An evaluation on four potential *SLA*s for West Greenland humpback and bowhead whales using the agreed evaluation and robustness trials

A. Brandão and D.S. Butterworth

MARAM (Marine Resources Assessment and Management Group)
Department of Mathematics and Applied Mathematics
University of Cape Town, Rondebosch 7701, South Africa

ABSTRACT

In what is an initial analysis, four possible *SLA*s are run for the evaluation and robustness trials developed at the Fourth AWMP Workshop for West Greenland humpbacks and bowhead whales. A simple integrative approach to provide a ready coarse comparison of the performance of each across all these trials is put forward, based on the lower 5%-iles of the N9 (need satisfaction) and D1 (depletion) performance statistics. There was generally little to choose between the four *SLA*s considered in terms of performance. There was a qualitative difference between the two species: for humpback the *SLA* using the most recent abundance estimate only was preferred, whereas for bowheads the preference was to use all estimates with little downweighting for time since the survey. However, none of the *SLA*s considered performed adequately in terms of resource depletion for the lowest $MSYR_{1+}$ values considered.

INTRODUCTION

This paper provides results from the application of the software developed by Andre Punt for the West Greenland humpback and bowhead whale trials as agreed at the Fourth AWMP Workshop (IWC, 2012) to four potential *SLA*s.

To facilitate comparison across these *SLA*s for each of the two species in what is an initial analysis only, a summary statistic is developed to reflect the improvement in the performance achieved by a candidate *SLA* compared to the extreme of a *Strike Limit = Need* approach.

*SLA*s CONSIDERED

Four *SLA*s are considered in this paper. Two of these form part of the 'reference *SLA*s' as given in IWC (2012) and are included here for a comprehensive description of the *SLA*s considered, while two others are variants of one of these 'reference *SLA*s'. A fifth *SLA* which sets the *Strike Limit* equal to need is also considered, but its primary use is to provide a baseline to which to compare the performances of the other *SLA*s. Hence it is not referred to in this paper as a separate *SLA*.

*SLA*1: Interim *SLA* which sets the *Strike Limit* as the lesser of need and $0.02\hat{N}e^{-1.645CV}$ where $\hat{N}$ is the most recent estimate of abundance and *CV* is the coefficient of variation of $\hat{N}$.

*SLA*2: Variant of the 'reference *SLA*' denoted here as *SLA*3 and described below. This variant sets the downweighting factor applied to the estimates of abundance to 0.8 instead of 0.9.

*SLA*3: Weighted-average interim *SLA* which uses all the abundance estimates and replaces $\hat{N}$ and *CV* in *SLA*1 by:

$$\hat{N} = \exp\left[\sum_i \frac{0.9^{t_i} \ln N_i}{CV_i^2} \Big/ \sum_i \frac{0.9^{t_i}}{CV_i^2}\right] \quad (1)$$

$$CV = \sqrt{\sum_i \frac{0.9^{2t_i}}{CV_i^2}} \Big/ \sum_i \frac{0.9^{t_i}}{CV_i^2} \quad (2)$$

where N_i is the *i*th estimate of abundance, CV_i is the coefficient of variation of N_i, and t_i is the time (in years) between when the *i*th estimate of abundance was obtained and the first year of the block for which a *Strike Limit* is needed. The downweighting factor which reduces the weight of earlier compared to more recent abundance estimates is 0.9.

*SLA*4: Variant of the 'reference *SLA*' *SLA*3 described above. This variant sets the downweighting factor applied to the estimates of abundance to 0.95.

APPROACH TO SUMMARISE RESULTS

There are over 50 evaluation and robustness trials to be considered for West Greenland bowhead whales, and even more for West Greenland humpback whales (IWC, 2012). For an initial comparison of the performance of different *SLA*s, some simple approach to summarise the results is needed. To this end two of the most important performance statistics have been selected to compare performances amongst the *SLA*s considered. These are the lower 5%-ile of average need satisfaction (N9) and the lower 5%-ile of final depletion (D1). For the purpose of this paper these two statistics are considered for the 1+ population only.

First an index is developed that provides a measure of the improvement in terms of depletion from applying one of the *SLA*s considered compared to the *SLA* that sets the *Strike Limit* equal to need. This index is defined as:

$$D_{imp} = \begin{cases} 1 & b \geq 0.7 \\ 1 & b < 0.7 \text{ and } a \geq 0.7 \\ \dfrac{a-b}{0.7-b} & b < 0.7 \text{ and } a < 0.7 \end{cases} \quad (3)$$

where *a* is the value of the lower 5%-ile depletion for the *SLA* under consideration and *b* is that for the *SLA* that sets the *Strike Limit* equal to need. In essence the D_{imp} index measures the extent by which the *SLA* under consideration improves depletion compared to the *Strike Limit = Need SLA*, but expresses this relative to the maximum improvement possible. The formulation assumes that a value of depletion above 0.7 is satisfactory, so that no benefit results from achieving a result above 0.7 (clearly results could be recalculated for a different choice for this threshold level, if desired).

The ideal result given values of the lower 5%-ile need satisfaction (N9) and of the index of depletion (D_{imp}) from a trial is for both to be (close to) 1. The statistic proposed to give a measure of the deviation from this ideal scenario for each trial and each *SLA* considered is given by:

$$Q_t^m = 1 - \frac{\sqrt{\left(1 - x_t^m\right)^2 + \left(1 - y_t^m\right)^2}}{\sqrt{2}} \tag{4}$$

where x_t^m is the lower 5%-ile average need satisfaction for trial *t* and SLA *m* and y_t^m is D_{imp} index for trial *t* and *SLA m*.

Note that Q_t^m is constructed to fall within the range [0, 1], where 1 reflects "perfect" and 0 "abysmal" performance. The statistic gives "equal" weight to need satisfaction and depletion avoidance but could readily be modified to increase the relative emphasis accorded to either.

There are two simple approaches to comparing the performance of *SLA*s under trials using this statistic, where averages are readily taken over all trials. These averages could apply either to the *Q* statistic itself or to a ranking for each trial based on the value of *Q* across the *SLA*s considered.

RESULTS AND DISCUSSION

Table 1 gives the lower 5%-ile N9 and D1 statistics for the humpback trials for each of the four *SLA*s considered, and Table 2 repeats this for the bowhead trials. Corresponding values of the *Q* statistic, and its ranking across the *SLA*s, are given in Tables 3 and 4, while Figures 1 and 2 plot the 5%-ile N9 against the D_{imp} statistic for each trial, as used to calculate the *Q* index (see equation 4), for the humpback and bowhead trials respectively. Note that the Appendix gives details of all the trials and need envelopes considered.

Unsurprisingly, Tables 1 and 2 reflect that the trials showing poor results in terms of the lower 5%-ile D1 statistic are almost all associated with the lowest value of $MSYR_{1+}$ considered (generally 3% for humpbacks for the largest need envelope and 1% for bowheads). For humpbacks extinction occurs at the 5%-ile for $MSYR_{1+}$=1% or if *M* increases for $MSYR_{1+}$=3%.

In terms of the summary *Q* statistic, there are appreciably different patterns for the two species. There are greater differences, and for more of the trials, for humpbacks compared to bowheads (Tables 3 and 4).

For humpbacks the averages for *Q* over all the trials show a clear preference for *SLA*1 (which uses only the most recent abundance estimate), though this might be surpassed by an *SLA* including more of the abundance estimates but with a downweighting factor reduced below 0.8. Under averaging of ranks across trials, however, there is rather less to choose between the four *SLA*s considered.

In contrast, for the bowheads the average Q values hardly differ, but in terms of average rank *SLA*4 is clearly preferred, and for almost every trial. Thus here the preference is to use multiple survey results, and with little historical downweighting, but this preference does not reflect a very large difference in performance in absolute terms.

In summary then:

- There is generally little to choose between the four *SLA*s in terms of performance.
- None perform adequately in terms of resource depletion for the lowest $MSYR_{1+}$ values considered.
- The qualitative difference in preference for single or multiple abundance index use between the two species is a little surprising. It might be that population model based *SLA*s would be needed if a more common (generic) approach is desired.

ACKNOWLEDGMENT

We thank the IWC for financial support for this work, and Andre Punt for developing the code for the trials.

REFERENCE

International Whaling Commission. 2012. Report of the Fourth AWMP Workshop on the Development of *SLA*s for the Greenlandic Hunts.

Table 1. Lower 5%-ile values for average need satisfaction (N9) and final depletion (D1) for West Greenland humpback whales. Results are shown for the four *SLA*s considered.

a) Evaluation Trials

Trial	Lower 5%-ile N9				Lower 5%-ile D1			
	***SLA*1**	***SLA*2**	***SLA*3**	***SLA*4**	***SLA*1**	***SLA*2**	***SLA*3**	***SLA*4**
GH01AA	0.99	1.00	1.00	1.00	0.948	0.948	0.948	0.948
GH01AB	0.99	0.99	0.99	1.00	0.906	0.905	0.905	0.905
GH01AC	0.96	0.97	0.99	1.00	0.878	0.871	0.854	0.853
GH01AD	0.94	0.94	0.95	0.97	0.878	0.873	0.868	0.863
GH01BA	0.93	0.94	0.96	0.97	0.766	0.753	0.739	0.727
GH01BB	0.91	0.93	0.96	0.97	0.703	0.679	0.660	0.616
GH01BC	0.86	0.87	0.90	0.94	0.636	0.595	0.561	0.542
GH01BD	0.79	0.80	0.77	0.77	0.481	0.435	0.369	0.337
GH01CA	0.99	1.00	1.00	1.00	0.939	0.939	0.939	0.939
GH01CB	0.91	0.94	0.97	1.00	0.892	0.888	0.886	0.868
GH01CC	0.85	0.87	0.92	0.96	0.866	0.859	0.821	0.805
GH01CD	0.85	0.87	0.92	0.97	0.865	0.852	0.827	0.816
GH02AB	0.99	1.00	1.00	1.00	0.906	0.905	0.905	0.905
GH02AD	0.96	0.98	0.98	0.99	0.878	0.863	0.863	0.863
GH02BB	0.93	0.96	0.97	0.98	0.688	0.639	0.588	0.549
GH02BD	0.81	0.83	0.84	0.83	0.496	0.349	0.286	0.267
GH03AB	1.00	1.00	1.00	1.00	0.912	0.912	0.912	0.912
GH03AD	0.95	0.96	0.98	0.99	0.879	0.878	0.876	0.872
GH03BB	0.89	0.90	0.93	0.95	0.692	0.683	0.656	0.611
GH03BD	0.75	0.75	0.77	0.78	0.390	0.380	0.280	0.196
GH04AB	1.00	1.00	1.00	1.00	0.908	0.908	0.908	0.908
GH04AD	0.93	0.96	0.98	0.98	0.884	0.875	0.873	0.873
GH04BB	0.94	0.95	0.96	0.98	0.826	0.819	0.813	0.810
GH04BD	0.87	0.88	0.90	0.90	0.743	0.715	0.640	0.615
GH05AB	0.94	0.96	0.99	1.00	0.849	0.844	0.820	0.799
GH05AD	0.95	0.95	0.96	0.98	0.878	0.873	0.868	0.863
GH05BB	0.87	0.89	0.92	0.93	0.541	0.541	0.492	0.484
GH05BD	0.69	0.68	0.68	0.66	0.291	0.256	0.165	0.127
GH06AB	0.99	0.99	0.99	1.00	0.972	0.972	0.972	0.972
GH06AD	0.94	0.95	0.95	0.96	0.948	0.944	0.941	0.939
GH06BB	0.90	0.90	0.93	0.95	0.802	0.785	0.770	0.760
GH06BD	0.77	0.78	0.80	0.78	0.551	0.501	0.386	0.300
GH07AB	0.99	0.99	0.99	1.00	0.873	0.873	0.873	0.873
GH07AD	0.95	0.95	0.96	0.98	0.840	0.840	0.836	0.833
GH07BB	0.91	0.93	0.96	0.97	0.698	0.684	0.632	0.579
GH07BD	0.80	0.83	0.79	0.79	0.444	0.407	0.358	0.322

Table 1cont. Lower 5%-ile values for average need satisfaction (N9) and final depletion (D1) for West Greenland humpback whales. Results are shown for the four *SLA*s considered.

b) Robustness Trials

Trial	**Lower 5%-ile N9**				**Lower 5%-ile D1**			
	***SLA*1**	***SLA*2**	***SLA*3**	***SLA*4**	***SLA*1**	***SLA*2**	***SLA*3**	***SLA*4**
GH21AB	0.94	0.96	0.99	1.00	0.465	0.464	0.452	0.444
GH21AD	0.86	0.88	0.94	0.95	0.453	0.448	0.437	0.387
GH21BB	0.86	0.88	0.94	0.96	0.419	0.401	0.391	0.379
GH21BD	0.77	0.77	0.77	0.77	0.367	0.342	0.302	0.226
GH22AB	0.96	0.97	0.98	0.99	0.251	0.249	0.249	0.249
GH22AD	0.88	0.90	0.94	0.95	0.219	0.216	0.211	0.211
GH22BB	0.53	0.56	0.62	0.72	0.000	0.000	0.000	0.000
GH22BD	0.36	0.39	0.45	0.49	0.000	0.000	0.000	0.000
GH23AB	0.99	1.00	1.00	1.00	0.910	0.907	0.905	0.905
GH23AD	0.96	0.96	0.97	0.97	0.878	0.873	0.870	0.863
GH23BB	0.94	0.95	0.96	0.97	0.689	0.667	0.614	0.551
GH23BD	0.79	0.80	0.76	0.74	0.477	0.435	0.369	0.337
GH24AB	0.99	1.00	1.00	1.00	0.892	0.892	0.892	0.892
GH24AD	0.94	0.95	0.96	0.97	0.847	0.845	0.844	0.844
GH24BB	0.90	0.91	0.94	0.95	0.631	0.602	0.575	0.544
GH24BD	0.66	0.66	0.65	0.65	0.513	0.469	0.375	0.307
GH24CB	0.88	0.92	0.97	0.99	0.894	0.888	0.874	0.871
GH24CD	0.76	0.79	0.86	0.92	0.871	0.862	0.854	0.842
GH25DB	0.32	0.34	0.38	0.48	0.000	0.000	0.000	0.000
GH25DD	0.22	0.23	0.27	0.33	0.000	0.000	0.000	0.000
GH26AB	0.95	0.97	0.99	1.00	0.882	0.875	0.866	0.866
GH26AD	0.88	0.91	0.94	0.95	0.847	0.838	0.814	0.802
GH26BB	0.94	0.95	0.97	0.99	0.717	0.704	0.674	0.645
GH26BD	0.80	0.80	0.79	0.77	0.481	0.435	0.369	0.337

Table 2. Lower 5%-ile values for average need satisfaction (N9) and final depletion (D1) for West Greenland bowhead whales. Results are shown for the four *SLA*s considered.

a) Evaluation Trials

Trial	Lower 5%-ile N9				Lower 5%-ile D1			
	***SLA*1**	***SLA*2**	***SLA*3**	***SLA*4**	***SLA*1**	***SLA*2**	***SLA*3**	***SLA*4**
GB01AA	0.99	1.00	1.00	1.00	0.698	0.698	0.698	0.698
GB01AB	0.97	1.00	1.00	1.00	0.685	0.685	0.685	0.685
GB01AC	0.96	0.99	1.00	1.00	0.671	0.671	0.671	0.671
GB01BA	0.90	0.94	0.99	1.00	0.033	0.031	0.031	0.031
GB01BB	0.83	0.89	0.95	1.00	0.025	0.022	0.019	0.019
GB01BC	0.71	0.79	0.90	0.97	0.019	0.015	0.008	0.006
GB01CA	0.90	0.94	0.99	1.00	0.965	0.965	0.965	0.965
GB01CB	0.80	0.85	0.92	0.99	0.942	0.938	0.937	0.937
GB01CC	0.71	0.76	0.84	0.90	0.931	0.924	0.903	0.892
GB02AA	0.98	1.00	1.00	1.00	0.698	0.698	0.698	0.698
GB02AC	0.97	1.00	1.00	1.00	0.673	0.671	0.671	0.671
GB02BA	0.90	0.99	1.00	1.00	0.033	0.031	0.031	0.031
GB02BC	0.75	0.86	0.92	0.97	0.017	0.009	0.007	0.006
GB03AA	1.00	1.00	1.00	1.00	0.698	0.698	0.698	0.698
GB03AC	0.98	0.99	1.00	1.00	0.676	0.674	0.671	0.671
GB03BA	0.90	0.95	0.99	1.00	0.031	0.031	0.031	0.031
GB03BC	0.77	0.77	0.81	0.91	0.017	0.017	0.014	0.011
GB04AA	0.96	0.99	1.00	1.00	0.905	0.905	0.905	0.905
GB04AC	0.94	0.96	0.99	1.00	0.887	0.881	0.876	0.876
GB04BA	0.91	0.96	1.00	1.00	0.138	0.125	0.125	0.125
GB04BC	0.81	0.87	0.94	0.99	0.102	0.099	0.096	0.096
GB05AA	0.99	1.00	1.00	1.00	0.817	0.817	0.817	0.817
GB05AC	0.93	0.97	1.00	1.00	0.779	0.779	0.779	0.779
GB05BA	0.92	0.97	1.00	1.00	0.186	0.183	0.182	0.182
GB05BC	0.84	0.89	0.95	1.00	0.133	0.126	0.126	0.126
GB06AA	1.00	1.00	1.00	1.00	0.650	0.650	0.650	0.650
GB06AC	0.96	1.00	1.00	1.00	0.620	0.620	0.620	0.620
GB06BA	0.94	0.99	1.00	1.00	0.161	0.158	0.158	0.158
GB06BC	0.89	0.93	0.96	1.00	0.124	0.124	0.124	0.124
GB07AA	0.99	1.00	1.00	1.00	0.685	0.685	0.685	0.685
GB07AC	–	–	–	–	–	–	–	–
GB07BA	0.88	0.94	0.99	1.00	0.022	0.019	0.019	0.019
GB07BC	0.69	0.76	0.85	0.91	0.008	0.001	0.000	0.000
GB08AA	0.99	1.00	1.00	1.00	0.672	0.672	0.672	0.672
GB08AC	0.96	0.99	1.00	1.00	0.642	0.642	0.642	0.642
GB08BA	0.86	0.92	0.99	1.00	0.009	0.006	0.006	0.006
GB08BC	0.65	0.69	0.80	0.92	0.000	0.000	0.000	0.000
GB09AA	0.99	1.00	1.00	1.00	0.701	0.701	0.701	0.701
GB09AC	0.96	0.99	1.00	1.00	0.674	0.674	0.674	0.674
GB09BA	0.90	0.96	1.00	1.00	0.037	0.036	0.036	0.036
GB09BC	0.71	0.80	0.90	0.97	0.024	0.019	0.012	0.010

Table 2cont. Lower 5%-ile values for average need satisfaction (N9) and final depletion (D1) for West Greenland bowhead whales. Results are shown for the four *SLA*s considered.

b) Robustness Trials

Trial	Lower 5%-ile N9				Lower 5%-ile D1			
	***SLA*1**	***SLA*2**	***SLA*3**	***SLA*4**	***SLA*1**	***SLA*2**	***SLA*3**	***SLA*4**
GB21AA	0.99	1.00	1.00	1.00	0.472	0.472	0.472	0.472
GB21AC	0.95	0.98	1.00	1.00	0.461	0.461	0.461	0.461
GB21BA	0.90	0.94	0.99	1.00	0.033	0.031	0.031	0.031
GB21BC	0.67	0.72	0.86	0.97	0.019	0.015	0.008	0.006
GB22AA	0.99	1.00	1.00	1.00	0.339	0.339	0.339	0.339
GB22AC	0.96	1.00	1.00	1.00	0.871	0.871	0.871	0.871
GB22BA	0.90	0.94	0.99	1.00	0.033	0.031	0.031	0.031
GB22BC	0.74	0.81	0.90	0.97	0.019	0.015	0.008	0.006
GB23AA	1.00	1.00	1.00	1.00	0.698	0.698	0.698	0.698
GB23AC	1.00	1.00	1.00	1.00	0.671	0.671	0.671	0.671
GB23BA	0.95	0.99	1.00	1.00	0.031	0.031	0.031	0.031
GB23BC	0.74	0.77	0.83	0.92	0.017	0.015	0.013	0.011

Table 3. Summary statistics to compare potential *SLA*s for West Greenland humpback whales. Trials that show the greatest differences (a *Q* difference exceeding 0.1) amongst the different *SLA*s considered are highlighted. Where ranks are equal, in the averaging a central value is taken: thus for example 1, 2, 2, 4 is counted as 1, 2.5, 2.5, 4.

a) Evaluation Trials

Trial	Q_t				Rank			
	***SLA*1**	***SLA*2**	***SLA*3**	***SLA*4**	***SLA*1**	***SLA*2**	***SLA*3**	***SLA*4**
GH01AA	0.993	1.000	1.000	1.000	4	1	1	1
GH01AB	0.993	0.993	0.993	1.000	2	2	2	1
GH01AC	0.972	0.979	0.993	1.000	4	3	2	1
GH01AD	0.958	0.958	0.965	0.979	3	3	2	1
GH01BA	0.951	0.958	0.972	0.979	4	3	2	1
GH01BB	0.936	0.900	0.832	0.652	1	2	3	4
GH01BC	0.846	0.785	0.734	0.705	1	2	3	4
GH01BD	0.734	0.697	0.628	0.599	1	2	3	4
GH01CA	0.993	1.000	1.000	1.000	4	1	1	1
GH01CB	0.936	0.958	0.979	1.000	4	3	2	1
GH01CC	0.894	0.908	0.943	0.972	4	3	2	1
GH01CD	0.894	0.908	0.943	0.979	4	3	2	1
GH02AB	0.993	1.000	1.000	1.000	4	1	1	1
GH02AD	0.972	0.986	0.986	0.993	4	2	2	1
GH02BB	0.930	0.746	0.536	0.375	1	2	3	4
GH02BD	0.754	0.626	0.567	0.546	1	2	3	4
GH03AB	1.000	1.000	1.000	1.000	1	1	1	1
GH03AD	0.965	0.972	0.986	0.993	4	3	2	1
GH03BB	0.915	0.899	0.806	0.619	1	2	3	4
GH03BD	0.640	0.632	0.546	0.468	1	2	3	4
GH04AB	1.000	1.000	1.000	1.000	1	1	1	1

Table 3cont. Summary statistics to compare potential *SLA*s for West Greenland humpback whales. Trials that show the greatest differences (a *Q* difference exceeding 0.1) amongst the different *SLA*s considered are highlighted. Where ranks are equal, in the averaging a central value is taken: thus for example 1, 2, 2, 4 is counted as 1, 2.5, 2.5, 4.

a) Evaluation Trials cont.

Trial	Q_t				Rank			
	SLA1	*SLA2*	*SLA3*	*SLA4*	*SLA1*	*SLA2*	*SLA3*	*SLA4*
GH04AD	0.951	0.972	0.986	0.986	4	3	1	1
GH04BB	0.958	0.965	0.972	0.986	4	3	2	1
GH04BD	0.908	0.915	0.804	0.731	2	1	3	4
GH05AB	0.958	0.972	0.993	1.000	4	3	2	1
GH05AD	0.965	0.965	0.972	0.986	3	3	2	1
GH05BB	0.692	0.696	0.612	0.598	2	1	3	4
GH05BD	0.532	0.498	0.414	0.373	1	2	3	4
GH06AB	0.993	0.993	0.993	1.000	2	2	2	1
GH06AD	0.958	0.965	0.965	0.972	4	2	2	1
GH06BB	0.929	0.929	0.951	0.965	3	3	2	1
GH06BD	0.778	0.746	0.653	0.567	1	2	3	4
GH07AB	0.993	0.993	0.993	1.000	2	2	2	1
GH07AD	0.965	0.965	0.972	0.986	3	3	2	1
GH07BB	0.936	0.907	0.663	0.401	1	2	3	4
GH07BD	0.705	0.681	0.624	0.590	1	2	3	4

b) Robustness Trials

Trial	Q_t				Rank			
	SLA1	*SLA2*	*SLA3*	*SLA4*	*SLA1*	*SLA2*	*SLA3*	*SLA4*
GH21AB	0.362	0.360	0.328	0.306	1	2	3	4
GH21AD	0.445	0.437	0.417	0.307	1	2	3	4
GH21BB	0.442	0.410	0.395	0.372	1	2	3	4
GH21BD	0.626	0.603	0.566	0.494	1	2	3	4
GH22AB	0.295	0.293	0.293	0.293	1	4	3	2
GH22AD	0.316	0.313	0.309	0.309	1	2	4	3
GH22BB	0.219	0.227	0.244	0.266	4	3	2	1
GH22BD	0.160	0.172	0.193	0.206	4	3	2	1
GH23AB	0.993	1.000	1.000	1.000	4	1	1	1
GH23AD	0.972	0.972	0.979	0.979	3	3	1	1
GH23BB	0.938	0.859	0.643	0.384	1	2	3	4
GH23BD	0.730	0.697	0.625	0.590	1	2	3	4
GH24AB	0.993	1.000	1.000	1.000	4	1	1	1
GH24AD	0.958	0.965	0.972	0.979	4	3	2	1
GH24BB	0.863	0.821	0.782	0.731	1	2	3	4
GH24BD	0.694	0.665	0.589	0.532	1	2	3	4
GH24CB	0.915	0.943	0.979	0.993	4	3	2	1
GH24CD	0.830	0.852	0.901	0.943	4	3	2	1
GH25DB	0.145	0.153	0.168	0.203	4	3	2	1
GH25DD	0.103	0.108	0.125	0.149	4	3	2	1
GH26AB	0.965	0.979	0.993	1.000	4	3	2	1
GH26AD	0.915	0.936	0.958	0.965	4	3	2	1
GH26BB	0.958	0.965	0.885	0.760	2	1	3	4
GH26BD	0.737	0.697	0.634	0.599	1	2	3	4

Average overall	0.801	0.791	0.766	0.739	2.667	2.500	2.492	2.342

Table 4. Summary statistics to compare potential *SLA*s for West Greenland bowhead whales. Trials that show the greatest differences amongst the different *SLA*s considered are highlighted. Where ranks are equal, in the averaging a central value is taken: thus for example 1, 2, 2, 4 is counted as 1, 2.5, 2.5, 4.

a) Evaluation Trials

Trial	Q_t				Rank			
	*SLA*1	*SLA*2	*SLA*3	*SLA*4	*SLA*1	*SLA*2	*SLA*3	*SLA*4
GB01AA	0.293	0.293	0.293	0.293	4	1	1	1
GB01AB	0.293	0.293	0.293	0.293	4	1	1	1
GB01AC	0.292	0.293	0.293	0.293	4	3	1	1
GB01BA	0.291	0.292	0.293	0.293	4	3	2	1
GB01BB	0.289	0.292	0.292	0.293	4	3	2	1
GB01BC	0.276	0.286	0.291	0.293	4	3	2	1
GB01CA	0.929	0.958	0.993	1.000	4	3	2	1
GB01CB	0.859	0.894	0.943	0.993	4	3	2	1
GB01CC	0.795	0.830	0.887	0.929	4	3	2	1
GB02AA	0.293	0.293	0.293	0.293	4	1	1	1
GB02AC	0.341	0.293	0.293	0.293	1	2	2	2
GB02BA	0.291	0.293	0.293	0.293	4	3	1	1
GB02BC	0.282	0.289	0.292	0.293	4	3	2	1
GB03AA	0.293	0.293	0.293	0.293	1	1	1	1
GB03AC	0.415	0.366	0.293	0.293	1	2	3	3
GB03BA	0.289	0.292	0.293	0.293	4	3	2	1
GB03BC	0.285	0.285	0.288	0.295	3	3	2	1
GB04AA	0.972	0.993	1.000	1.000	4	3	1	1
GB04AC	0.958	0.972	0.993	1.000	4	3	2	1
GB04BA	0.306	0.292	0.293	0.293	1	4	2	2
GB04BC	0.287	0.290	0.292	0.293	4	3	2	1
GB05AA	0.993	1.000	1.000	1.000	4	1	1	1
GB05AC	0.951	0.979	1.000	1.000	4	3	1	1
GB05BA	0.296	0.294	0.293	0.293	1	2	3	3
GB05BC	0.292	0.289	0.292	0.293	2	4	3	1
GB06AA	0.293	0.293	0.293	0.293	1	1	1	1
GB06AC	0.292	0.293	0.293	0.293	4	1	1	1
GB06BA	0.296	0.293	0.293	0.293	1	4	2	2
GB06BC	0.289	0.291	0.292	0.293	4	3	2	1
GB07AA	0.293	0.293	0.293	0.293	4	1	1	1
GB07AC	–	–	–	–	–	–	–	–
GB07BA	0.291	0.292	0.293	0.293	4	3	2	1
GB07BC	0.267	0.274	0.285	0.290	4	3	2	1
GB08AA	0.293	0.293	0.293	0.293	4	1	1	1
GB08AC	0.292	0.293	0.293	0.293	4	3	1	1
GB08BA	0.289	0.291	0.293	0.293	4	3	2	1
GB08BC	0.251	0.260	0.279	0.291	4	3	2	1
GB09AA	0.993	1.000	1.000	1.000	4	1	1	1
GB09AC	0.292	0.293	0.293	0.293	4	3	1	1
GB09BA	0.290	0.292	0.293	0.293	4	3	1	1
GB09BC	0.278	0.288	0.291	0.293	4	3	2	1

Table 4cont. Summary statistics to compare potential *SLA*s for West Greenland bowhead whales. Trials that show the greatest differences amongst the different *SLA*s considered are highlighted. Where ranks are equal, in the averaging a central value is taken: thus for example 1, 2, 2, 4 is counted as 1, 2.5, 2.5, 4.

b) Robustness Trials

Trial	Q_t				Rank			
	*SLA*1	*SLA*2	*SLA*3	*SLA*4	*SLA*1	*SLA*2	*SLA*3	*SLA*4
GB21AA	0.293	0.293	0.293	0.293	4	1	1	1
GB21AC	0.315	0.316	0.316	0.316	4	3	1	1
GB21BA	0.291	0.292	0.293	0.293	4	3	2	1
GB21BC	0.268	0.275	0.288	0.293	4	3	2	1
GB22AA	0.293	0.293	0.293	0.293	4	1	1	1
GB22AC	0.972	1.000	1.000	1.000	4	1	1	1
GB22BA	0.291	0.292	0.293	0.293	4	3	2	1
GB22BC	0.282	0.289	0.291	0.293	4	3	2	1
GB23AA	0.293	0.293	0.293	0.293	1	1	1	1
GB23AC	0.293	0.293	0.293	0.293	1	1	1	1
GB23BA	0.292	0.293	0.293	0.293	4	3	1	1
GB23BC	0.280	0.283	0.290	0.296	4	3	2	1

Average overall	0.404	0.408	0.411	0.414	3.548	2.779	2.067	1.606

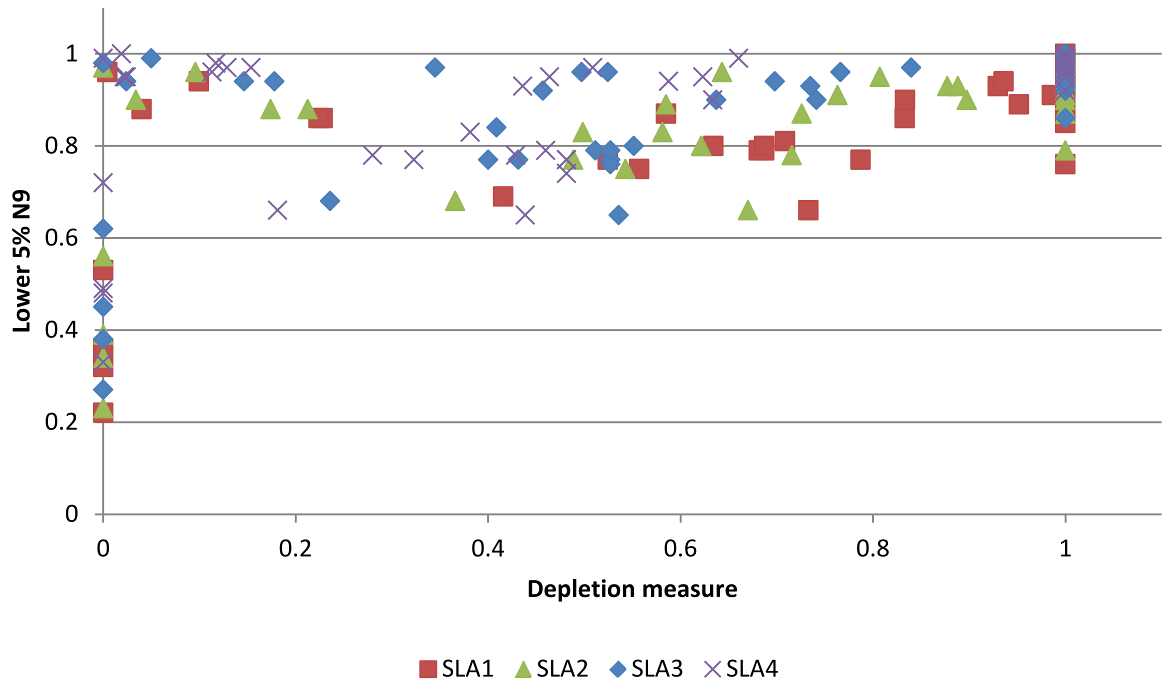

Figure 1. Plot of the lower 5%-ile average need satisfaction (N9) against the depletion improvement statistic (D_{imp}) for four potential *SLA*s for West Greenland humpback whales for all of the associated trials.

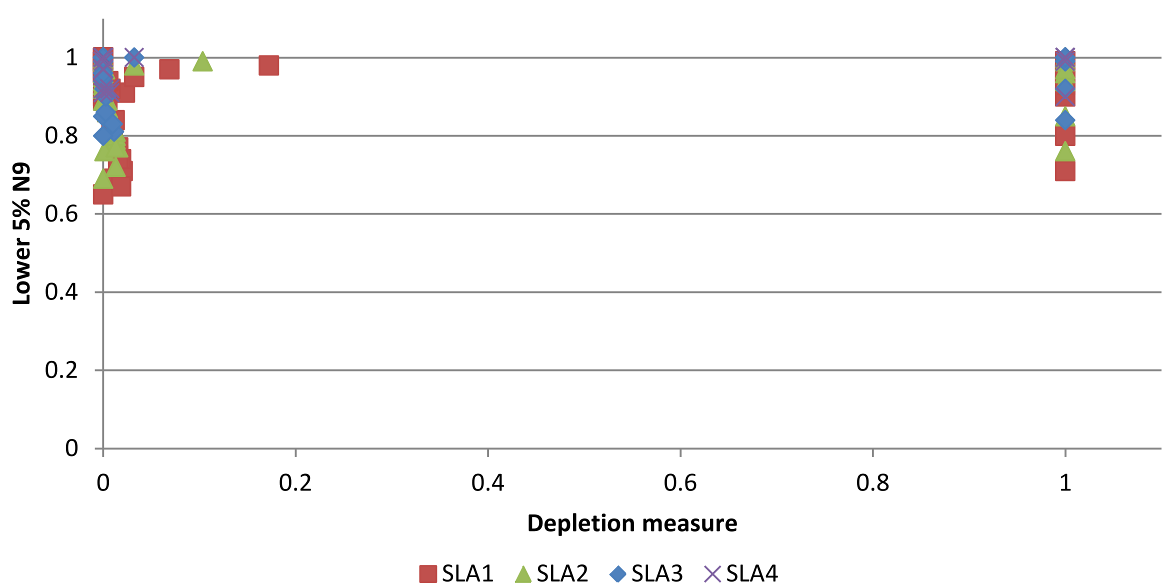

Figure 2. Plot of the lower 5%-ile average need satisfaction (N9) against the depletion improvement statistic (D_{imp}) for four potential *SLA*s for West Greenland bowhead whales for all of the associated trials.

APPENDIX

List of evaluation and robustness trials (see IWC, 2012, Table 5 of Annex F)

a) Evaluation trials for humpback whales

Trial	Description
GH01AA	$MSYR_{1+}$ = 5%; need scenario A; survey frequency = 10; historic survey bias = 1
GH01AB	$MSYR_{1+}$ = 5%; need scenario B; survey frequency = 10; historic survey bias = 1
GH01AC	$MSYR_{1+}$ = 5%; need scenario C; survey frequency = 10; historic survey bias = 1
GH01AD	$MSYR_{1+}$ = 5%; need scenario D; survey frequency = 10; historic survey bias = 1
GH01BA	$MSYR_{1+}$ = 3%; need scenario A; survey frequency = 10; historic survey bias = 1
GH01BB	$MSYR_{1+}$ = 3%; need scenario B; survey frequency = 10; historic survey bias = 1
GH01BC	$MSYR_{1+}$ = 3%; need scenario C; survey frequency = 10; historic survey bias = 1
GH01BD	$MSYR_{1+}$ = 3%; need scenario D; survey frequency = 10; historic survey bias = 1
GH01CA	$MSYR_{1+}$ = 7%; need scenario A; survey frequency = 10; historic survey bias = 1
GH01CB	$MSYR_{1+}$ = 7%; need scenario B; survey frequency = 10; historic survey bias = 1
GH01CC	$MSYR_{1+}$ = 7%; need scenario C; survey frequency = 10; historic survey bias = 1
GH01CD	$MSYR_{1+}$ = 7%; need scenario D; survey frequency = 10; historic survey bias = 1
GH02AB	$MSYR_{1+}$ = 5%; need scenario B; survey frequency = 5; historic survey bias = 1
GH02AD	$MSYR_{1+}$ = 5%; need scenario D; survey frequency = 5; historic survey bias = 1
GH02BB	$MSYR_{1+}$ = 3%; need scenario B; survey frequency = 5; historic survey bias = 1
GH02BD	$MSYR_{1+}$ = 3%; need scenario D; survey frequency = 5; historic survey bias = 1
GH03AB	$MSYR_{1+}$ = 5%; need scenario B; survey frequency = 15; historic survey bias = 1
GH03AD	$MSYR_{1+}$ = 5%; need scenario D; survey frequency = 15; historic survey bias = 1
GH03BB	$MSYR_{1+}$ = 3%; need scenario B; survey frequency = 15; historic survey bias = 1
GH03BD	$MSYR_{1+}$ = 3%; need scenario D; survey frequency = 15; historic survey bias = 1
GH04AB	$MSYR_{1+}$ = 5%; need scenario B; survey frequency = 10; historic survey bias = 0.8
GH04AD	$MSYR_{1+}$ = 5%; need scenario D; survey frequency = 10; historic survey bias = 0.8
GH04BB	$MSYR_{1+}$ = 3%; need scenario B; survey frequency = 10; historic survey bias = 0.8
GH04BD	$MSYR_{1+}$ = 3%; need scenario D; survey frequency = 10; historic survey bias = 0.8
GH05AB	$MSYR_{1+}$ = 5%; need scenario B; survey frequency = 10; historic survey bias = 1.2
GH05AD	$MSYR_{1+}$ = 5%; need scenario D; survey frequency = 10; historic survey bias = 1.2
GH05BB	$MSYR_{1+}$ = 3%; need scenario B; survey frequency = 10; historic survey bias = 1.2
GH05BD	$MSYR_{1+}$ = 3%; need scenario D; survey frequency = 10; historic survey bias = 1.2
GH06AB	$MSYR_{1+}$ = 5%; need scenario B; survey frequency = 10; historic survey bias = 1; 3 episodic events
GH06AD	$MSYR_{1+}$ = 5%; need scenario D; survey frequency = 10; historic survey bias = 1; 3 episodic events
GH06BB	$MSYR_{1+}$ = 3%; need scenario B; survey frequency = 10; historic survey bias = 1; 3 episodic events
GH06BD	$MSYR_{1+}$ = 3%; need scenario D; survey frequency = 10; historic survey bias = 1; 3 episodic events
GH07AB	$MSYR_{1+}$ = 5%; need scenario B; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years
GH07AD	$MSYR_{1+}$ = 5%; need scenario D; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years
GH07BB	$MSYR_{1+}$ = 3%; need scenario B; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years
GH07BD	$MSYR_{1+}$ = 3%; need scenario D; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years

b) Robustness trials for humpback whales

Trial	Description
GH21AB	Linear decrease in *K*; $MSYR_{1+}$ = 5%; need scenario B
GH21AD	Linear decrease in *K*; $MSYR_{1+}$ = 5%; need scenario D
GH21BB	Linear decrease in *K*; $MSYR_{1+}$ = 3%; need scenario B
GH21BD	Linear decrease in *K*; $MSYR_{1+}$ = 3%; need scenario D
GH22AB	Linear increase in *M*; $MSYR_{1+}$ = 5%; need scenario B
GH22AD	Linear increase in *M*; $MSYR_{1+}$ = 5%; need scenario D
GH22BB	Linear increase in *M*; $MSYR_{1+}$ = 3%; need scenario B
GH22BD	Linear increase in *M*; $MSYR_{1+}$ = 3%; need scenario D
GH23AB	Strategic surveys; $MSYR_{1+}$ = 5%; need scenario B
GH23AD	Strategic surveys; $MSYR_{1+}$ = 5%; need scenario D
GH23BB	Strategic surveys; $MSYR_{1+}$ = 3%; need scenario B
GH23BD	Strategic surveys; $MSYR_{1+}$ = 3%; need scenario D
GH24AB	Alternative priors; $MSYR_{1+}$ = 5%; need scenario B
GH24AD	Alternative priors; $MSYR_{1+}$ = 5%; need scenario D
GH24BB	Alternative priors; $MSYR_{1+}$ = 3%; need scenario B
GH24BD	Alternative priors; $MSYR_{1+}$ = 3%; need scenario D
GH24CB	Alternative priors; $MSYR_{1+}$ = 7%; need scenario B
GH24CD	Alternative priors; $MSYR_{1+}$ = 7%; need scenario D
GH25DB	$MSYR_{1+}$ = 1%; need scenario B
GH25DD	$MSYR_{1+}$ = 1%; need scenario D
GH26AB	Include mark-recapture estimates in the conditioning; $MSYR_{1+}$ = 5%; need scenario B
GH26AD	Include mark-recapture estimates in the conditioning; $MSYR_{1+}$ = 5%; need scenario D
GH26BB	Include mark-recapture estimates in the conditioning; $MSYR_{1+}$ = 3%; need scenario B
GH26BD	Include mark-recapture estimates in the conditioning; $MSYR_{1+}$ = 3%; need scenario D

c) Evaluation trials for bowhead whales

Trial	Description
GB01AA	$MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1
GB01AB	$MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1
GB01AC	$MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 1
GB01BA	$MSYR_{1+}$ = 1%; need scenario A; survey frequency = 10; historic survey bias = 1
GB01BB	$MSYR_{1+}$ = 1%; need scenario B; survey frequency = 10; historic survey bias = 1
GB01BC	$MSYR_{1+}$ = 1%; need scenario C; survey frequency = 10; historic survey bias = 1
GB01CA	$MSYR_{1+}$ = 4% (and MSYL1+=0.8); need scenario A; survey frequency = 10; historic survey bias = 1
GB01CB	$MSYR_{1+}$ = 4% (and MSYL1+=0.8); need scenario B; survey frequency = 10; historic survey bias = 1
GB01CC	$MSYR_{1+}$ = 4% (and MSYL1+=0.8); need scenario C; survey frequency = 10; historic survey bias = 1
GB02AA	$MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 5; historic survey bias = 1
GB02AC	$MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 5; historic survey bias = 1
GB02BA	$MSYR_{1+}$ = 1%; need scenario A; survey frequency = 5; historic survey bias = 1
GB02BC	$MSYR_{1+}$ = 1%; need scenario C; survey frequency = 5; historic survey bias = 1
GB03AA	$MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 15; historic survey bias = 1
GB03AC	$MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 15; historic survey bias = 1
GB03BA	$MSYR_{1+}$ = 1%; need scenario A; survey frequency = 15; historic survey bias = 1

GB03BC	$MSYR_{1+}$ = 1%; need scenario C; survey frequency = 15; historic survey bias = 1
GB04AA	$MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 0.5
GB04AC	$MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 0.5
GB04BA	$MSYR_{1+}$ = 1%; need scenario A; survey frequency = 10; historic survey bias = 0.5
GB04BC	$MSYR_{1+}$ = 1%; need scenario C; survey frequency = 10; historic survey bias = 0.5
GB05AA	$MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; 3 episodic events
GB05AC	$MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 1; 3 episodic events
GB05BA	$MSYR_{1+}$ = 1%; need scenario A; survey frequency = 10; historic survey bias = 1; 3 episodic events
GB05BC	$MSYR_{1+}$ = 1%; need scenario C; survey frequency = 10; historic survey bias = 1; 3 episodic events
GB06AA	$MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years
GB06AC	$MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years
GB06BA	$MSYR_{1+}$ = 1%; need scenario A; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years
GB06BC	$MSYR_{1+}$ = 1%; need scenario C; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years
GB07AA	$MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches B
GB07AC*	$MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches B
GB07BA	$MSYR_{1+}$ = 1%; need scenario A; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches B
GB07BC	$MSYR_{1+}$ = 1%; need scenario C; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches B
GB08AA	$MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches C
GB08AC	$MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches C
GB08BA	$MSYR_{1+}$ = 1%; need scenario A; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches C
GB08BC	$MSYR_{1+}$ = 1%; need scenario C; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches C
GB09AA	$MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches D
GB09AC	$MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches D
GB09BA	$MSYR_{1+}$ = 1%; need scenario A; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches D
GB09BC	$MSYR_{1+}$ = 1%; need scenario C; survey frequency = 10; historic survey bias = 1; alternative future Canadian catches D

* Trial broke down under computation, so no results are produced.

d) Robustness trials for bowhead whales

Trial	Description
GB21AA	Linear decrease in *K*; $MSYR_{1+}$ = 2.5%; need scenario A
GB21AC	Linear decrease in *K*; $MSYR_{1+}$ = 2.5%; need scenario C
GB21BA	Linear decrease in *K*; $MSYR_{1+}$ = 1%; need scenario A
GB21BC	Linear decrease in *K*; $MSYR_{1+}$ = 1%; need scenario C
GB22AA	Linear increase in *M*; $MSYR_{1+}$ = 2.5%; need scenario A
GB22AC	Linear increase in *M*; $MSYR_{1+}$ = 2.5%; need scenario C
GB22BA	Linear increase in *M*; $MSYR_{1+}$ = 1%; need scenario A
GB22BC	Linear increase in *M*; $MSYR_{1+}$ = 1%; need scenario C
GB23AA	Strategic surveys; $MSYR_{1+}$ = 2.5%; need scenario A
GB23AC	Strategic surveys; $MSYR_{1+}$ = 2.5%; need scenario C
GB23BA	Strategic surveys; $MSYR_{1+}$ = 1%; need scenario A
GB23BC	Strategic surveys; $MSYR_{1+}$ = 1%; need scenario C

Note: The last four rows reflect corrections of typos for $MSYR_{1+}$ values given in the draft meeting report (IWC, 2012).

Description of the different need scenarios and alternative future Canadian catches (see IWC, 2012, Table 4 of Annex F)

Need scenario	Description
Humpback whales	
A	Need envelop: [10, 15, 20–20 over years 18–100]
B	Need envelop: [10, 15, 20–40 over years 18–100]
C	Need envelop: [10, 15, 20–40 over years 18–100]
D	Need envelop: [20, 25, 30, 20–50 over years 18–100]

Bowhead whales	
A	Need envelop: [5 -> 5 over 100 years]
B	Need envelop: [5 -> 10 over 100 years]
C	Need envelop: [5 -> 15 over 100 years]
Alternative future Canadian catches	
A	[5 -> 5 over 100 years]
B	[5 -> 10 over 100 years]
C	[5 -> 15 over 100 years]
D	[2.5 -> 2.5 over 100 years]