table 2. The additional variance for the estimates of absolute abundance and indices of relative abundance are assumed to be the same. It is not necessary to draw values for $MSYR_{1+}$ and $MSYL_{1+}$ because the values for these quantities are pre-specified rather than being determined during the conditioning process.
(b) Solve the system of equations that relate *MSYL*, *MSYR*, S_0, S_{1+}, f_{max}, a_m, a_T, *A* and *z* to find values for S_0, *A* and *z*.
(c) Calculate the likelihood of the projection which is given by[2]:

$L = L_1 L_2$ (L_2 applies only to the sighting rates for bowheads) where:

$$L_1 = \prod_t \frac{1}{\sqrt{\Omega_t^2 + CV^2_{add2,t}}} \exp\left(-\frac{(\ell n P^{obs}_t - \ell n(B_c \hat{P}_t))^2}{2(\Omega_t^2 + CV^2_{add2,t})}\right) \tag{A8.1a}$$

$$L_2 = \prod_t (\rho \hat{P}_t)^{N^{obs}_t} e^{-\rho \hat{P}_t} \tag{A8.1a}$$

P^{obs}_t is the estimate of the (1+) abundance at the start of year *t* (Table 3);

$\hat{P}_t$ is the model-estimate of the (1+) abundance which pertains to the survey estimate of abundance at the start of year *t*:

$$\hat{P}_t = \tilde{S}^f \sum_{a=1}^{x} (R^f_{t,a} + U^f_{t,a}) + \tilde{S}^m \sum_{a=1}^{x} (R^m_{t,a} + U^m_{t,a}) \tag{A.8.2}$$

Ω_t is the (sampling) standard deviation of the logarithm of P^{obs}_t (approximated by its coefficient of variation, $CV^{obs}_{est,t}$ - see Table 3);

$\tilde{S}^f, \tilde{S}^m$ are the relative selectivities for females and males (1:1 for humpbacks and 1:0.25 for bowheads);

$E(CV^2_{add2,t})$ is the square of the actual CV of the additional variation for year *t* (using the formula developed under the RMP first stage screening trials for a single stock IWC, 1991, p.109; IWC 1994, p.85):

$$E(CV^2_{add2,t}) = \eta(0.1 + 0.013P^*/\hat{P}_t) = CV^2_{add2} \frac{0.1 + 0.013P^*/\hat{P}_t}{0.1 + 0.013P^*/\hat{P}_\Psi} \tag{A8.3}$$

N^{obs}_t is the number of animals counted during year *t* (a relative index of abundance; Table 3b);

ρ is the constant of proportionality between the number of 1+ animals and the population counts; and

B_c is the bias associated with a relative index of abundance (different for each relative index).

(d) Steps (a) – (c) are repeated a large number (typically 1,000,000) of times.

[2] The priors for the survey bias and additional variation are integrated out as these are nuisance parameters.

(e) 100 sets of parameters vectors are selected randomly from those generated using steps (a) – (c), assigning a probability of selecting a particular vector proportional to its likelihood. The number of times steps (a) – (c) are repeated is chosen to ensure that each of the 100 parameter vectors is unique.

The bulk of the trials for humpbacks are conditioned on the estimate of absolute abundance (Table 3a) and the time series of relative abundance based on aerial surveys (Table 3b). The relative indices of abundance based on mark-recapture (Table 3b) are used when conditioning one of the *Robustness Trials*.

B. Data generation

B.1 Absolute Abundance Estimates

The historic (t<2013) abundance estimates (and their CVs) are provided to the *SLA* and are taken to be those in Table 3a for humpback whales and the relative indices of abundance for bowhead whales in Table 3b. An estimate of abundance together with an estimate of its CV is generated, and is provided to the *SLA,* once every U years during the management period (starting in year 2017 for humpbacks and 2022 for bowheads; U=10 years beyond the year with the last estimate of abundance). The CV of the abundance estimate (CV_{true}) is different from the CV provided to the *SLA*.

The survey estimate, $\hat{S}$, may be written as:

$$\hat{S} = B_A \;\; P \;\; Y \;\; w / \mu = B_A \;\; P^* \;\; \beta^2 \;\; Y \;\; w \qquad \text{(B1.1)}$$

B_A is the bias;

P is the current 1+ population size ($= \hat{P}_t$); (B1.2)

Y is a lognormal random variable: $Y = e^{\phi}$ where: $\phi \sim N[0;\sigma_\phi^2]$ and $\sigma_\phi^2 = \ell n(1+\alpha^2)$; (B1.3)

w is a Poisson random variable, independent of Y, with $E(w) = \text{var}(w) = \mu = (P / P^*)/\beta^2$; and (B1.4)

P^* is the reference population level (the pristine value of $\hat{P}_t$).

[3]The steps used in the program to generate the abundance estimates and their CVs are given below.

The *SLA* is provided with estimates of CV_{est} for each future sightings estimate. The estimate of $CV_{est,t}$ is given by:

$$\hat{C}V_{est,t} = \sqrt{\sigma_t^2 (\chi_n^2 / n)} \qquad \sigma_t^2 = \ell n(1 + E(CV_{est,t}^2)) \qquad \text{(B1.5)}$$

$E(CV_{est,t}^2)$ is the sum of the squares of the actual CVs due to estimation error:

$$E(CV_{est,t}^2) = \theta^2 (a^2 + b^2 / w\beta^2) \qquad \text{(B1.6)}$$

χ_n^2 is a random number from a χ^2 distribution with n (=19; the value assumed for the single stock trials for the RMP) degrees of freedom; and

a^2, b^2 are constants and equal to 0.02 and 0.012 respectively.

The relationship between CV_{est} and CV_{true} is given by:

$$\eta = [E(CV_{true}^2) - E(CV_{est}^2)] / (0.1 + 0.013 P^* / P) \qquad \text{(B1.7)}$$

where η is a constant known as the additional variance factor. The value of η is based on the population size and CVs for year Ψ:

$$\eta = CV_{add}^2 \; / \; (0.1 + 0.013 P^* / P_\Psi) \qquad \text{(B1.8)}$$

The values of α and β are then computed as:

$$\alpha^2 = \theta^2 a^2 + \eta \quad 0.1 , \qquad \beta^2 = \theta^2 b^2 + \eta \quad 0.013 \qquad \text{(B1.9)}$$

C. Need

The level of need supplied to the *SLA* is the total need for the 6-year period for which strike limits are to be set. The scenarios regarding need are listed in Table 4:

D. Trials

Table 4 lists all of the factors considered in the trials. The set of *Evaluation Trials* is given in Table 5 and the set of *Robustness Trials* in Table 6.

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[3] The steps used to generate estimates of abundance and their CVs are as follows (steps i) – iii) are part of the conditioning process).

(i) Read in CV_{est} (Table 3). Generate values of CV_{add}^2 for year Ψ.

(ii) Set η using equation B1.8 and the value of CV_{add} from step(i).

(iii) Set θ^2 using equation B1.6 with the values for CV_{est} from step (i) and $w\beta^2 = P / P^* = P_{1968} / P^*$. Set α^2 and β^2 using equation B1.9.

(iv) Generate w (Poisson random variable –equation B1.4) and ϕ (lognormal random variable –equation B1.3).

(v) Set abundance estimate $\hat{S}$ using equation B1.1.

(vi) Generate $\hat{C}V_{est,t}$ from a χ_n^2 distribution using equation B1.5.

F. Statistics

The risk- and recovery-related performance statistics are computed for the mature female and for the total (1+) population sizes (i.e. P_t is either the size of the mature female component of the population, N_t^f, or the size of the total (1+) population, N_t^{1+}). P_t^* is the population size in year *t* under a scenario of zero strikes over the years *t*≥2013 (defined as *t*=0 below). Note that incidental removals may still occur in the absence of strikes. To emphasize this distinction, $P_t^*(0)$ is used to denote the population size in year *t* under a scenario of zero strikes or removals of any kind, and $P_t^*(\text{inc}) = P_t^*$ reflects the case when there are zero strikes but some incidental removals may occur. K^* is the population size in year *t* if there had never been any anthropogenic removals.

The trials are based on a 100-year time horizon, but a final decision regarding the time horizon will depend *inter alia* on interactions between the Committee and the Commission regarding need envelopes and on the period over which recovery might occur. To allow for this, results are calculated for *T*=20 and 100 (*T** denotes the number of blocks for a given *T*; *T** is 3 and 19 respectively for *T*=20 and *T*=100).

Statistics marked in bold face are considered the more important. Note that the statistic identification numbers have not been altered for reasons of consistency over time. Hence, there are gaps in the numbers where some statistics have been deleted.

F.1 Risk

D1. Final depletion: P_T / K . In trials with varying *K* this statistic is defined as P_T / K_t^* .

D2. Lowest depletion: $\min(P_t / K) : t = 0,1,...,T$. In trials with varying *K* this statistic is defined as $\min(P_t / K_t^*): \ t = 0,1,...,T$.

D6. Plots for simulations 1-100 of { $P_t : t = 0,1,..,T$} and { $P_t^* : t = 0,1,..,T$}.

D7. Plots of { $P_{t[x]} : t = 0,1,..,T$} and { $P_{t[x]}^* : t = 0,1,..,T$} where $P_{t[x]}$ is the *x*th percentile of the distribution of P_t . Results are presented for $x = 5$ and $x = 50$.

D8. Rescaled (1+) final population: P_T / P_T^* . There are two versions of this statistic: D8(0) = P_T / P_T^* *(0)* and D8(inc) = P_T / P_T^* *(inc)*.

D9. Minimum (mature female) population level**:** $\min(P_t): \ t = 0,1,...,T$ **.**

D10. Relative increase of 1+ population size, P_T / P_0

F.2 Need

N1. Total need satisfaction: $\sum_{t=0}^{T-1} C_t / \sum_{t=0}^{T-1} Q_t$.

N2. Length of shortfall = (negative of the greatest number of consecutive years in which $C_b < Q_b$) / T^* , where C_b is the catch for block *b* and Q_b is the total need for block *b*.

N4. Fraction of years in which $C_t = Q_t$.

N7. Plot of $\{V_{t[x]} : t = 0,1, T-1\}$ where $V_{t[x]}$ is the *x*th percentile of the distribution of $V_t = C_t / Q_t$.

N8. Plots of V_t for simulations 1-100.

N9. Average need satisfaction: $\frac{1}{T}\sum_{t=0}^{T-1}\frac{C_t}{Q_t}$.

N10. AAV (Average Annual Variation): $\sum_{b=0}^{T^*-1} |C_{b+1} - C_b| / \sum_{b=0}^{T^*-1} C_b$.

N11. Anti-curvature: $\frac{1}{T^*-1}\sum_{b=0}^{T^*-2}\left|\frac{C_b - M_b}{\max(10, M_b)}\right|$ where $M_b = \left(C_{b+1} + C_{b-1}\right)/2$.

N12. Mean downstep (or modified AAV): $\sum_{b=0}^{T^*-1}\left|\min\left(C_{b+1} - C_b, 0\right)\right| \ / \ \sum_{b=0}^{T^*-1} C_b$

F.3 Recovery

R1. Relative recovery: $P_{t_r^*} / P_{t_r^*}^*$ where t_r^* is the first year in which P_t^* passes through *MSYL*. If P_t^* never reaches *MSYL*, the statistic is P_T / P_T^* . If $P_0 > MSYL$ the statistic is min (1, $P_T / MSYL$).

The following plots are to be produced to evaluate conditioning.

- Time-trajectories of 1+ population size in absolute terms and relative to carrying capacity, along with the fits to abundance estimates. This plot allows an evaluation of whether conditioning has been achieved satisfactorily.
- Histograms of the 100 parameter vectors for each trial. This plot allows an evaluation of whether and how conditioning has impacted the priors for these parameters.

H. References

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Punt, A.E. and Butterworth, D.S. 2002. An examination of certain of the assumptions made in the Bayesian approach used to assess the eastern Pacific stock of gray whales (*Eschrichtius robustus*). *Rep. int. Whal. Commn* 4(1): 99-110.

Table 1. Total removals of bowhead and humpback whales. Direct catches (Dir) and By-catches (BC) from West Greenland (WG) and Canada (C). Catches of unknown sex have been allocated to sex as detailed in Annex F.

(a) Bowheads:

Year	WG-Dir M	WG-Dir F	WG-BC M	WG-BC F	C-Dir M	C-Dir F	C-BC M	C-BC F	Year	WG-Dir M	WG-Dir F	WG-BC M	WG-BC F	C-Dir M	C-Dir F	C-BC M	C-BC F
1940	0	0	0	0	1	1	0	0	1980	0	0	0.2	0.8	0	0	0	0
1941	0	0	0	0	0.5	0.5	0	0	1981	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	1982	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	0	1983	0	0	0	0	0	0	0	0
1944	0	0	0	0	0	0	0	0	1984	0	0	0	0	0	0	0	0
1945	0	0	0	0	1.5	1.5	0	0	1985	0	0	0	0	0.5	0.5	0	0
1946	0	0	0	0	0.5	0.5	0	0	1986	0	0	0	0	0	0	0	0
1947	0	0	0	0	0.5	0.5	0	0	1987	0	0	0	0	0	0	0	0
1948	0	0	0	0	0	0	0	0	1988	0	0	0	0	0	0	0.5	0.5
1949	0	0	0	0	0	0	0	0	1989	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0	1990	0	0	0	0	0	0	0.5	0.5
1951	0	0	0	0	0	0	0	0	1991	0	0	0	0	0	0	0	0
1952	0	0	0	0	0	0	0	0	1992	0	0	0	0	0	0	0.5	0.5
1953	0	0	0	0	0	0	0	0	1993	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	1994	0	0	0	0	0	1	0.5	0.5
1955	0	0	0	0	0.5	0.5	0	0	1995	0	0	0	0	0	0	0	0
1956	0.2	0.8	0	0	0	0	0	0	1996	0	0	0	0	1	0	0.5	0.5
1957	0	0	0	0	0	0	0	0	1997	0	0	0	0	0	0	0	0
1958	0	0	0	0	0	0	0	0	1998	0	0	0	0	1	0	0.5	0.5
1959	0	0	0	0	0.5	0.5	0	0	1999	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	2000	0	0	0	0	1	0	0.5	0.5
1961	0	0	0	0	0.5	0.5	0	0	2001	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	2002	0	0	0	0	0	1	0.5	0.5
1963	0	0	0	0	0	0	0	0	2003	0	0	0.2	0.8	0	0	0	0
1964	0	0	0	0	0.5	0.5	0	0	2004	0	0	0.2	0.8	0	0	0	0
1965	0	0	0	0	0.5	0.5	0	0	2005	0	0	0	0	0	1	1	1
1966	0	0	0	0	0	0	0	0	2006	0	0	0	0	0	0	0.5	0.5
1967	0	0	0	0	0.5	0.5	0	0	2007	0	0	0.4	1.6	0	0	0	0
1968	0	0	0	0	0	0	0	0	2008	0	0	0	0	3.5	0.5	0	1
1969	0	0	0	0	0	0	0	0	2009	1	2	0	0	1.5	2.5	0	0
1970	0	0	0	0	0	0	0	0	2010	0	3	0	0	2	2	0	0
1971	0	0	0	0	1	1	0	0	2011	0	1	0.4	1.6	1	2	0	0
1972	0	0	0	0	0	0	0	0	2012	0	0	0	0	2	1	0	0
1973	0.2	0.8	0	0	0	0	0	0	2013	0	0	0	0	2	1	0	0
1974	0	0	0	0	0	0	0	0									
1975	0	0	0	0	1.5	1.5	0	0	**Total**	1.4	7.6	1.4	5.6	26	23	5.5	6.5
1976	0	0	0	0	0.5	0.5	0	0									
1977	0	0	0	0	0	0	0	0									
1978	0	0	0	0	0	0	0	0									
1979	0	0	0	0	0.5	0.5	0	0									

(b) Humpbacks

	WG-Dir	WG-Dir	WG-BC	WG-BC	C-Dir	C-Dir	C-BC	C-BC		WG-Dir	WG-Dir	WG-BC	WG-BC	C-Dir	C-Dir	C-BC	C-BC
Year	M	F	M	F	M	F	M	F	**Year**	M	F	M	F	M	F	M	F
1960	0	1	0	0	0	0	0	0	1990	0	1	0	0	0	0	1.88	1.88
1961	1	0	0	0	0	0	0	0	1991	0	0	1	1	0	0	3.48	3.48
1962	1	1	0	0	0	0	0	0	1992	0.5	0.5	0	0	0	0	1.45	1.45
1963	0	0	0	0	0	0	0	0	1993	0	0	0	0	0	0	0.53	0.53
1964	0	0	0	0	0	0	0	0	1994	0	0	0	0	0	0	0.5	0.5
1965	0.5	0.5	0	0	0	0.05	0	0	1995	0	0	0	0	0	0	0.53	0.53
1966	0	4	0	0	0	0	0	0	1996	0	1	0	1	0	0	0.13	0.13
1967	2.5	2.5	0	0	0	0	0	0	1997	0	0	0	0	0	0	0.1	0.1
1968	2.5	2.5	0	0	0	0	0	0	1998	0	0	0.5	0.5	0	0	0.18	0.18
1969	1.5	1.5	0	0	0.1	0.2	0.03	0.03	1999	1	1	0	1	0	0	0.3	0.3
1970	0	0	0	0	0.3	0.45	0	0	2000	0	0	0	2	0	0	0.3	0.3
1971	2	2	0	0	0.4	0.6	0	0	2001	1	1	1	1	0	0	0.55	0.55
1972	1.5	1.5	0	0	0	0	0.03	0.03	2002	1	1	2	2	0	0	0.2	0.2
1973	5.5	5.5	0	0	0	0	0.05	0.05	2003	1	0	0.5	0.5	0	0	0.2	0.2
1974	4.5	4.5	0	0	0	0	0.05	0.05	2004	1	0	1	1	0	0	0.3	0.3
1975	4.5	4.5	0	0	0	0	0.15	0.15	2005	0	0	2	3	0	0	0.05	0.05
1976	4.5	4.5	0	0	0	0	0.08	0.08	2006	0.5	0.5	0	0	0	0	0.38	0.38
1977	8.5	8.5	0	0	0	0	0.13	0.13	2007	0	0	1	2	0	0	0.58	0.58
1978	11.5	11.5	0	0	0	0	0.28	0.28	2008	0	0	1.5	1.5	0	0	0.58	0.58
1979	7	7	0	0	0	0	1.33	1.33	2009	0	0	0	0	0	0	0.25	0.25
1980	7.5	7.5	0	0	0	0	1.53	1.53	2010	3.5	5.5	1	0	0	0	0.38	0.38
1981	6	6	0	0	0	0	0.83	0.83	2011	4	4	1	0	0	0	0.23	0.23
1982	5.5	6.5	0	0	0	0	0.88	0.88	2012	4	6	1.5	0.5	0	0	0.28	0.28
1983	7	7	0.5	0.5	0	0	0.88	0.88									
1984	7.5	7.5	0	0	0	0	0.65	0.65	**Total**	115.5	124.5	14.5	17.5	0.8	1.3	26.8	26.8
1985	4.5	4.5	0	0	0	0	1.3	1.3									
1986	0	0	0	0	0	0	0.85	0.85									
1987	0	0	0	0	0	0	1.13	1.13									
1988	0.5	0.5	0	0	0	0	1.65	1.65									
1989	1	1	0	0	0	0	1.75	1.75									

Table 2 The prior distributions

Parameter	**Prior distribution (Humpbacks)**	**Prior distribution (Bowheads)**
Non-calf survival rate, S_{1+}	U[0.90, 0.995]	N(1.059; 0.0378^2), truncated at 0.995
Age-at-maturity, a_m	U[4, 12]	N(20;3^2) truncated at 13.5 and 26.5
Transition age from juvenle to adult survival, a_T	0	U[1,9]
K^{1+}	U[0, 30,000]	U[0, 40,000]
$MSYL_{1+}$	Pre-specified	Pre-specified
$MSYR_{1+}$	Pre-specified	Pre-specified
Maximum pregnancy rate, $1/f_{max}$	U[1.25, 2.5]	U[2.5, 4]
Additional variation (population estimates), CV_{add}, in year Ψ	U[0, 0.35]	U[0, 0.35]
Abundance in year Ψ*, P_Ψ	$\ell nP_{2007} = N(\ell n2,704;(0.34^2+CV_{add}^2))$	A: $\ell nP_{2002} = N(\ell n6,340;(0.38^2+CV_{add}^2))$ B: $\ell nP_{2006} = N(\ell n1,229;(0.47^2+CV_{add}^2))$ *
Additional variation (relative indices), CV_{add2}	U[0.2, 0.6]	U[0.2, 0.6]
Bias of relative abundance indices, B_c	$\ell nB_c \sim U[-\infty,\infty]$ (see[&])	$\ell nB_c \sim U[-\infty,\infty]$ (see[&])

[*] Note: the reference years Ψ are either 2002 or 2006.
[&] This is the non-informative prior for a scale parameter

*NB: the 1,229 should be 1,103 (editing problem will sort this out!

Table 3 Estimates of absolute abundance (a) and estimates of relative abundance (b)

(a) Estimate of absolute abundance

Year	**Estimate**	**CV**
Bowhead whales		
2002	6,340	0.38
2006	1,103	0.47
2012	744	0.34
Humpback whales		
2007	2,704	0.34

(b) Estimates of relative abundance

Bowhead whales			Humpback whales					
Year	Effort L, (km)	Count	Year	Estimate	CV	Year*	Estimate*	CV*
1981	951	1	1984	99	0.40	1982	271	0.13
1982	2,273	1	1985	177	0.44	1989	357	0.16
1990	591	1	1987	220	0.62	1990	355	0.12
1991	1,088	3	1988	200	0.74	1991	566	0.42
1993	577	0	1989	272	0.75	1992	376	0.19
1994	1,092	0	1993	873	0.53	1993	348	0.12
1998	1,184	5	2005	1,158	0.35			
1999	1,104	0	2007	1,020	0.35			
2006	791	9						
2012	1,574	25						

* – Not used in the *Evaluation Trials*

Table 4 Factors tested in the trials

Factors	Levels (Reference levels shown bold and underlined)	
	Humpback whales	**Bowhead whales**
MSYR $_{1+}$	1%, 3%, **<u>5%</u>**, 7%	1%, **<u>2.5%</u>**, 4%
$MSYL_{1+}$	0.6	**<u>0.6</u>**, **0.8**
Time dependence in *K* *	**<u>Constant</u>**, Halve linearly over 100yr	
Time dependence in natural mortality, *M* *	**<u>Constant,</u>** Double linearly over 100yr	
Episodic events *	**<u>None</u>**; 3 events occur between yrs 1-75 (with at least 2 in yrs 1-50) in which 20% of the animals die; Events occur every 5 years in which 5% of the animals die	
Need envelope	A: 10, 15, 20; 20 thereafter **<u>B: 10, 15, 20; 20->40 over years 17-100</u>** C: 10, 15, 20; 20->60 over years 17-100 **<u>D: 20, 25, 30; 30->50 over years 17-100</u>**	**<u>A: 2, 3, 5; 5 thereafter</u>** B: 2, 3, 5; 5 -> 10 over years 17-100
Future Canadian catches	N/A	**<u>A: 5 constant over 100 years</u>** B: 2-> 8 over 100 years D[&]: 2 constant over 100 years
Survey frequency	5 yr, **<u>10 yr</u>**, 15 yr	
Historic survey bias	0.8, **<u>1.0</u>**, 1.2	0.5, **<u>1.0</u>**
First year of projection, τ	**<u>1960</u>**	**<u>1940</u>**
Alternative Priors	S_{1+} ~ U[0.9, 0.99]; f_{max} ~ U[0.4, 0.6]; a_m ~ U[5, 12]	N/A
Strategic surveys	Extra survey if a survey estimate is less than half of the previous survey estimate	
Asymmetric environmental stochasticity	$\tilde{\rho}_f$ **<u>= 0.320</u>**	
Depletion	**<u>Depletion = 0.3</u>** Depletion = 0.15/ 0.6	

*Effects of these factors begin in year 2013 (i.e. at start of management). The adult survival rate is adjusted so that if catches were zero, then the average population size during years 250-500 equals the carrying capacity. <u>Note</u>: for some biological parameters and levels of episodic events, it may not be possible to find an adult survival rate which satisfies this requirement.

& Not renamed "C" for consistency with previous trial names.

Table 5

The *Evaluation Trials*. Values given in bold type show differences from the base trial

(a) Humpback whales

Trial	Description	***MSYR*** $_{1+}$	**Need Scenarios**	**Survey freq.**	**Historic Survey Bias**	**Conditioning Option**
1A	$MSYR_{1+}$ = 5%	5%	A, B, C, D	10	1	Y
1B	$MSYR_{1+}$ = 3%	**3%**	A, B, C, D	10	1	Y
1C	$MSYR_{1+}$ = 7%	**7%**	A, B, C, D	10	1	Y
2A	5 year surveys	5%	B, C, D	**5**	1	1A
2B	5 year surveys; $MSYR_{1+}$ =3%	**3%**	B, C, D	**5**	1	1B
3A	15 year surveys	5%	B, C	**15**	1	1A
3B	15 year surveys; $MSYR_{1+}$ =3%	**3%**	B, C	**15**	1	1B
4A	Survey bias = 0.8	5%	B, C, D	10	**0.8**	Y
4B	Survey bias = 0.8; $MSYR_{1+}$ =3%	**3%**	B, C, D	10	**0.8**	Y
5A	Survey bias = 1.2	5%	B, C, D	10	**1.2**	Y
5B	Survey bias = 1.2; $MSYR_{1+}$ =3%	**3%**	B, C, D	10	**1.2**	Y
6A	3 episodic events	5%	B, C, D	10	1	1A
6B	3 episodic events; $MSYR_{1+}$ =3%	**3%**	B, C, D	10	1	1B
7A	Stochastic events every 5 years	5%	B, C, D	10	1	1A
7B	Stochastic events every 5 years; $MSYR_{1+}$ = 3%	**3%**	B, C, D	10	1	1B
8A	Asymmetric environmental stochasticity (depletion = 0.3)	5%*	B, C, D	10	1	Y*
8B	Asymmetric environmental stochasticity; $MSYR_{1+}$ = 3% (depletion = 0.3)	**3%***	B, C, D	10	1	Y*

* These trials are conditioned twice as outlined in Appendix 1

(b) Bowhead whales (each conducted conditioning to the estimate of abundance for West Greenland, treating this as absolute abundance)

Trial	Description	***MSYR*** $_{1+}$	**Need Scenario**	**Survey freq.**	**Canadian Catches**	**Historic Survey Bias**	**Conditioning Option**
1A	$MSYR_{1+}$ = 2.5%	2.5%	A, B	10	A	1	Y
1B	$MSYR_{1+}$ = 1%	**1%**	A, B	10	A	1	Y
1C	$MSYR_{1+}$ = 4% (and $MSYL_{1+}$=0.8)	**4%**	A, B	10	A	1	Y
2A	5 year surveys	2.5%	A, B	**5**	A	1	1A
2B	5 year surveys; $MSYR_{1+}$ =1%	**1%**	A, B	**5**	A	1	1B
3A	15 year surveys	2.5%	A, B	**15**	A	1	1A
3B	15 year surveys; $MSYR_{1+}$ =1%	**1%**	A, B	**15**	A	1	1B
4A	Survey bias = 0.5	2.5%	A, B	10	A	**0.5**	Y
4B	Survey bias = 0.5; $MSYR_{1+}$ =1%	**1%**	A, B	10	A	**0.5**	Y
5A	3 episodic events	2.5%	A, B	10	A	1	1A
5B	3 episodic events; $MSYR_{1+}$ =1%	**1%**	A, B	10	A	1	1B
6A	Stochastic events every 5 years	2.5%	A, B	10	A	1	1A
6B	Stochastic events every 5 years; $MSYR_{1+}$ = 1%	**1%**	A, B	10	A	1	1B
7A	Alternative future Canadian catches	2.5%	A, B	10	**B**	1	1A
7B	Alternative future Canadian catches; $MSYR_{1+}$=1%	**1%**	A, B	10	**B**	1	1B
9A	Alternative future Canadian catches	2.5%	A, B	10	**D**	1	1A
9B	Alternative future Canadian catches; $MSYR_{1+}$=1%	**1%**	A, B	10	**D**	1	1B
10A	Asymmetric environmental stochasticity (depletion = 0.3)	2.5%*	A, B	10	A	1	Y*
10B	Asymmetric environ. stochasticity; $MSYR_{1+}$=1% (depletion = 0.3)	**1%***	A, B	10	A	1	Y*

* These trials are conditioned twice as outlined in Appendix 1

Table 6 The *Robustness Trials*.

Humpback whales				Bowhead whales[4]			
Trial No.	**Factor**	**Need Scenario**	**Conditioning option**	**Trial No.**	**Factor**	**Need Scenario**	**Conditioning option**
1A	Linear decrease in *K*; $MSYR_{1+}$=5%	B, D	1A	1A	Linear decrease in *K*; $MSYR_{1+}$=2.5%	A	1A
1B	Linear decrease in *K*; $MSYR_{1+}$=3%	B, D	1B	1B	Linear decrease in *K*; $MSYR_{1+}$=1%	A	1B
2A	Linear increase in *M*; $MSYR_{1+}$=5%	B, D	1A	2A	Linear increase in *M*; $MSYR_{1+}$=2.5%	A	1A
2B	Linear increase in *M*; $MSYR_{1+}$=3%	B, D	1B	2B	Linear increase in *M*; $MSYR_{1+}$=1%	A	1B
3A	Strategic Surveys; $MSYR_{1+}$=5%	B, D	1A	3A	Strategic Surveys; $MSYR_{1+}$=2.5%	A	1A
3B	Strategic Surveys; $MSYR_{1+}$=3%	B, D	1B	3B	Strategic Surveys; $MSYR_{1+}$=1%	A	1B
4A	Alternative priors; $MSYR_{1+}$=5%	B, D	4A*	4A	Asymmetric environ. stochasticity; $MSYR_{1+}$=2.5% (depletion=0.15)	A	1A*
4B	Alternative priors; $MSYR_{1+}$=3%	B, D	4B*	4B	Asymmetric environ. stochasticity; $MSYR_{1+}$=1% (depletion=0.15)	A	1B*
4C	Alternative priors; $MSYR_{1+}$=7%	B, D	4C*	5A	Asymmetric environ. stochasticity; $MSYR_{1+}$=2.5% (depletion=0.6)	A	1A*
5D	$MSYR_{1+}$=1%	B, D	5D*	5B	Asymmetric environ. stochasticity; $MSYR_{1+}$=1% (depletion=0.6)	A	1B*
6A	Include mark-recapture estimates in the conditioning; $MSYR_{1+}$=5%	B, D	6A*				
6B	Include mark-recapture estimates in the conditioning; $MSYR_{1+}$=3%	B, D	6B*				
7A	Asymmetric environ. stochasticity; $MSYR_{1+}$=5% (depletion=0.15)	B, D	1A*				
7B	Asymmetric environ. stochasticity; $MSYR_{1+}$=3% (depletion=0.15)	B, D	1B*				
8A	Asymmetric environ. stochasticity; $MSYR_{1+}$=5% (depletion=0.6)	B, D	1A*				
8B	Asymmetric environ. stochasticity; $MSYR_{1+}$=3% (depletion=0.6)	B, D	1B*				

* Trial which needs to be conditioned

Appendix 1 : The Environmentally-driven Stochasticity Model

A. Basic principles
The number of calves born annually is modelled as:

$$C_y = f_y N_y^{mat} \qquad \text{(App.1.1)}$$

where f_y is the fecundity during year *y*, and N_y^{mat} is the number of mature females at the start of year *y*; f_y is assumed to be density-dependent:

$$f_y = f_0(1 + A(1-(N_y^{1+}/K^+)^z)) \quad \text{or} \quad f_y = f_0 + (f_{\max} - f_0)(1-(N_y^{1+}/K^+)^z) \qquad \text{(App.1.2)}$$

To incorporate stochasticity, f_y is modelled as follows:

$$f_y^{act} = \frac{f_{\max} f_0 e^{x_y}}{f_0 e^{x_y} + (f_{\max} - f_0)} \text{ with } x_y = \log\left[\frac{\hat{f}_y (f_{\max} - f_0)}{(f_{\max} - \hat{f}_y) f_0}\right] + \alpha_y \qquad \text{(App.1.3)}$$

where $\hat{f}_y$ is the "expected" value of f_y from equation App.1.1, and α_y accounts for auto-correlated noise. At the maximum value of *f* ($f_{\max}$), $\text{var}(f_y) = 0$, and $\text{var}(f_y)$ increases with decreasing f_y. The noise term α_y is modelled as:

$$\alpha_y = \rho_\alpha \alpha_{y-1} + \sqrt{1+\rho_\alpha^2}\,\eta_y \qquad \eta_y \sim N(0;\sigma_\alpha^2) \qquad \text{(App.1.4)}$$

where σ_α and ρ_α determine the extent of the variation and its auto-correlation respectively.

B. Parameterization
The values for σ_α and ρ_α for West Greenland humpbacks and bowheads are based on the realized variation and temporal autocorrelation of calving rates for the Eastern North Pacific humpback whales and the Bering-Chuckhi-Beaufort Seas stock of bowhead whales (Fig. App.1.1, left panel). The value for σ_α is computed for each stock by projecting equations App.1.1-App.1.4 forwards with values with $f_{\max}$ and f_0 set to the posterior medians from the conditioning process, and solving for ρ_α so that the resulting value for $\tilde{\sigma}_f$ allows the population model to match the CV of the calving rates (see Fig. App.1.1, right panel). Application of this approach involves setting N_y^{1+}/K^{1+} in equation App.1.2 (see Fig. App.1.2 for the sensitivity of variation in calving rates to the value of N_y^{1+}/K^{1+}). The base value for N_y^{1+}/K^{1+} is set to 0.3, and sensitivity is examined to values of 0.15 and 0.6 (half and double the base value) in *Robustness Trials*. The base value reflects the fact that the stocks selected by IWC (2014), which included the Eastern North Pacific humpback whales and the Bering-Chuckhi-Beaufort Seas stock of bowhead whales, were assessed to have been mainly at a low level of abundance (no more than approximately 30% of carrying capacity) over the period that the data analysed had been collected. The data for the B-C-B bowheads are too sparse to allow the extent of correlation in calving rates to be estimated reliability. The values of ρ_α for the two stocks are consequently set to the extent of autocorrelation in fecundity estimated by IWC (2014) for humpback whales.

C. Adjusting MSYR
It is well-known (e.g. Clark, 1993) that for the same parameter values MSY under stochastic conditions is less than under deterministic conditions. The aim of the trials with environmentally-driven stochasticity is to evaluate the consequences of environmental variation on fecundity without the confounding effect of a lower effective MSYR. Therefore, the input value of $MSYR_{1+}$ is adjusted for the trials with environmentally-driven stochasticity by projecting the operating model forward 100 times for 1000 years when the exploitation rate is $MSYR_{1+}$, and comparing the realized $MSYR_{1+}$ with the intended MSYR. The $MSYR_{1+}$ value input is then rescaled so that the realized $MSYR_{1+}$ equals the intended $MSYR_{1+}$. This means that each trial needs to be conducted twice, once to obtain the scaling factor for $MSYR_{1+}$ and the parameters needed to compute σ_α (see Section B above), and again once $MSYR_{1+}$ has been adjusted. The results of the second conditioning are then used to evaluate *SLA* variants.

References

Clark, W.G. 1993. The effect of recruitment variability on the choice of a target level of spawning biomass per recruit. Pages 233–246 *in* G. Kruse, R. J. Marasco, C. Pautzke, and T. J. Quinn II, editors. Proceedings of the international symposium on management strategies for exploited fish populations. University of Alaska, Alaska Sea Grant College Program Report 93-02, Fairbanks

IWC. 2014. International Whaling Commission. 2010b. Report of the Scientific Committee. Annex D. Report of the sub-committee on the Revised Management Procedure (RMP). *J. Cetacean Res. Manage (Suppl.)* 15:00-00..

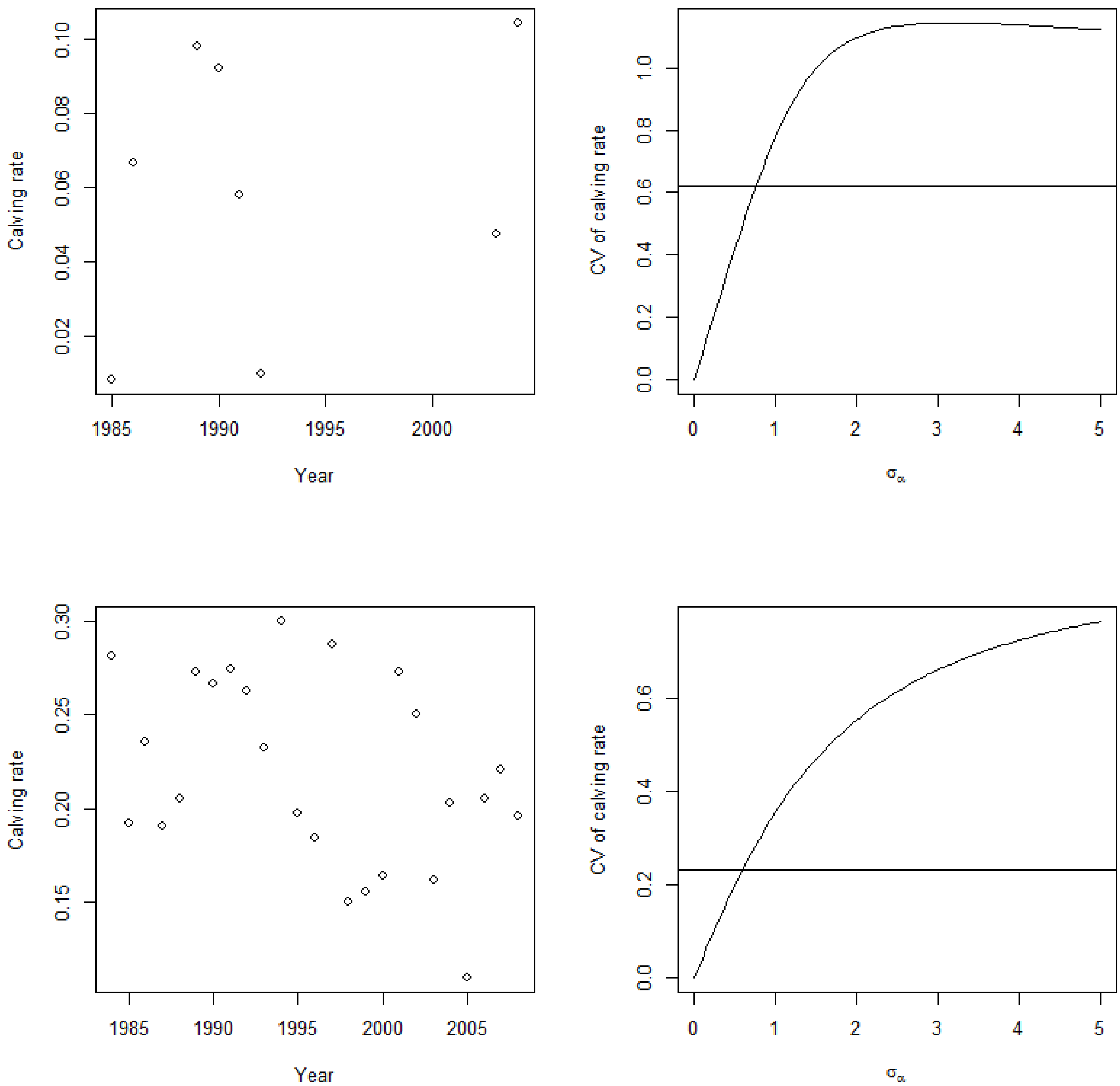

Figure App.1.1. Calving rates (left panels) and the inferred relationships between the CV of the calving rate and σ_α based on equations App.1.1-App.1.4 (right panels). The horizontal line in the right panels indicates the observed CVs of the calving rates. Results are shown for the Eastern North Pacific humpback whales and the Bering-Chuckhi-Beaufort Seas stock of bowhead whales in the upper and lower sets of panels. The calving rates for the Eastern North Pacific humpback whales are restricted to the years in which the population size was at least 30 animals to avoid the impact of observation error being interpreted as true variation in calving rates.

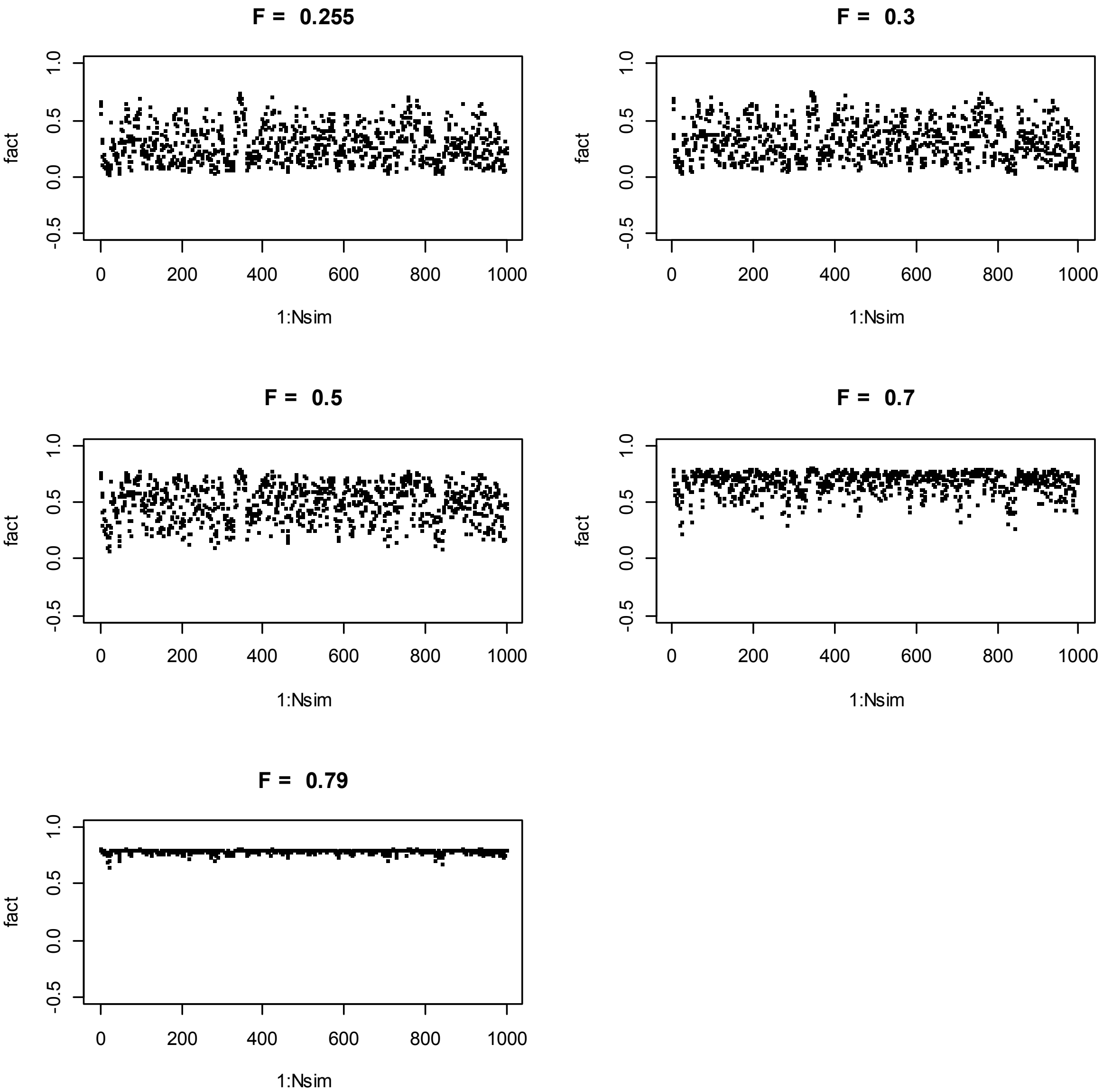

Figure App.1.2. Time-trajectories of fecundity for $\sigma_\alpha = 1$ and $\rho_\alpha = 0.707$ for different levels of exploitation rate *F* (which correspond to different levels of depletion of the 1+ component of the population).

Annex E

An approximate adjustment to the 2006 sightings abundance estimate for bowhead whales to allow for time-in-view (tiv)

D.S Butterworth

Table 1
Population estimates: the first three values are from Heide-Jørgensen *et al.;* the final entry is explained below.

Year	tiv adjusted	Estimate (CV) [95%CI	σ
2012	No	829 (0.35)[425-1,618]	0.341
2012	Yes	744 (0.34) [357-1,461]	0.344
2006	No	1,229 (0.47) [495 – 2,939]	0.445
2006	Yes	1,103 (0.47) [442-2,648]	0.447

This approximate procedure assumes that the Heide-Jørgensen *et al.* estimates are lognormally distributed. From this:

$$\text{Upper 95\%/estimate} = 1.96\ \sigma$$

With resultant values shown in Table 1.

Assuming that the tiv correction factor is independent, multiplicative and equal to 744/829 (i.e. 0.897), its σ value is:

$$\sigma_{tiv} = \sqrt{\sigma\ (2012\text{ without tiv})^2 + 0.046^2} = 0.447$$

Reversing the process it follows that:

$$\sigma_{tiv} = \sqrt{\sigma\ (2006\text{ with tiv})^2 - \sigma\ (2012\text{ without tiv})} = 0.046$$

Estimates for the tiv-corrected abundance for 2006 an dits estimates of precision then follow straightforwardly by reversing the process above.

Annex F

Historical Catches Used in the Trials

C. Allison

The catch series are compiled using the following assumptions, as agreed by the workshop (see this report Item 4).

(1) whales killed for humanitarian reasons that would be expected to die from non-anthropomorphic causes (e.g. whales trapped in ice) are excluded;
(2) whales which collide with skiffs are excluded as no visible injury is reported;
(3) whales injured by hunters but not killed are included as this is the most conservative assumption; and
(4) bycatches whose fate is unknown or which escaped towing gear are included as this is the most conservative assumption.

1. Bowhead catches since 1940

Details of catches of bowhead whales in the North Atlantic by Canada and Denmark (Greenland) since 1940 are listed in Table 1. The areas mentioned are shown in Fig 1. In addition eight bowhead whales were reported entangled in nets in Eastern Canada and West Greenland prior to 2003 (Higdon 2010) and have been incorporated into the final catch series. The catch series is believed to be complete for the period since 1940 (when the trials begin) so there is no need for an alternative catch series.

West Greenland catches of unknown sex are allocated to sex in the ratio 20M:80F, based on data from ~600 biopsy samples taken off West Greenland over the past 13 years (Heide-Jørgensen et al., 2010). A sex ratio of 50:50 is used to allocate Canadian catches of unknown sex.

The final catch series is given in Table 1a of Annex D.

Table 1. Details of the catches of bowhead whales in the North Atlantic by Canada and Denmark (Greenland) since 1940, both direct catches (D) and bycatches (BC). Struck and lost whales are shown as Type D-L. In addition eight bowhead whales were reported entangled in nets in Eastern Canada and West Greenland prior to 2003 (Higdon 2010).

Year	Area	Type	At	Date	Sex	Length	Reference	Notes
1940	C-FB	D	Lyon Inlet, SW FB				Reeves *et al* 1983; Higdon 2010	
1940	C	D					Higdon 2010	
1941	C	D					Higdon 2010	
1945	C	D					Higdon 2010	
1945	C	D					Higdon 2010	
1945	C	D					Higdon 2010	
1946	C-DS	D	Clearwater Fjord, Cumberland Sound	July		10.97m	Reeves *et al* 1983; Higdon 2010	First whale killed in this area since 1918.
1947	C	D					Higdon 2010	
1955	C	D					Higdon 2010	
1956	WG	D	~64°30'-65°N, SW Greenland	March		Small	Reeves *et al* 1983; R&HJ 1996	From Freuchen and Salomonsen, 1958. Killed: shot with rifles
1959	C	D					Higdon 2010	
1961	C	D					Higdon 2010	
1964	C-FB	D	East Igloolik Is. Area, N.FB			Large	Reeves *et al* 1983	See $. One shot.
1964	C-FB	D-L	Near Igloolik Is., N.FB	20-Aug			Reeves *et al* 1983	See $. Mother & calf, attempted kill
1964	C-FB	D	Near Jens Munk Is., N.FB	20-Aug			Reeves *et al* 1983	See $. Immature
1965	C-FB	D	Off Jens Munk Is., N.FB	End July		55ft	Reeves *et al* 1983	Just after ice breakup, harpooned then shot
1967	C-FB	D	Off Nuwuktee Is, few miles S of Jens Munk Is				Reeves *et al* 1983	Driven to shallow water and killed
1971	C-FB	D	Near Repulse Bay	13-Sep			Reeves *et al* 1983	
1971	C-FB	D	S.Foster Bay ~68°51'N 81°25'W	17-Sep		~40ft	Reeves *et al* 1983	Mitchell & Reeves, 1981; Fig 4; 1982
1973	WG	D	Qeqertarsuaq, W. Greenland	Apr			R&HJ 1996; Higdon 2010	
1975	C-FB	D	Repulse Bay Area	Summer		30ft	Reeves *et al* 1983; Mitchell 1977	Eskimo hunters
1975	C-HB	D-L	Coral Harbour Area, SE Southampton Is.				Reeves *et al* 1983; Mitchell 1977	Attempted kill; at least 1 whale known struck but lost.

Year	Area	Type	At	Date	Sex	Length	Reference	Notes
1975	C-FB	D-L	Igloolik-Hall Beach area, NW FB				Reeves *et al* 1983; Mitchell 1977	At least 1 whale known struck but lost.
1976	C-FB	D-L	Igloolik				Mitchell 1978	2 attempts made; one bowhead was shot at but not killed
1979	C	D-L	Nunavik				Higdon 2010	Not killed, escaped even after some skin and blubber removed. Other sources report that this event occurred in the 1960s not 1970s
1980	WG	BC	Kangaarsuk, NW Greenland (73°15'N 56°12'W)	~3-Nov		~9-10m	Kapel 1985	Young whale dead in white whale net. Included in Appendix 1 of Higdon 2010.
1985	C-HB	D	Arviat, W Hudson Bay				Higdon 2010	Hunters shot whale; fate unknown but a carcass washed ashore soon after
1994	C-FB	D	Near Igloolik	14-Sep	F	9m	Reeves 2012, Pomerleau et al 2011	Unlicensed; 'Young of the year calf' (DFO Science stock status report E5-52 (1999).
1996	C-FB	D	Repulse Bay	17-Aug	M	14.9m	Reeves 2012, DFO 2008	Adult. Whale sank, floated 24hrs later.
1998	C-DS	D	Pangnirtung	21-Jul	M	12.8m	Reeves 2012, DFO 2008	
2000	C-HB	D	Coral Harbour	11-Aug	M	11.7m	Reeves 2012, DFO 2008	
2002	C-FB	D	Igloolik/Hall Beach	10-Aug	F	14.2m	Reeves 2012, DFO 2008	Taken as the one listed in Higdon 2010 as 2003
2003	~~C~~	~~D~~	-	-	-	-	~~Higdon 2010~~	See 2002.
2003	WG	BC	Disko Bay, W. Greenland				Higdon 2010	May be the same whale reported as 2004.
2004	WG	BC					Higdon 2010	Caught in net; escaped after being shot
2005	C-FB	D	Repulse Bay	18-Aug	F	16.4m	Reeves 2012, DFO 2008	
2005	C	BC	Baffin Bay, Nunavut	05-Aug		Juvenile	L&H 2006; Higdon 2010	In net set for narwhals; escaped towing net. **
2005	C	BC	Nunavut				Higdon 2010	Disappeared with at least part of net. **
2006	C-BB	BC	Tremblay Sound, N Baffin Is	Aug			Postma et al 2007, Higdon 2010	Caught in narwhal net; swam off with net. **
2007	WG	BC					SC/60/ProgRepDenmark	Caught in fishing gear for crabs; freed itself
2007	WG	BC					SC/60/ProgRepDenmark	Entangled whale died
2008	C-FB	D	Hall Beach	18 Aug	M	13.4m	Reeves 2012	
2008	C-PRI	D	Near Kugaaruk	4 Sept	M	10.5m	Reeves 2012, P.*et al* 2011	
2008	C-PRI	D-L	Kugaaruk				Reeves 2012	Whale was struck but not secured
2008	C-HS	D	Kangiqsujuaq	9 Aug	M	14.9m	Reeves 2012	
2008	C	BC	Leading Tickles, Notre Dame Bay, Newfoundland	02-Sep	F	6.7m	L&H2009	Juvenile dead in boat mooring entangled in anchor rope. Samples taken.
2009	C-HB	D	Rankin Inlet	28 Aug	F	16.2m	Reeves 2012	
2009	C-PRI	D	Kugaaruk				Reeves 2012	No information. Reported catch was zero.
2009	C-HS	D	Cape Dorset	29 Sept	M	15.8m	Reeves 2012	
2009	C-HS	D	~20km SE of Kangiqsujuaq	22 Aug	F	17.3m	Reeves 2012, P.*et al* 2011	
2009	WG	D	Disko Bay, W. Greenland	30-Apr	M	14.1m	IR SC/62/BRG27	Mature
2009	WG	D	Disko Bay, W. Greenland	08-May	F	14.8m	IR SC/62/BRG27	With 3.87m male foetus
2009	WG	D	Disko Bay, W. Greenland	10-May	F	15.5m	IR SC/62/BRG27	Mature
2010	BB	D	Pond Inlet	5 Aug	M	12.8m	Reeves 2012	
2010	C-FB	D	Repulse Bay	28 Aug	F	14.3m	Reeves 2012	
2010	C-PRI	D-L	Kugaaruk	3 Sept			Reeves 2012	Whale was struck but not secured
2010	C-PRI	D-L	Kugaaruk	3 Sept			Reeves 2012	Whale was struck but not secured
2010	WG	D	Disko Bay, W. Greenland	09-Apr	F	14.35m	IR SC/62/BRG27	Mature
2010	WG	D	Disko Bay, W. Greenland	09-Apr	F	15.85m	IR SC/62/BRG27	Mature
2010	WG	D	Disko Bay, W. Greenland	01-May	F	16.10m	IR SC/62/BRG27	Mature
2011	C-DS	D	63º20'N 68º06'W Frobisher Bay	15-Aug	M	47’	DFO (McMaster 2012)	
2011	C-PRI	D	Kugaaruk	20-Aug	F	29’ 8”	DFO (McMaster 2012)	

Year	Area	Type	At	Date	Sex	Length	Reference	Notes
2011	C-HB	D	Coral Harbour	20-Sep	F	53’ 9”	DFO (McMaster 2012)	
2011	WG	D			F		SC/64/ProgRepDenmark	
2011	WG	BC	Qeqertarsuaq, W. Greenland	May		16.5m	SC/64/ProgRepDenmark	Dead, entangled in fishing gear for crabs
2011	WG	BC	Qeqertarsuaq, W. Greenland	June			SC/64/ProgRepDenmark	Dead, entangled in fishing gear for crabs
2012	C-BB	D	Arctic Bay 72°35'N 86°31'W	11-Aug	M	8.94m	DFO (Cambell 2013)	Biological data & samples were collected
2012	C-FB	D	Repulse Bay 66°30'N 85°40'W	13-Aug	M	8.10m	DFO (Cambell 2013)	Biological data & samples were collected
2012	C	D	Taloyoak 69° 42'N 92°22'W	06-Sep	F	9.57m	DFO (Cambell 2013)	Biological data & samples were collected
2013	C-DS	D	Pangnirtung 65°42'N 65°49'W	06-Aug	M	12.8m	DFO (Vuckovic Feb 2014)	Biological data & samples were collected
2013	C-FB	D	Repulse Bay 66°27'N 85°55'W	02-Sep	F	15.72m	DFO (Vuckovic Feb 2014)	Biological data & samples were collected
2013	C-PRI	D	Gjoa Haven 69°42'N 92°14'W	14-Sep	M	9.75m	DFO (Vuckovic Feb 2014)	Biological data & samples were collected

Key:
Area: C Canada; DS: Davis Strait; BB: Baffin Bay; PRI: Prince Regent Inlet / Gulf of Boothia; HS: Hudson Strait; HB: Hudson Bay; WG: W. Greenland
References: IR: Infractions report; DFO: Canadian Department of Fisheries and Oceans, unpublished data; R & H-J 1996: Reeves and Heide-Jørgenesen 1996; L&H2006: Ledwell & Huntington 2006; L&H2009: Ledwell & Huntington 2009; P *et al* 2011: Pomerleau *et al* 2011
$ Only one catch from 1964 is included in the catch series, in accordance with Higdon 2010.
** Not shot at so is not included in Higdon’s harvest table (Higdon 2010, Appendix 1).

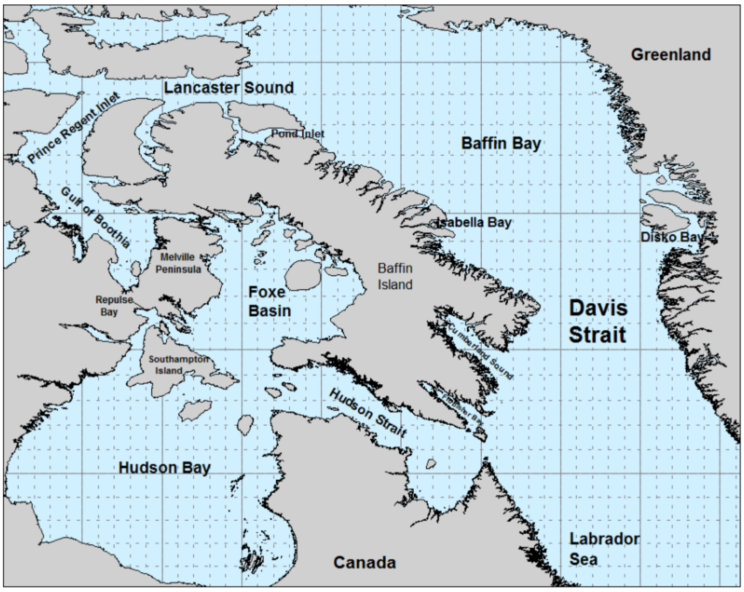

Figure 1. Map showing the main areas in which bowhead catches are recorded.

2. Humpback catches since 1960

Catches of humpback whales off West Greenland (both direct and incidental) from 1960 on are given in Table 2, since when the catches are known reliably and there is no need for an alternative series to be considered. Lost whales are not reported before 1990 but the numbers are thought to be small (IWC, 1982).

In view of possible migration routes (e.g. from telemetry data), the catch series makes an allowance for historical catches of humpback whales taken off Canada. Making simple assumptions (Greenland whales are estimated to be off Newfoundland for ~1 month in comparison to Canadian whales that are in the area for ~6 months and taking the relative abundances of the two populations into account) leads to an estimated potential catch of Greenland humpbacks off Canada of up to 5% of the total catch. Thus the catch series includes 5% of both the direct and bycatches taken off Eastern Canada. The direct catches off E. Canada are listed in Table 3.

Table 4 lists the by-catches off Eastern Canada since 1969 (the year of the first bycatch recorded in the area). From 1979 to 2008 a total of 997 humpback whales were reported as entangled in Newfoundland waters with a peak in 1991 of 139 whales (Ledwell and Huntington 2009). This peak was probably associated with large amounts of fishing gear used just prior to the moratorium on Atlantic cod fisheries in 1992. Declines in whale entrapment rates were observed following the 1992 moratorium. Recently, however, more entrapments have been reported further offshore, largely due to the expansion of fisheries targeting snow crab.

Neither catches from St. Vincent and the Grenadines or bycatches in the Gulf of Maine are included in the catch series as there is no evidence of interchange with animals from these areas (see IWC 2014, Rep 2 Item 4.3.1 and this report Item 4.1).

The final catch series is given in Table 1b of Annex D and includes a ship strike in 1997.

Table 2. Catches of humpback whales off West Greenland since 1960, both direct and indirect catches.

	Direct Catches								Bycatches					
			Total	Landed			Lost							
Year	**Start**	**End**	**Hbk**	**M**	**F**	**?**	**?**	**Source**	**Hbk**	**M**	**F**	**?**	**Source**	**Notes**
1960	Nov	Nov	1		1			CI Ka79						
1961	Nov	Nov	1	1				CI Ka79						
1962	Oct	Nov	2	1	1			CI Ka79						
1963			0											
1964			0											
1965			1			1		Ka79						
1966	Jul	Sep	4		4			CI Ka79						
1967	Aug	Aug	5			5		Ka79 CM						
1968			5			5		Ka79						
1969	Aug	Aug	3			3		CM Ka79						
1970			0											
1971	Aug	Aug	4			4		CM Ka79						
1972	Jul	Jul	3			3		CM Ka79						
1973			11			11		Ka79						
1974	Jul	Dec	9			9		CM Ka79						
1975			9			9		CM Ka79						No. = 34/PR
1976			9			9		34/PR						
1977			17			17		34/PR						
1978	Feb	Nov	23			23		35/PR						
1979	Jan	Oct	14			14		32/PR 35/PR						
1980			15			15		36/PR						
1981			12			12		34/PR 36/PR						
1982	Jan	Jun	12		1	11		IR 35/PR						Inc. 1 pregnant ♀ in Jan. =36/PR
1983	May	Oct	14			14		IR 36/PR	1			1	IR 36/PR	
1984	May		15			15		37/PR IR						
1985			9			9		GYB87						8 in 38/PR
1986			0											
1987			0											
1988			1			1		IR 41/PR						Killed as disabled
1989			2			2		IR 42/PR						Inc. 1 found dead, not an infraction
1990	May		1		1			IR LW						
1991			0					IR LW	2			2	LW	Excludes 1 caught in E. Greenland (Tasiilaq)
1992	Aug		1				1	IR LW 45/PR						Shot accidentally in minke hunt
1993			0					46/PR						Excludes one trapped in ice that was shot
1994			0			0		IR						Excludes one trapped in ice that was shot before permission was granted.
1995														
1996	Aug		1		1			IR LW	1		1		IR LW	
1997			0											
1998			0						1			1	51/PR	
1999			2				2	IR	1		1		52/PR	Includes 2 shot but not killed (infractions)

2000			0						2		2		53/PR	
2001	Jul	Aug	2				2	54/PRrev	2			2	54/PRrev	Direct catch: 2 lost whales
2002	Jul	Oct	2			2		IR	4			4	55/Inf6	Direct catch: shot after injury in rifle hunts
2003	Aug		1	1				IR	1			1	56/PR	Direct catch: calf
2004	Sep		1	1				IR	2	1	1		57/PR	
2005			0						5		1	4	58/PR	Includes 2 fate unknown
2006	Sep		1			1		IR						Illegal catch. $$
2007			0						3		1	2	60/PR	Including 1 bycatch which got free
2008			0						3			3	61/PR	
2009			0											
2010			9	3	5	1		IRrev	1	1			63/PR	
2011			8	4	4	0		IR	1	1			64/PR	
2012			10	2	4	1	3	IR	2	1		1	65a/PR	

Key to sources:

CI: Individual catch records (Allison (2013))
CM: Catch data by month and area
GYB87: Greenland year book 1987
IR: Infractions Report
Ka79: Kapel (1979).
LW: Individual data received from L. Witting March 2005
PR: Progress Report from Denmark for the given meeting e.g. 32/PR = SC/32/Prog Rep Denmark IWC 1981 p187; 34/PR: IWC 1983 p203; 35/PR: IWC 1984 p.191; 36/PR: IWC 1985 p163; 37/PR: IWC 1986 p151; 41/PR: IWC 1990 p190; 42/PR: IWC 1991 p231; 45/PR: IWC 1994 p214; 46/PR: IWC 1995 p233; 47/PR: IWC 1996 p248; (more recent Progress Reports were not published)

Additional notes

$$ 3 bycatch listed in SC60 PR as 2006 taken to mean (and listed above as) 2007
$a One fate unknown: whale not seen, but gear damaged and humpback whales seen in the area earlier

Table 3. Direct catches of humpback whales by Canada off Newfoundland and Nova Scotia since 1960, taken from individual catch records held in the IWC catch database (Allison 2013).

Year	Period	Total	Male	Fem	Notes
1965	Jun	1		1	
1969	Aug-Oct	5	1	4	Catches taken under special permit. Excludes one taken because it was entangled in netting (see table 4).
1970	Jun-Nov	15	6	9	Catches taken under special permit (samples collected)
1971	May-Nov	20	8	12	Catches taken under special permit (samples collected)

Table 4. Bycatches of humpback whales by Canada since 1969 (no records of bycatches prior to 1969 have been found). In addition a humpback was reported ship strike in 1997.

Year	Total	Alive	Fate unk.	Dead	M	F	Source	Notes
1960	0							
1961	0							
1962	0							
1963	0							
1964	0							
1965	0							
1966	0							
1967	0							
1968	0							
1969	1			1	1		CI; Perkins and Beamish 1979	Whale in cod net processed at Dildo
1970	0							
1971	0							
1972	1	1					Perkins and Beamish 1979	
1973	2		1	1			Perkins and Beamish 1979	
1974	2		1	1			Perkins and Beamish 1979	
1975	6	1	4	1	1	1	Perkins and Beamish 1979	5 entanglement events, 6 animals including a cow & calf.
1976	3	2		1	1	1	Perkins and Beamish 1979	
1977	5	3		2			Perkins and Beamish 1979	
1978	11	3	2	6			IWC 1982 p164	Not including catch in US nets (1-2 died see IWC 1980 p175)
1979	53	34		15	3	3	IWC 1981 p136, Lien 1981	Includes 47 entanglement events off Newfoundland involving 50 whales (Lien 1981) + 3 from New Brunswick and Nova Scotia.
1980	61	44		17	3	1	Lien 1994	Lien 1981 details 51 events involving 56 whales.
1981	33	25		8	2	2	IWC 1983 p199	IWC 1983 details 33 events. Lien 1994 reports 31 events including 8 dead.
1982	35	30		5	1	3	Lien 1994	SC/35/O 13 reports 4 trapped & killed.
1983	35	30		5			Lien 1994	IWC 1985 reports 6 dead.
1984	26	20		6	3		Lien 1994	
1985	52	44		8			Lien 1994	
1986	34	31		3			Lien 1994	
1987	45	41		3		1	Lien 1994, Benjamins *et al* 2012	44 in Lien 1994, inshore only. An extra whale in Benjamins *et al* is assumed to be off shore.
1988	66	54		12			Lien 1994	
1989	70	66		4			Lien 1994	
1990	75	65		10			Lien94	
1991	139						Ledwell and Huntington 2009	The peak in 1991 of 139 humpback whales reported entrapped
1992	58						Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
1993	21						Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
1994	20						Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
1995	21						Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
1996	5						Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
1997	3						Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
1998	7						Benjamins *et al* 2012	No. adjusted to include catches from unknown gear

1999	12		1		Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
2000	12		1		Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
2001	22			1	Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
2002	8				Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
2003	8			1	Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
2004	12				Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
2005	2				Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
2006	15				Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
2007	23		1		Benjamins *et al* 2012	No. adjusted to include catches from unknown gear
2008	23				Ledwell and Huntington 2009	
2009	10	2	1		Ledwell and Huntington 2010	
2010	15	2			Ledwell and Huntington 2011	
2011	9	2			Ledwell and Huntington 2012	
2012	11					No. unknown: 2009-11 average used

Key to sources:
CI: Individual catch records (Allison (2013))

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Annex G

Draft Agenda for the North Atlantic Minke Whale Stock Structure Workshop

1. OPENING REMARKS
2. APPOINTMENT OF CHAIR AND RAPPORTEURS
3. ADOPTION OF AGENDA
4. REVIEW OF AVAILABLE DOCUMENTS AND REPORTS
5. REVIEW OF EXISTING STOCK STRUCTURE HYPOTHESES
- **(1) Summary of existing hypotheses from the previous *Implementation***
- **(2) Progress and results of AWMPLite simulations to determine "management" tipping points**
- **(3) Progress and results of genetic simulations at "management" tipping points**

6. NEW OR REVISED INFORMATION AND ANALYSES RELATED TO STOCK STRUCTURE SINCE THE LAST *IMPLEMENTATION IN 200X*
- **(1) Genetic**
  - **a) Population level**
  - **b) Individual-based analyses**
- **(2) Non-genetic**
  - **a) Mark-recapture data**
  - **b) Satellite tagging**
  - **c) Morphometrics**
  - **d) Photo-identification**
  - **e) Acoustics**
  - **f) Biological parameters**
  - **g) Pollutant concentrations**
  - **h) Historical depletion patterns**
  - **i) Catch distribution**
  - **j) Sightings**
  - **k) Other**

7. DISCUSSION OF NEW INFORMATION/ANALYSES IN THE LIGHT OF THE PREVIOUS HYPOTHESES AND CONSIDERATION OF REVISED/NEW HYPOTHESES
8. FUTURE WORK AND RECOMMENDATIONS
9. OTHER BUSINESS
10. ADOPTION OF REPORT