DRAFT SPECIFICATIONS FOR THE AWMP / RMP IMPLEMENTATION SIMULATION TRIALS FOR THE NORTH ATLANTIC MINKE WHALES

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ABSTRACT

The purpose of this document is to provide a basis to assist in the discussions of the RMP sub-committee as it develops trials for the North Atlantic minke whales. It is written in the form of a 'trials appendix'. Some of the key pieces of additional information needed to complete the trial specifications are highlighted in yellow.

A. Basic concepts and stock-structure

The objective of these trials is to examine the performance of the RMP when managing a fishery for North Atlantic minke whales. Allowance is made for both commercial and aboriginal subsistence catches. The underlying dynamics model allows for multiple stocks and sub-stocks, and is age- and sex-structured.

The region to be managed (the Northern North Atlantic) is divided into 11 sub-areas (see Fig. 1). The term 'stock' refers to a group of whales from the same (putative) breeding ground. The 3-stock models assume there is western 'W' stock (which feeds at least in the 'WG' and 'WC' sub-areas), a central 'C' stock (which feeds at least in the 'CG', 'CIC', 'CIP', and 'CM' sub-areas), and a eastern 'E' stock (which feeds at least in the 'EN', 'EB', 'ESW', 'ESE', and 'EW' sub-areas). The 'E' and 'W' stocks are divided into sub-stocks for some of trials (sub-stocks 'E-1' and 'E-2' for the 'E' stock; sub-stocks 'W-1' and 'W-2' for the 'W' stock). There is no interchange between stocks, or sub-stocks, at least in the base-case trials. The rationale for the position of the sub-area boundaries is given in ref.

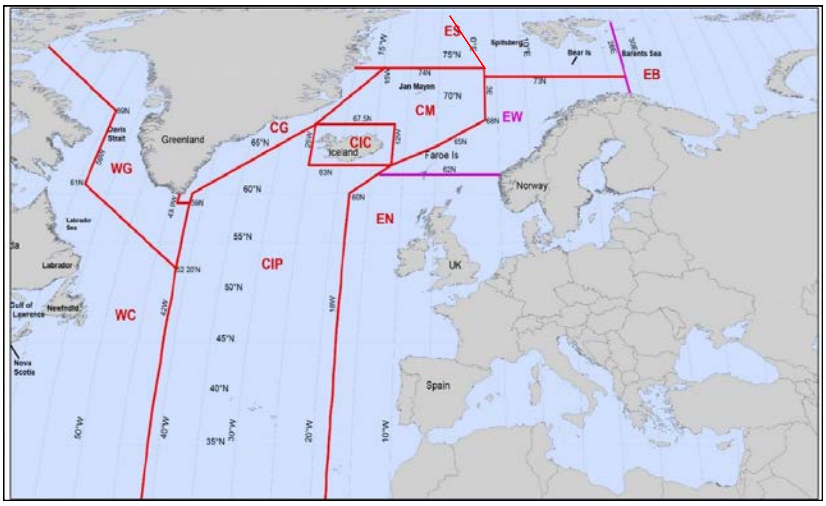

Fig. 1. Map of the North Atlantic showing the sub-areas defined for the North Atlantic Minke whales.

There are three general hypotheses regarding stock structure (see IWC [2014] for the rationale for these hypotheses):

(I) *Three stocks*. There are three stocks 'W', 'C', and 'E'. The 'W' stock consists of two sub-stocks ('W-1' and 'W-2') and the 'E' stock consists of two sub-stocks ('E-1' and 'E-2').

(II) *Two stocks.* There are three stocks 'W*', and 'E'. The 'W*' stock consists of two sub-stocks ('W' and 'C*') where the C* stock is the same as the 'C' stock for stock hypothesis I, except that the whales that occur primarily in the 'WG' sub-area are also part of this stock. The 'E' stock is defined as for stock hypothesis I.

(III) *One stock*. There is only a single ('O') stock of minke whales in the North Atlantic.

(IV) *Two cryptic stocks*. There are two stocks ('O-1' and 'O-2') of minke whales in the North Atlantic. The two stocks are found in all 11 sub-areas[1].

The trials (see Section H) include variants of these general hypotheses to capture further aspects of uncertainty regarding stock structure.

B. Basic dynamics

The dynamics of the animals in stock/sub-stock *j* are governed by equation B.1:

[1] This stock structure hypothesis was discussed by the April 2014 joint AWMP/RMP North Atlantic minke whale stock structure workshop, though it was not included in the final report of that meeting (IWC, 2014).

$$N_{t+1,a}^{g,j} = \begin{cases} 0.5 b_{t+1}^{j} & \text{if } a = 0 \\ (N_{t,a-1}^{g,j} - C_{t,a-1}^{g,j})\tilde{S}_{a-1} & \text{if } 1 \le a < x \\ (N_{t,x}^{g,j} - C_{t,x}^{g,j})\tilde{S}_{x} + (N_{t,x-1}^{g,j} - C_{t,x-1}^{g,j})\tilde{S}_{x-1} & \text{if } a = x \end{cases} \quad \text{(B.1)}$$

where $N_{t,a}^{g,j}$ is the number of animals of gender *g* and age *a* in stock/sub-stock *j* at the start of year *t*;

$C_{t,a}^{g,j}$ is the catch (in number) of animals of gender *g* and age *a* in stock/sub-stock *j* during year *t* (whaling is assumed to take place in a pulse at the start of each year);

b_t^j is the number of calves born to females from stock/sub-stock *j* at the start of year *t*;

$\tilde{S}_a$ is the survival rate = e^{-M_a} where M_a is the instantaneous rate of natural mortality (assumed to be independent of stock and gender); and

x is the maximum age (treated as a plus-group);

Note that *t*=0, the year for which catch limits might first be set, corresponds to 2014.

C. Births

Density-dependence is assumed to act on the female component of the 'mature' population. The convention of referring to the mature population is used here, although this actually refers to animals that have reached the age of first parturition.

$$b_t^j = B^j N_t^{f,j}\{1 + A^j(1 - (N_t^{f,j} / K^{f,j})^{z^j})\} \quad \text{(C.1)}$$

where B^j is the average number of births (of both sexes) per year for a mature female in stock/sub-stock *j* in the pristine population;

A^j is the resilience parameter for stock/sub-stock *j*;

z^j is the degree of compensation for stock/sub-stock *j*;

$N_t^{f,j}$ is the number of 'mature' females in stock/sub-stock *j* at the start of year *t*:

$$N_t^{f,j} = \sum_{a=3}^{x} \beta_a N_{t,a}^{f,j} \quad \text{(C.2)}$$

β_a is the proportion of females of age *a* which have reached the age-at-first partition; and

$K^{f,j}$ is the number of mature females in stock/sub-stock *j* in the pristine (pre-exploitation, written as *t*=-∞) population:

$$K^{f,j} = \sum_{a=3}^{x} \beta_a N_{-\infty,a}^{f,j} \quad \text{(C.3)}$$

The values of the parameters A^j and z^j for each stock/sub-stock are calculated from the values for $MSYL^j$ and $MSYR^j$ (Punt, 1999). Their calculation assumes harvesting equal proportions of males and females.

D. Catches

It is assumed that whales are homogeneously distributed across a sub-area. The catch/strike limit for a sub-area is therefore allocated to stocks/sub-stocks by sex and age relative to their true density within that sub-area and a mixing matrix *V*, i.e.:

$$C_{t,a}^{g,j} = \sum_k F_t^{g,k} V_{t,a}^{g,j,k} S_a^g N_{t,a}^{g,j} \quad \text{(D.1)}$$

$$F_t^{g,k} = \frac{C_t^{g,k}}{\sum_{j'} \sum_{a'} V_{t,a}^{g,j',k} S_{a'}^g N_{t,a'}^{g,j'}} \quad \text{(D.2)}$$

where $F_t^{g,k}$ is the exploitation rate in sub-area *k* on fully recruited ($S_a^g \to 1$) animals of gender *g* during year *t*;

S_a^g is the selectivity on animals of gender *g* and age *a* :

$$S_a^g = (1 + e^{-(a - a_{50}^g)/\delta^g})^{-1} \quad \text{(D.3)}$$

a_{50}^g, δ^g are the parameters of the (logistic) selectivity ogive for gender *g*;

$C_t^{g,k}$ is the catch of animals of gender *g* in sub-area *k* during year *t* (see Adjunct A); and

$V_{t,a}^{g,j,k}$ is the fraction of animals in stock/sub-stock *j* of gender *g* and age *a* that is in sub-area *k* during year *t*.

E. Mixing

The entries in the mixing matrix *V* are selected to model the distribution of each stock/sub-stock at the time when the catch is removed / when the surveys are conducted. Mixing is stochastic. For the two and three stock hypotheses, the mixing matrix for each year is selected at random from a matrix in which mixing is 'high' and in which it is 'low' (matrices A and B in Table 1). For the one stock and two cryptic stocks hypotheses, the values for the mixing matrix in Table 1 are each multiplied by a log-normal normal random variable, with mean 1 and CV xxx and renormalized. The entries in the mixing matrices for sub-stocks W-1 and W-2 (hypothesis I) and W (hypothesis II) sum to less than 1 for males and juveniles because the survey / catch data indicate that insufficient males are available in the areas for which data are available given the greater than 50% proportions of females in the catches (IWC, 2014).

Table 1

The mixing matrices. The γs and Ωs indicate that the entry concerned is to be estimated during the conditioning process. An asterisk indicates that the row concerned sums to 1. Note that the values for the γs and Ωs are the same for the high and low mixing matrices for each stock structure hypothesis.

Stock structure hypothesis I (matrix A) [high mixing]

	WC	WG	CIP	CG	CIC	CM	EN	EW	ESW	ESE	EB
Adult females (ages 10+)											
W-1 *	0.50	0.50									
W-2 *	0.20	0.45	0.10	0.20							
C *		0.1	γ_2	γ_3	0.5 γ_4	γ_5	0.05		γ_6		
E-1 *							0.1	γ_7	0.1γ_8	γ_8	γ_9
E-2 *						0.1	0.8	0.1			
Adult males (ages 10+) and juveniles											
W-1	0.5 Ω_1	0.5 Ω_2									
W-2	0.2 Ω_1	0.45 Ω_2	0.10 Ω_3	0.20Ω_4							
C *		0.1 Ω_2	γ_2 Ω_3	$\gamma_3\Omega_4$	$\gamma_4\Omega$	γ_5 Ω_6	0.05Ω_7				
E-1 *							0.1 Ω_7	γ_7 Ω_8	0.1γ_8 Ω_9	$\gamma_8\Omega_{10}$	$\gamma_9\Omega_{11}$
E-2 *						0.1Ω_6	0.8 Ω_7	0.1 Ω_8			

Stock structure hypothesis I (matrix B) [low mixing]

	WC	WG	CIP	CB	CIC	CM	EN	EW	ESW	ESE	EB
Adult females (ages 10+)											
W-1 *	1										
W-2 *		1									
C *			γ_2	γ_3	γ_4	γ_5					
E-1 *								γ_7	5γ_8	5 γ_8	γ_9
E-2 *							1				
Adult males (ages 10+) and juveniles											
W-1	Ω_1										
W-2		Ω_2									
C *			γ_2 Ω_3	γ_3 \ Ω_4	2 γ_4 Ω_5	γ_5 Ω_6					
E-1 *								γ_7 Ω_8	5γ_8 Ω_9	5 γ_8 Ω_{10}	γ_9 Ω_{11}
E-2 *							Ω_7				

Stock structure hypothesis II (matrix A) [high mixing]

	WC	WG	CIP	CG	CIC	CM	EN	EW	ESW	ESE	EB
Adult females (ages 10+)											
W *	0.6	0.2	0.	0.1							
C *		γ_1	γ_2	γ_3	0.5 γ_4	γ_5	0.05		γ_8		
E-1 *							0.1	γ_7	0.1γ_8	γ_8	γ_9
E-2 *						0.1	0.8	0.1			
Adult males (ages 10+) and juveniles											
W	0.2 Ω_1	γ_1 Ω_2	0.10 Ω_3	0.20Ω_4							
C *		0.1 Ω_2	γ_2 Ω_3	$\gamma_3\Omega_4$	$\gamma_4\Omega_5$	γ_5 Ω_6	0.05Ω_7				
E-1 *							0.1 Ω_7	γ_7 Ω_8	0.1$\gamma_8\Omega_9$	$\gamma_8\Omega_{10}$	$\gamma_9\Omega_{11}$
E-2 *						0.1Ω_6	0.8 Ω_7	0.1 Ω_8			

Stock structure hypothesis II (matrix B) [low mixing]

	WC	WG	CIP	CB	CIC	CM	EN	EW	ESW	ESE	EB
Adult females (ages 10+)											
W *	1										
C *		γ_1	γ_2	γ_3	γ_4	γ_5					
E-1 *								γ_7	5γ_8	5 γ_8	γ_9
E-2 *							1				
Adult males (ages 10+) and juveniles											
W	Ω_1										
C *		γ_1 Ω_2	γ_2 Ω_3	γ_3 \ Ω_4	2 γ_4 Ω_5	γ_5 Ω_6					
E-1 *								γ_7 Ω_8	5γ_8 Ω_9	5 γ_8 Ω_{10}	γ_9 Ω_{11}
E-2 *							Ω_7				

Stock structure hypotheses III and IV [high mixing]

	WC	WG	CIP	CG	CIC	CM	EN	EW	ESW	ESE	EB
Adult females (ages 10+)											
O *	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6	γ_7	γ_8	γ_9	γ_{10}	γ_{11}
Adult males (ages 10+) and juveniles											
O *	$\gamma_1\ \Omega_1$	$\gamma_2\ \Omega_2$	$\gamma_3\ \Omega_3$	$\gamma_4\ \Omega_4$	$\gamma_5\ \Omega_5$	$\gamma_7\ \Omega_6$	$\gamma_7\ \Omega_7$	$\gamma_8\ \Omega_8$	$\gamma_9\ \Omega_9$	$\gamma_{10}\ \Omega_{10}$	$\gamma_{11}\ \Omega_{11}$

F. Generation of Data

The actual historical estimates of absolute abundance (and their associated CVs) provided to the RMP are listed in Table 2. The proposed plan for future surveys is given in Table 3. The trials assume that it takes two years for the results of a sighting survey to become available for use by the RMP and *SLA*, i.e. a survey conducted in 2009 could first be used for setting the catch limit in 2011.

Table 2
The estimates of abundance and their sampling standard errors [To come]

Table 3
Sighting survey plan [To come]

The future estimates of abundance for a survey area (a sub-area for these trials) (say survey area E) are generated using the formula:

$$\hat{P} = P\,Y\,w / \mu = P^*\,\beta^2\,Y\,w \tag{F.1}$$

where Y is a lognormal random variable $Y = e^{\varepsilon}$ where $\varepsilon \sim N(0;\sigma_\varepsilon^2)$ and $\sigma_\varepsilon^2 = \ell\text{n}(1+\alpha^2)$;

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

P is the current total (1+) population size in survey area E:

$$P = P_t^E = \sum_{k\in E}\sum_j V_t^{j,k}\sum_g\sum_{a\ge 1} N_{t,a}^{g,j} \tag{F.2}$$

P^* is the reference population level, and is equal to the total (1+) population size in the survey area prior to the commencement of exploitation in the area being surveyed; and

F is the set of sub-areas making up survey area E.

Note that under the approximation $CV^2(ab) = CV^2(a) + CV^2(b)$, $E(\hat{P}) = P$ and $CV^2(\hat{P}) = \alpha^2 + \beta^2 P^*/P$. For consistency with the first stage screening trials for a single stock (IWC, 1991, p.109; IWC 1994, p.85), the ratio $\alpha^2 : \beta^2 = 0.12 : 0.025$, so that:

$$CV^2(\hat{P}) = \tau(0.12 + 0.025P^*/P) \tag{F.3}$$

The value of τ is calculated from the survey sampling CV's of earlier surveys in area E. If $\overline{CV^2}$ is the average value of CV^2 estimated for each of these surveys, and $\bar{P}$ is the average value of the total (1+) population sizes in area E in the years of these surveys, then:

$$\tau = \overline{CV^2} / \left(0.12 + 0.025P/\bar{P}\right) \tag{F.4}$$

Note therefore that:

$$\alpha^2 = 0.12\tau \qquad \beta^2 = 0.025\tau \tag{F.5}$$

The above equations apply in the absence of additional variance. If this is present with a *CV* of CV_{add}, then the following adjustment is made:

$$\sigma_\varepsilon^2 = \ell n\left(1 + \alpha^2 + CV_{add}^2\right) \tag{F.6}$$

An estimate of the *CV* is generated for each sighting survey estimate of abundance $\hat{P}$:

$$CV\left(\hat{P}\right)_{est}^2 = \sigma^2\chi^2/n \tag{F.7}$$

where $\sigma^2 = \ell n\left(1 + \alpha^2 + \beta^2 P^*/\hat{P}\right)$, and

χ^2 is a random number from a Chi-square distribution with n degrees of freedom (where n=10 as used for NP minke trials; IWC, 2004).

G. Parameters and conditioning

The values for the biological and technological parameters are listed in Table 4.

Table 4
The values for the biological and technological parameters that are fixed (IWC, 1993)

Parameter	Value
Plus group age, *x*	20 yrs
Natural mortality, *M*	$M_a = \begin{cases} 0.085 & \text{if } a \le 4 \\ 0.0775 + 0.001875a & \text{if } 4 < a < 40 \\ 0.115 & \text{if } a \ge 20 \end{cases}$
Selectivity, S_a^g	$a_{50}^g = 4; \delta^g = 1.2$
Maturity (first parturition), β_a	$a_{50} = 7; \delta = 1.2$
Maximum Sustainable Yield Level, *MSYL*	0.6 in terms of mature female component of the population

The 'free' parameters of the model above are the initial (pre-exploitation) sizes of each of the sub-stocks/stocks, and the values that determine the mixing matrices (i.e. the γ and Ω parameters). The process used to select the values for these 'free' parameters is known as conditioning. The conditioning process involves first generating 100 sets of 'target' data as detailed in steps (a) and (b) below, and then fitting the population model to each (in the spirit of a bootstrap). The number of animals in sub-area *k* at the start of year *t* is calculated starting with guessed values of the initial population sizes and projecting the operating model forward to 2013 to obtain values of abundance etc. for comparison with the generated data.

The information used in the conditioning process is as follows.

(a) The 'target' values for the historical abundance by sub-area are generated using the formula:

$$P_t^k = O_t^k \exp[\mu_t^k - (\sigma_t^k)^2/2]; \; \mu_t^k \sim N[0;(\sigma_t^k)^2] \qquad \text{(G.1)}$$

where P_t^k is the abundance for sub-area *k* in year *t*;

O_t^k is the actual survey estimate for sub-area *k* in year *t* (Table 2); and

σ_t^k is the CV of O_t^k.

(b) The 'target' values for the sex-ratios by sub-area are obtaining by assigning sex ratios to each sub-area and year for which the actual sex-ratio is non-zero by sampling sex-ratios with replacement for that sub-area, and computing an overall sex ratio by weighting each resampled sex-ratio by the annual catch (this approach accounts better for overdispersion than would sampling animals at random from the historical catch).

The likelihood function consists of two components.

a) Abundance estimates

$$L_1 = 0.5\sum_k \sum_t \frac{1}{(\sigma_t^k)^2}\left(P_t^k / \hat{P}_t^k\right)^2 \qquad \text{(G.2)}$$

where $\hat{P}_t^k$ is the model estimate of the number of animals aged 1 and older at the start of year *t*.

b) Catch sex ratio

$$L_2 = w\sum_k (\hat{\lambda}^k - \lambda^k)^2 \qquad \text{(G.3)}$$

where λ^k is the observed catch sex-ratio (proportion of females) for sub-area *k*;

$\hat{\lambda}^k$ is the model-estimate of the sex-ratio:

$$\hat{\lambda}^k = \sum_t (C_t^{m,k} + C_t^{f,k}) \frac{\sum_a \sum_j V_{t,a}^{f,j,k} S_a^f N_{t,a}^{f,j}}{\sum_g \sum_a \sum_j V_{t,a}^{g,j',k} S_{a'}^g N_{t,a'}^{g,j'}} \Big/ \sum_{t'} (C_{t'}^{m,k} + C_{t'}^{f,k}) \qquad \text{(G.4)}$$

w is a weight (selected so that the model fits the sex-ratio data well).

H. Trials

The *Implementation Simulation Trials* for the North Atlantic minke whales are listed in Table 5.

Table 5
The *Implementation Simulation Trials* for North Atlantic minke whales [More to Come]

Trial No.	Stock Hypothesis	*MSYR*	No. of Stocks	Boundaries	Trial Weight	Notes
NM01-1	I	1%[1]	3	Baseline		3 stocks, E and W with sub-stocks
NM01-4	I	4%[2]	3	Baseline		3 stocks, E and W with sub-stocks
NM02-1	I	1%[1]	2	Baseline		2 stocks, E with sub-stocks
NM02-4	I	4%[2]	2	Baseline		2 stocks, E with sub-stocks
NM03-1	I	1%[1]	1	Baseline		1 stock
NM03-4	I	4%[2]	1	Baseline		1 stock
NM04-1	I	1%[1]	2	Baseline		2 cryptic stocks
NM04-4	I	4%[2]	2	Baseline		2 cryptic stocks
NM05-1	I	1%[1]	3	Stock C not in ESW		3 stocks, E and W with sub-stocks
NM05-4	I	4%[2]	3	Stock C not in ESW		3 stocks, E and W with sub-stocks
NM06-1	I	1%[1]	2	Stock C not in ESW		2 stocks, E with sub-stocks
NM06-4	I	4%[2]	2	Stock C not in ESW		2 stocks, E with sub-stocks

1 – 1+; 2 –mature

I. Management Options

The following management variants will be considered:

V1 [Status-quo-like] Catch limits for sub-area WG are based on an *SLA*; Sub-areas CIC, CM, EN, EB, ES and EW are *Small Areas*, with the catch limits for these *Small Areas* based on catch cascading from the C and E *Medium Areas*. The catch limits set for the CG and CIP *Small Area* are not taken; sub-area WC is a Residual Area.

V2 To Come

J. Output Statistics

The population-size statistics are produced for each feeding ground and stock, while the catch-related statistics are for each sub-area.

(1) Total catch (TC) distribution: (a) median; (b) 5th value; (c) 95th value.
(2) Initial mature female population size ($P_{initial}$) distribution: (a) median; (b) 5th value; (c) 95th value.
(3) Final mature female population size (P_{final} distribution: (a) median; (b) 5th value; (c) 95th value.
(4) Lowest mature female population size (P_{lowest}) distribution: (a) median; (b) 5th value; (c) 95th value.
(5) Average catch by sub-area over the first ten years of the 100 year management period: (a) median; (b) 5th value; (c) 95th value.
(6) Average catch by sub-area over the last ten years of the 100 year management period: (a) median; (b) 5th value; (c) 95th value.

K. References

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