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Further examination of the relationship between MSYR1+ and MSYRmature based on individual based energetics modelling.

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Further examination of the relationship between $MSYR_{1+}$ and $MSYR_{mature}$ based on individual based energetics modelling.

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ABSTRACT

The paper reports progress on using an individual based energetics model to examine the relationship between the MSY (maximum sustainable yield) rates applicable to the population aged one year and above compared with that from the mature component of the population. The results here are for a 'like minke' energetics model. Comparing the results from the individual based model (IBM) with those from Baleen II show that the ratio between $MSYR_{mature}$ and $MSYR_{1+}$ is higher for the energetics model than for Baleen II. However, the proportion of the 1+ population that is mature is substantially lower from the IBM than for Baleen II with the consequence that using Baleen II to calculate MSY_{mature} from $MSYR_{1+}$ leads to a numeric MSY that is larger than would be obtained from the energetics model for the same 1+ population size. Averaged over the cases here the numerical MSY from applying the Baleen II model is too large by about 42%.

KEYWORDS: MSY RATE, RMP, ENERGETICS, INDIVIDUAL BASED MODELS, BALEEN II, SIMULATION

Testing and tuning of the Revised Management Procedure (RMP) is based on simulations using predominantly deterministic population models. An important feature of those models is captured in the maximum sustainable yield rate (MSYR). Recently the Scientific Committee adopted a new range and metric for MSYR in the RMP by refining the range of MSYR to 1% to 4% (IWC; 2013). The substantive change is that this range is now applied as if the population of animals aged one year and above were exploited. Previously the range applied to the mature population. It has usually been assumed that commercial whaling is likely to exploit larger and hence mature animals. Consequently in RMP trials it is necessary to convert the new range of MSYRs inferred for populations aged one and above (designated $MSYR_{1+}$) to MSYRs of mature populations ($MSYR_{mat}$).

Conventional population modelling using BALEEN II (which uses a Pella-Tomlinson model stock recruitment relationship) (de la Mare and Cooke, 1992) shows that the relationship between $MSYR_{1+}$ and $MSYR_{mat}$ depends on assumptions on the component of the population deemed to drive density dependence (de la Mare and Cooke 1994) and the rate of natural mortality (M) (Butterworth and Punt, 1992). For example with M ~ 0.05, the value typically used in the RMP models, $MSYR_{mat}$ is about 1.5 greater than $MSYR_{1+}$.

However, the conventional Pella-Tomlinson model used in the RMP has density dependence only on recruitment. Natural mortality rates were assumed both density-independent and independent of age except for calves. Calf mortality is set using an implicit balance equation, and is also assumed to be density independent. Even without density dependence in mortality, age dependence in mortality leads to the average natural mortality being related to exploitation rate (de la Mare, 1985) and this is not accounted for in the conventional formulation.

The analyses that led to the revision of the range of MSYR relied on inferring MSY rate from the rate of increase of depleted populations (IWC; 2013). These analyses took into account evidence the rate of increase was influenced by random environmental fluctuations (Cook; 2011). Density dependence in mortality was also shown to be potentially important, but there was little in the way of direct evidence to calculate the likely magnitude of any such density dependence. De la Mare (2013a) developed an individual based energetics model (IBM) to determine the likely size of such effects by using a process-based model in which whale population rate of increase is dependent on prey abundance and variability. This model leads to density dependence in both birthrates and in calf and age-dependent natural mortality and also includes the effects due to harvest induced changes in age structure on reproduction and mortality. This model thus allows for the relationship between $MSYR_{1+}$ and $MSYR_{mat}$ to be calculated taking into account that density dependence will be occur in both recruitment and mortality.

The IBM has now been set up with parameters to give minke like population dynamics. Runs of the model with differences in prey abundance have been run at different exploitation rates to obtain a set of yield curves. The yield curves are estimated by fitting a smoothing function to the model outputs from a single replicates of 2500 years of exploitation. The fitted curve is used purely as a descriptive model to calculate MSYR and MSYL. Table 1 shows the properties of the yield curves from all the model realisations including the ratio of MSY_{mat} to $MSYR_{1+}$. The table also includes the corresponding ratios for $MSYR_{mat}$ to $MSYR_{1+}$ from the Baleen II model for similar ages of maturity but with constant natural mortality for animals aged 1 and above. The Baleen II calculations are set up so that the same $MSYL_{mat}$ and $MSYR_{mat}$ is obtained as for the IBM. This means that in general the BALEEN model gives different values $MSYL_{1+}$ and $MSYR_{1+}$ than those from the IBM. Interestingly, the results from the IBM here give a higher ratio of $MSYR_{mat}$ to $MSYR_{1+}$ than from the Baleen II model. This is different from the results reported in de la Mare and Miller (2015) for "humpback like" energetics models where the ratio for the energetics model was lower. These differences are probably due to the earlier ages of maturity for the humpback models. The average ratio here for the IBM is 1.93 and the value does not seem to depend to any great extent on MSYR. For Baleen II the corresponding average is 1.625.

In setting up simulation models for the RMP values of $MSYR_{1+}$ are scaled up to $MSYR_{mat}$ through a population model. However, a second scaling occurs through the calculation of the mature population size from the 1+ population size. These two scale factors determine the numerical value of MSY for the mature population. For RMP simulation trials it is the numerical MSY, not MSYR alone, that determines the outcomes in terms of catch and depletion. The Table shows the proportion of the total 1+ population that is mature for both models. For the IBM the mean value of this ratio is 0.408. Obviously the ratio of mature to 1+ population size depends on juvenile survival. The proportion of the total 1+ population that is mature in the Baleen II case is 0.688. For the IBM the ratio is less than for the BALEEN model, for which it has been assumed that juvenile and adult natural mortality rates are the same.

We can use these figures to get a rough idea of the difference between the two models in scaling the numerical MSY. The approximate numerical yield from the IBM model for an MSYR of 1% is $0.01*1.93*0.408*MSYL_{mat}$. If we scale to the same MSYR and MSYL the numerical yield for the BALEEN II model is $0.01*1.625*0.688*MSYL_{mat}$. The numerical MSY_{mat} from the BALEEN II model is therefore about 42% greater than from the IBM.

Consequently for setting up RMP simulations we need to pay attention not only to the relationship between $MSYR_{1+}$ and MSYR of the exploited population but also to the relationship between the abundance of the exploited population and the total 1+ population. This latter factor depends on age dependence in mortality, particularly for young age-classes. The IBM models provide a means for improving this aspect of the simulation models.

The results of the simulations have been use to estimate a range of demographic parameters, including their variability and the correlation between them. The full results are available as flat files readable in R. Various summary plots of the results are available as pdfs that can be made available in a zip file. The raw results from the simulations can also be made available, however the total size of these files is about 20 gigabytes.

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Table 1. Minke yield statistics for different MSY rates derived from different prey scenarios with related calculations using BALEEN II

1+						Mature						Energetics Model			Baleen II		
K	r_0	MSYR	MSYL	$\frac{MSYR}{r_0}$	MSY	K	r_0	MSYR	MSYL	$\frac{MSYR}{r_0}$	MSY	$\frac{MSYRm}{MSYR1+}$	$\frac{MSYm}{MSY1+}$	$\frac{Km}{K1+}$	$\frac{MSYRm}{MSYR1+}$	$\frac{MSYm}{MSY1+}$	$\frac{Km}{K1+}$
87355	0.0701	0.0360	0.691	0.5142	2174.85	35522	0.1422	0.0759	0.594	0.5335	1601.07	2.106	0.736	0.407	1.817	0.863	0.688
67782	0.0667	0.0361	0.546	0.5406	1334.17	28136	0.1313	0.0692	0.507	0.5267	986.71	1.919	0.740	0.415	1.757	0.869	0.688
53973	0.0632	0.0321	0.513	0.5075	888.51	22777	0.1262	0.0579	0.498	0.4587	656.53	1.804	0.739	0.422	1.693	0.881	0.688
41071	0.0599	0.0279	0.499	0.4662	572.61	17525	0.1174	0.0530	0.458	0.4516	425.48	1.897	0.743	0.427	1.654	0.887	0.688
44423	0.0638	0.0304	0.673	0.4763	908.56	18048	0.1329	0.0618	0.590	0.4652	658.39	2.035	0.725	0.406	1.737	0.878	0.688
31002	0.0582	0.0274	0.521	0.4712	443.05	12899	0.1167	0.0534	0.468	0.4578	322.60	1.948	0.728	0.416	1.659	0.886	0.688
22432	0.0516	0.0239	0.655	0.4632	351.01	8891	0.1064	0.0477	0.594	0.4482	251.76	1.995	0.717	0.396	1.657	0.893	0.688
38480	0.0602	0.0297	0.521	0.4929	594.43	15992	0.1207	0.0603	0.453	0.4997	437.05	2.035	0.735	0.416	1.765	0.918	0.688
41024	0.0608	0.0298	0.499	0.4893	609.22	17303	0.1238	0.0536	0.477	0.4324	441.98	1.799	0.725	0.422	1.664	0.886	0.688
32452	0.0606	0.0269	0.674	0.4431	587.50	13096	0.1232	0.0521	0.620	0.4229	422.95	1.939	0.720	0.404	1.687	0.888	0.688
31002	0.0577	0.0274	0.521	0.4744	442.40	12899	0.1166	0.0534	0.469	0.4581	323.11	1.950	0.730	0.416	1.660	0.886	0.688
45993	0.0661	0.0294	0.521	0.4449	704.01	19378	0.1221	0.0555	0.485	0.4546	521.61	1.889	0.741	0.421	1.676	0.884	0.688
42111	0.0402	0.0136	0.388	0.3396	222.70	16195	0.0774	0.0261	0.383	0.3374	162.08	1.917	0.728	0.385	1.503	0.918	0.688
90789	0.0461	0.0168	0.525	0.3643	800.76	36445	0.0892	0.0325	0.494	0.3644	585.48	1.936	0.731	0.401	1.557	0.911	0.688
82824	0.0488	0.0168	0.481	0.3442	669.68	33906	0.0839	0.0299	0.493	0.3561	499.30	1.777	0.746	0.409	1.544	0.914	0.688
99848	0.0477	0.0178	0.529	0.3724	938.08	40104	0.0926	0.0337	0.508	0.3634	685.95	1.896	0.731	0.402	1.567	0.910	0.688
108077	0.0491	0.0184	0.522	0.3749	1037.49	44248	0.0915	0.0360	0.474	0.3932	754.42	1.956	0.727	0.409	1.572	0.907	0.688
66554	0.0467	0.0133	0.523	0.2836	461.55	25525	0.0826	0.0250	0.527	0.3031	336.56	1.887	0.729	0.384	1.523	0.920	0.688
62642	0.0404	0.0144	0.476	0.3559	428.48	25105	0.0792	0.0284	0.446	0.3581	317.43	1.973	0.741	0.401	1.528	0.916	0.688
66471	0.0498	0.0154	0.475	0.3087	485.60	27191	0.0787	0.0282	0.461	0.3588	353.99	1.836	0.729	0.409	1.529	0.916	0.688
14153	0.0331	0.0121	0.448	0.3666	76.91	5641	0.0731	0.0241	0.411	0.3294	55.85	1.986	0.726	0.399	1.500	0.921	0.688
23621	0.0604	0.0123	0.427	0.2045	124.46	9795	0.0633	0.0244	0.380	0.3851	90.67	1.974	0.728	0.415	1.494	0.920	0.688
											Means ->	1.930	0.732	0.408	1.625	0.899	0.688