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Progress report on modelling the relationship between MSYRmat and MSYR1+ based on energetics modelling

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Progress report on modelling the relationship between $MSYR_{mat}$ and $MSYR_{1+}$ based on 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 energetics based model indicates that MSY rates of 1% to 7% for the mature population translates into a range for MSY rates for the population aged one and above of 0.9% to 5.5%. The modelling work to produce results for a like minke energetics model is on-track for completion in the coming year.

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. The most 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 ($MSYR_{mat}$).

Tuning of the RMP has been undertaken using $MSYR_{mat}$ = 1%. The consequence of the change to $MSYR_{1+}$ assumed, for example, that $MSYR_{1+}$ = 1% leads to $MSYR_{mat}$ calculated to be greater than 1%. 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, $MSYR_{1+}$ was multiplied by 1.5 to convert it to $MSYR_{mat}$.

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 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 (IBEM) 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 MSYR1+ and $MSYR_{mat}$ to be calculated taking into account that density dependence will be occur in both recruitment and mortality.

De la Mare (2013b) presented results from 29 realisations of the IBEM covering ranges of $MSYR_{1+}$ from less than 1% to greater than 7%. The energetics of the species and its relationships to population demography are the same in all 29 models. Thus the differences in the model realisations derive only from the characteristics of the prey populations; the different yield curves do not derive from changes in the functional relationships between population energetics and food.

Last year the SC agreed that further work on this issue was required and requested that demographic parameters be generated from the IBEM so that they can be incorporated into simpler age-structured models that are less computationally intensive. These models will make it easier to explore the relative importance of different demographic relationships in determining the ratios between MSYR1+ and MSRYmat.

The same basic models conditioned on humpback whale demography will be used here to calculate $MSYR_{1+}$ and $MSYR_{mat}$ from yield curves derived from exploiting the corresponding population segments at a range of fixed harvest rates. However, the growth model has been adjusted to reduce the amount of change that can occur in growth rates and hence ages at sexual maturity. This was achieved by changing the heritability of growth so that the intrinsic growth curve for a calf is set half way between the population mean growth curve and the growth curve of the mother (taking into account the calf's sex and including a stochastic term). The previous results were from a model that had a calf inheriting the growth curve of the mother (including a sex and stochastic terms). This resulted in some cases the ages at sexual maturity becoming lower than expected. That behaviour is avoided in the new model, and is the probable reason why the MSYR multipliers are a bit higher in this version than last year's. However, the adjusted model has also had an effect of reducing R0 and MSYrates by about 25% as well. Four of the previous 29 model runs are either not feasible with the adjusted model or require longer year spans to get more consistent estimates of yield curves.

The yield curves are estimated by fitting a Pella-Tomlinson yield curve to the model outputs from a single replicates of 500 years of exploitation (in the lowest yield realisation the year span was increased to 2500 years improve accuracy). 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 2 model realisations including the ratio of MSY_{mat} to $MSYR_{1+}$. Fig 1 shows a quadratic regression passing through the origin to give the following expression for converting $MSYR_{1+}$ (y_{mat}) to $MSYR_{mat}$ (y_{1+}):

$$y_{mat} = y_{1+}\left(1.069 + 3.905 y_{1+}\right)$$

Thus at $MSYR_{1+}$ = 0.01, $MSYR_{mat}$ = 0.0111, that is a multiplier of 1.11. The value $MSYR_{1+}$ = 0.0546 produces $MSYR_{mat}$ = 0.0700, which is a multiplier of 1.28.

The results of the simulations have been use to estimate a range of demographic parameters, including their variability and the correlation between them. Table 2 shows and example of the calculated outputs. The full results are available as flat files readable in R. Figs 2 to 5 show some examples of model results including effects of density dependence in natural mortality of matures, juveniles and calves for the 1+ exploited population along with pregnancy rate. As expected the mature and juvenile mortality rates decline with reduction in population abundance, while pregnancy rate increases. Perhaps counterintuitive is that calf mortality increases at lower density. However, pregnancy rate increases at lower abundance (as expected) but the increase in calf mortality is probably due to the increase in pregnancy rates. General inspection of the results suggests that although there is some density dependence in most of the demographic parameters, these are not particularly substantial except in the cases of juvenile and mature mortality, which are the main drivers of the density dependent response at least in these like humpback populations.

PROGRESS

The modelling is progressing on schedule. The current results and analysis scripts can be made available to SC members who are considering developing age-structured models to emulate the IBEM results. The next round of modelling is to condition the energetics and demographic parameters to be like minke whales. It is anticipated that these further results will be available in the coming year.

REFERENCES

Butterworth, D. S. and Punt, A. E. 1992. The Scientific Committee '... agreed that the MSY rate would most likely lie between 1 and 4%' - but which MSY rate? Rep int. Whal. Commn 42:583-91.

Cooke, J. G. 2011. Further analyses of the expected relationship between variability in reproductive rate and net recruitment rate based on life history trade-off models. SC/63/RMP 26 presented to the IWC Scientific Committee, June 2011

Cooke, J. G. and de la Mare, W. K. 1994. Some aspects of the estimation and modelling of baleen whale sustainable yields. *Rep int. Whal. Commn* 44:451-7.

de la Mare, W. K. 1985. On the estimation of mortality rates from whale age data, with particular reference to minke whales (*Balaenoptera acutorostrata*) in the Southern Hemisphere. *Rep. int. Whal. Commn* 35:239-50.

de la Mare, W. K. and Cooke, J. G. 1992. Baleen II: The population model used in the Hitter/Fitter programs. *International Whaling Commission Technical Report.* International Whaling Commission, Cambridge. *25pp.*

de la Mare, W. K. 2013a. Implications of energy budgets in determining the characteristics of whale yield curves. Paper presented to the Fourth MSYR Workshop, La Jolla, March 2013.

de la Mare, W. K. 2013b. A note on variability in R0 calculated from an individually based baleen whale energetic model. Paper SC/65a/RMP09 presented to the Scientific Committee, Jeju, Republic of Korea, 2013.

IWC. 2013. Report of the Scientific Committee Annual Meeting 2013.

Table 1. Updated statistics from 25 different prey abundance and variability scenarios

Model	Prey abund.	Prey CV	1+					Mature					MSYRmat / MSYR1+
			K	r0	MSYR	MSYL	MSYR/r0	K	r0	MSYR	MSYL	MSYR/r0	
1	10000	0.	64422	0.0742	0.0534	0.609	0.7195	48989	0.1094	0.0685	0.556	0.6259	1.283
2	10000	0.5	54235	0.0744	0.0493	0.575	0.6626	40272	0.1078	0.0632	0.536	0.5859	1.282
3	10000	0.7	48740	0.0749	0.0467	0.555	0.6240	35923	0.1082	0.0609	0.526	0.5623	1.304
4	10000	0.9	43224	0.0866	0.0507	0.536	0.5855	31610	0.1159	0.0637	0.520	0.5499	1.256
5	5000	0.5	25704	0.0746	0.0431	0.532	0.5777	19008	0.0936	0.0529	0.527	0.5468	1.227
6	5000	0.7	20549	0.0619	0.0369	0.541	0.5954	15704	0.0865	0.0454	0.510	0.5245	1.230
7	5000	0.9	17135	0.0620	0.0361	0.534	0.4894	13203	0.0895	0.0438	0.496	0.4894	1.213
8	3000	0.5	9871	0.0673	0.0313	0.487	0.4653	7505	0.0760	0.0357	0.489	0.4702	1.141
9	3000	0.7	6900	0.0703	0.0262	0.456	0.3732	5181	0.1007	0.0333	0.444	0.3311	1.271
10	3000	0.9	4311	0.1112	0.0233	0.412	0.2094	3116	0.0977	0.0271	0.429	0.2773	1.163
11	2500	0.5	5465	0.0685	0.0257	0.457	0.3743	4124	0.0933	0.0313	0.445	0.3353	1.218
12	2500	0.7	3484	0.1817	0.0263	0.397	0.1449	2597	0.2882	0.0358	0.393	0.1242	1.361
13	2500	0.9	3811	0.0949	0.0235	0.421	0.2476	2908	0.1570	0.0278	0.404	0.1770	1.183
14	3000	0.5	35958	0.0436	0.0228	0.509	0.5224	27321	0.0546	0.0272	0.499	0.4985	1.193
15	3000	0.7	30833	0.0399	0.0204	0.504	0.5104	23543	0.0545	0.0249	0.484	0.4575	1.221
16	3000	0.9	20090	0.0478	0.0173	0.453	0.3632	15193	0.0519	0.0204	0.463	0.3939	1.179
17	2500	0.5	20299	0.0372	0.0223	0.542	0.5988	19356	0.0458	0.0210	0.485	0.4591	0.942
18	2300	0.9	14985	0.0506	0.0176	0.449	0.3480	11474	0.0572	0.0197	0.448	0.3440	1.119
19	2300	0.7	24872	0.0473	0.0197	0.470	0.4174	16792	0.0514	0.0250	0.495	0.4870	1.270
20	2500	0.7	43244	0.0497	0.0249	0.500	0.5009	32939	0.0605	0.0293	0.494	0.4852	1.177
21	2500	0.9	32045	0.0534	0.0233	0.477	0.4366	24033	0.0599	0.0273	0.483	0.4550	1.172
22	2000	0.9	13667	0.0522	0.0311	0.487	0.4638	7744	0.0437	0.0231	0.512	0.5294	0.743
23	1800	0.9	6642	0.0422	0.0117	0.429	0.2776	4940	0.0520	0.0150	0.432	0.2876	1.282
24	1600	0.9											
25	1500	0.9											
26	1800	0.9	21563	0.0206	0.0060	0.433	0.2913	14365	0.1043	0.0063	0.547	0.6085	1.055
27	1800	0.0											
28	2500	1.0	36903	0.0435	0.0219	0.501	0.5032	28357	0.0589	0.0276	0.488	0.4681	1.260
29	1800	0.5											
Mean				0.0652	0.0285	0.491	0.4521		0.0887	0.0342	0.484	0.4429	1.190

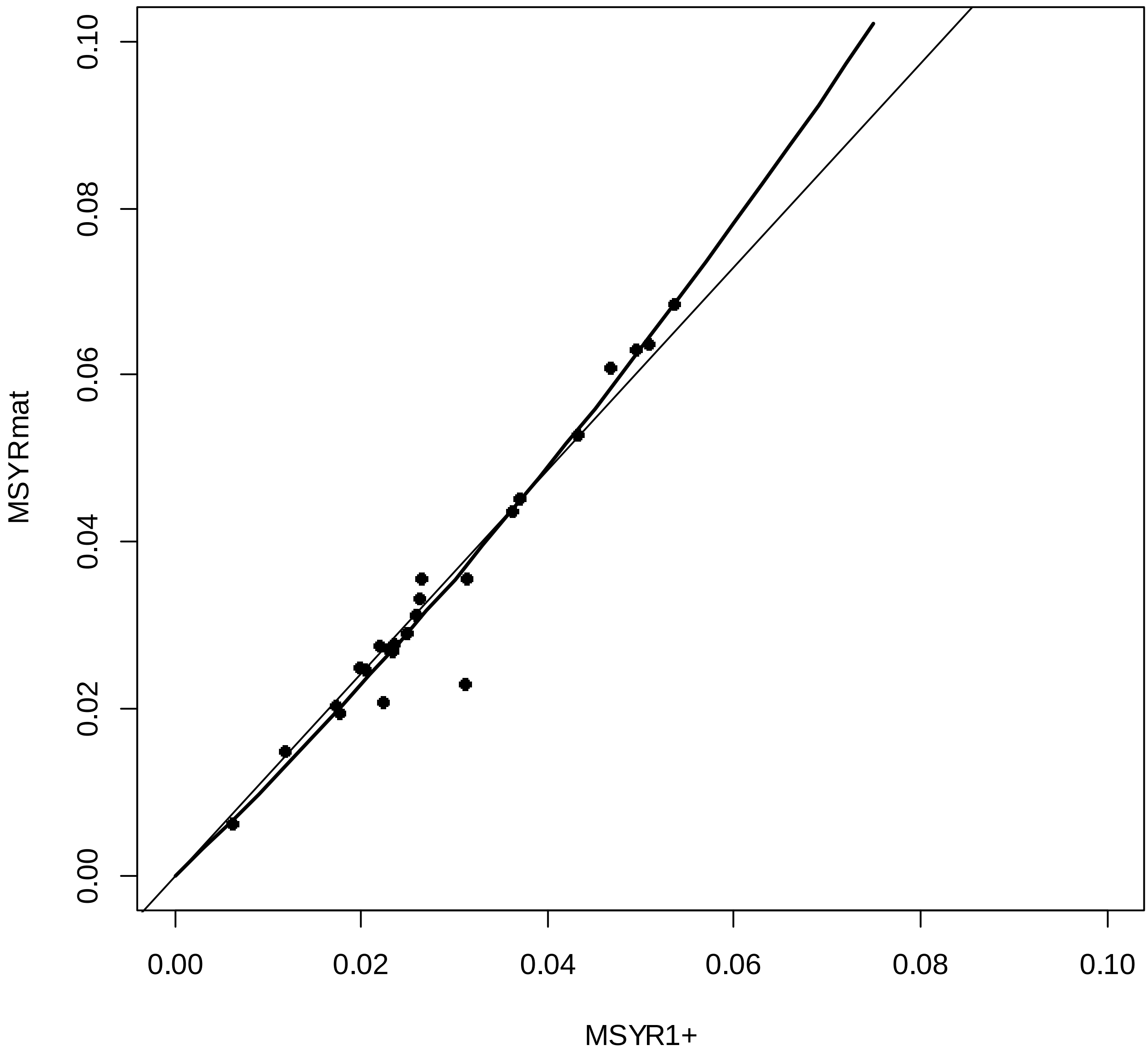


Fig 1. Relationship between $MSYR_{mat}$ and $MSYR_{1+}$. Curve is a quadratic regression passing through the origin.

Table 2. Some examples of results from the demographic analysis at two exploitation rates (from model 13).

Exploitation rate = 0.0

Pmat	2980	CV 0.614	
Mmat	0.0693	CV 0.905	
P1+	3888	CV 0.62	
M1+	0.0843	CV 0.897	
Pjuv	908	CV 0.646	
Mjuv	0.1413	CV 1.026	
Births	364	CV 0.647	
Mcalf	0.1324	CV 0.221	
Fec	0.2528	CV 0.131	
kMat	1.9809	CV 0.175	
a50Mat	3.8038	CV 0.095	
CatchRate	0	CV NaN	
Females Linf	12.8868	vBk 0.5595	t0 -0.7163
Males Linf	10.9607	vBk 0.8074	t0 -0.5854

Correlation in demographic parameters

	Mmat	M1p	Mjuv	Mcalf	Fec	matK	a50Mat
Mmat	1.0000						
M1p	0.9847	1.0000					
Mjuv	0.8796	0.9453	1.0000				
Mcalf	0.2630	0.2780	0.2778	1.0000			
Fec	-0.5119	-0.5643	-0.6164	-0.1699	1.0000		
matK	0.1811	0.2000	0.2373	0.1006	-0.2498	1.0000	
a50Mat	0.2278	0.2601	0.3060	0.1365	-0.3178	-0.1260	1.0000

Exploitation rate = 0.035

Pmat	1042	CV 0.66	
Mmat	0.0541	CV 0.909	
P1+	1431	CV 0.666	
M1+	0.067	CV 0.897	
Pjuv	389	CV 0.69	
Mjuv	0.1059	CV 1.051	
Births	153	CV 0.692	
Mcalf	0.1656	CV 0.276	
Fec	0.2987	CV 0.143	
kMat	1.7023	CV 0.259	
a50Mat	3.9452	CV 0.083	
CatchRate	0.0349	CV 0.215	
Females Linf	13.1473	vBk 0.5106	t0 -0.7684
Males Linf	11.9089	vBk 0.5844	t0 -0.7351

Correlation in demographic parameters

	Mmat	M1p	Mjuv	Mcalf	Fec	matK	a50Mat
Mmat	1.0000						
M1p	0.9775	1.0000					
Mjuv	0.8753	0.9505	1.0000				
Mcalf	0.2261	0.2167	0.1971	1.0000			
Fec	-0.4306	-0.4892	-0.5280	-0.0691	1.0000		
matK	0.1396	0.1576	0.1858	0.0048	-0.1624	1.0000	
a50Mat	0.1374	0.1582	0.1779	-0.0032	-0.0768	-0.3714	1.0000

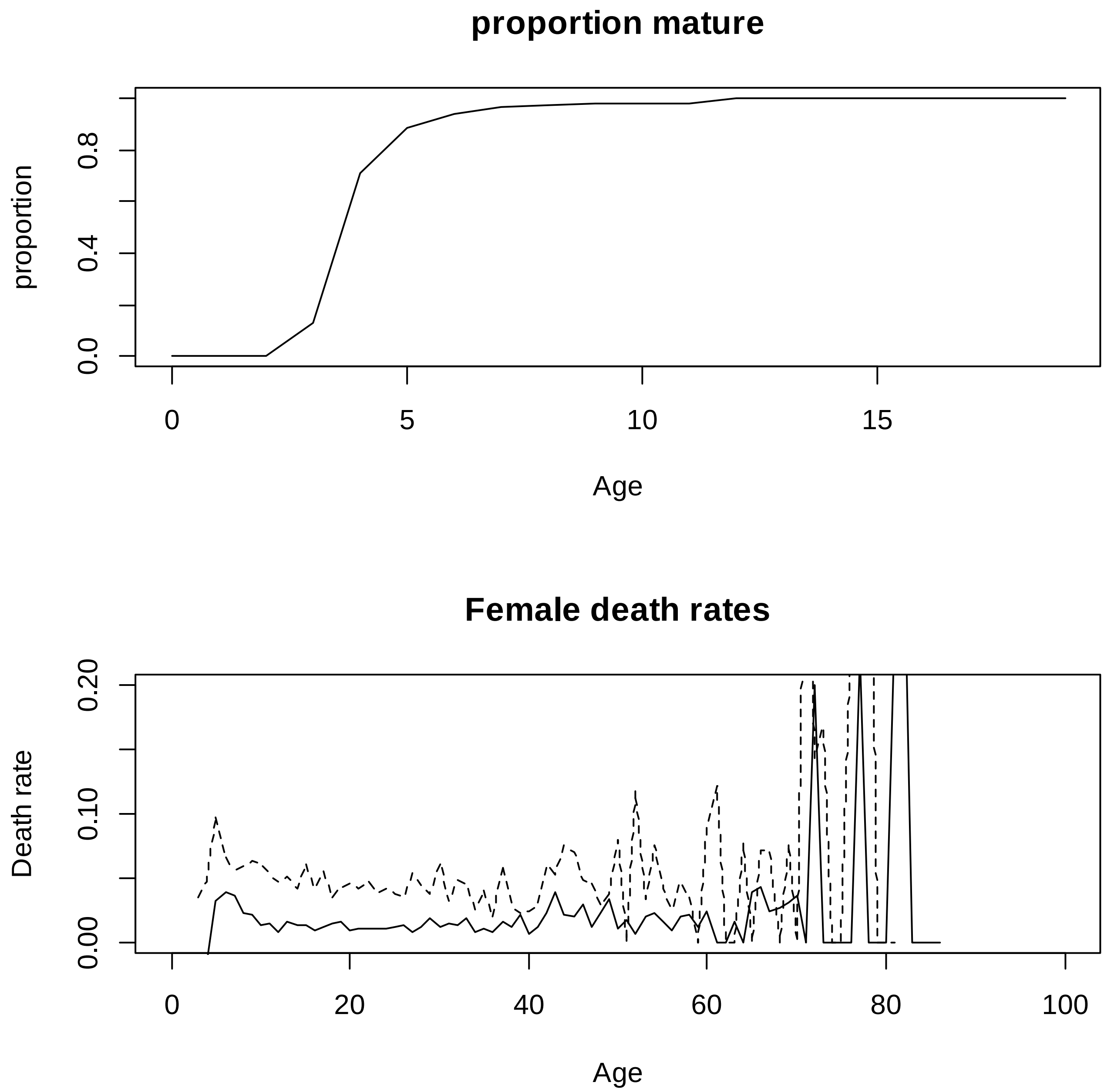
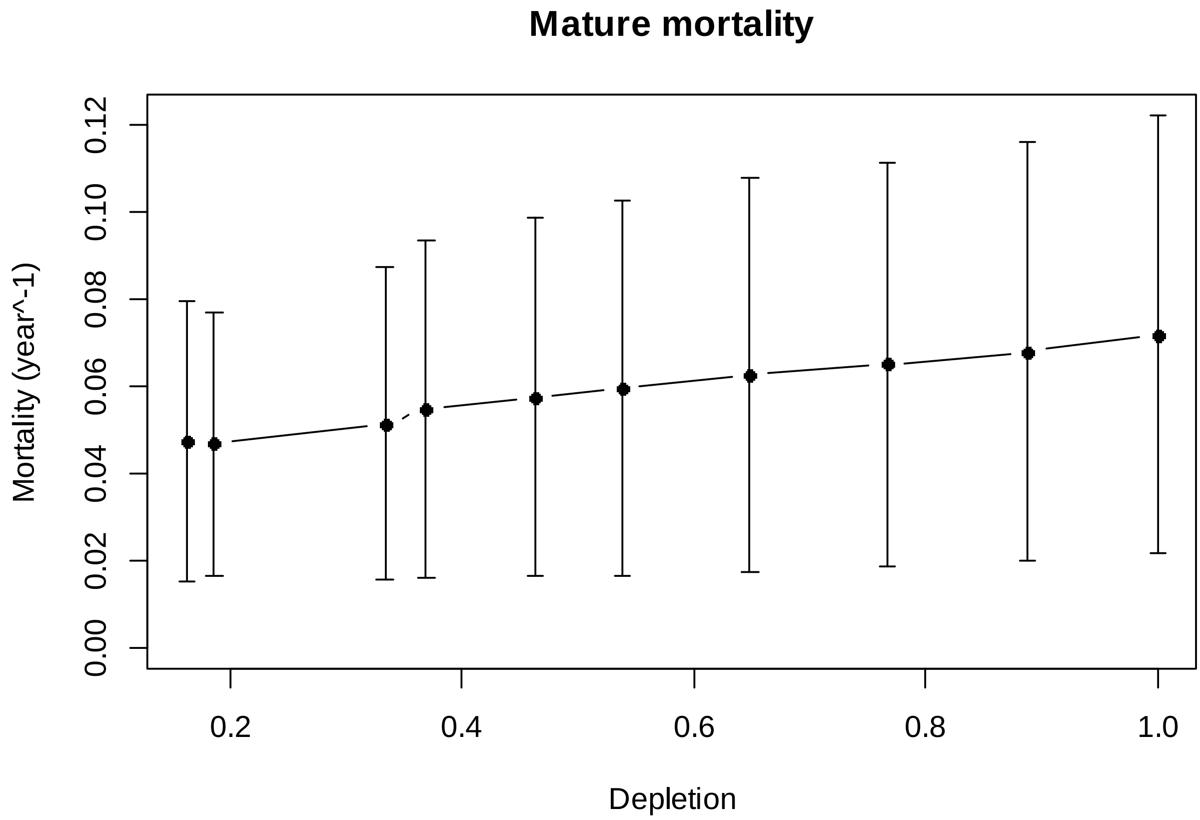


Fig 2. Examples of some demographics from Model 12. Upper curve is proportion mature at age in a depleted population. Lower curve shows the age specific death rate for mature females. The dashed line is the deaths of pregnant females; the solid line is the deaths of non-pregnant females.



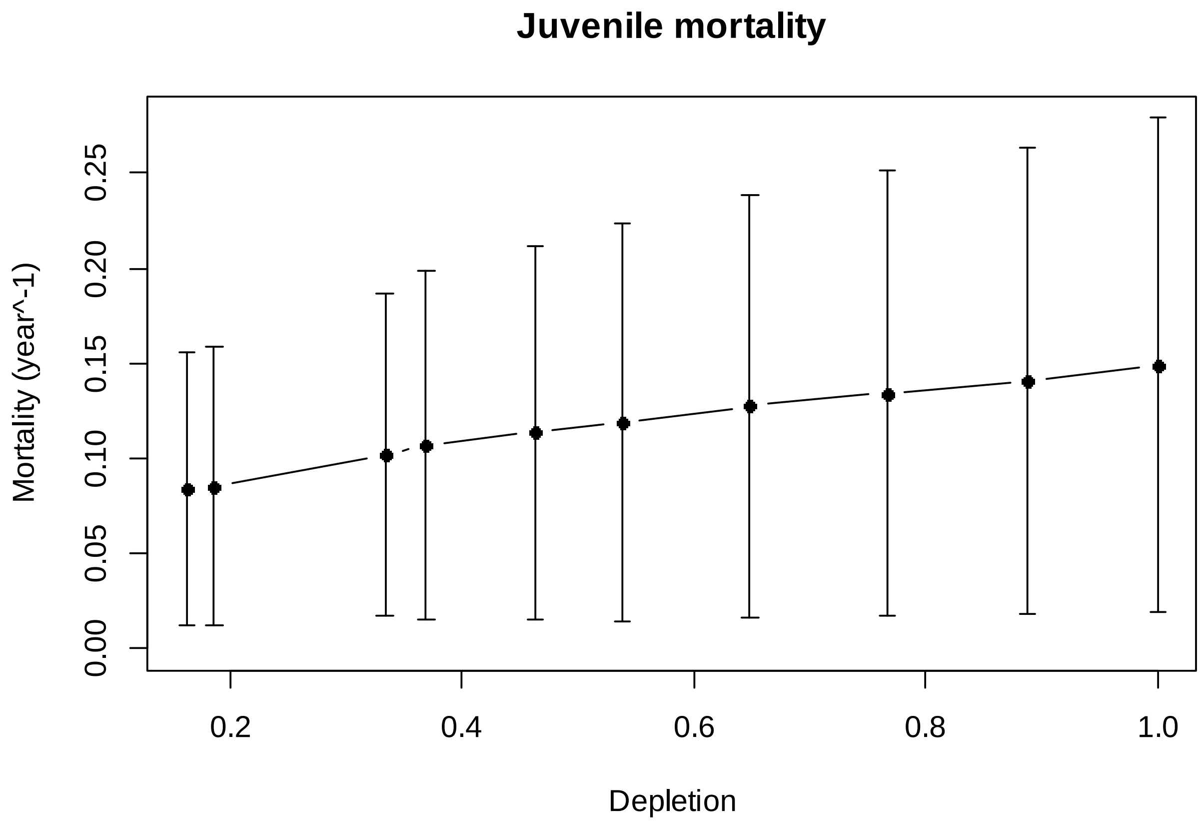


Fig 3. Density dependent response in mature and juvenile mortality (model 12). Error bars are ± 1 std dev.

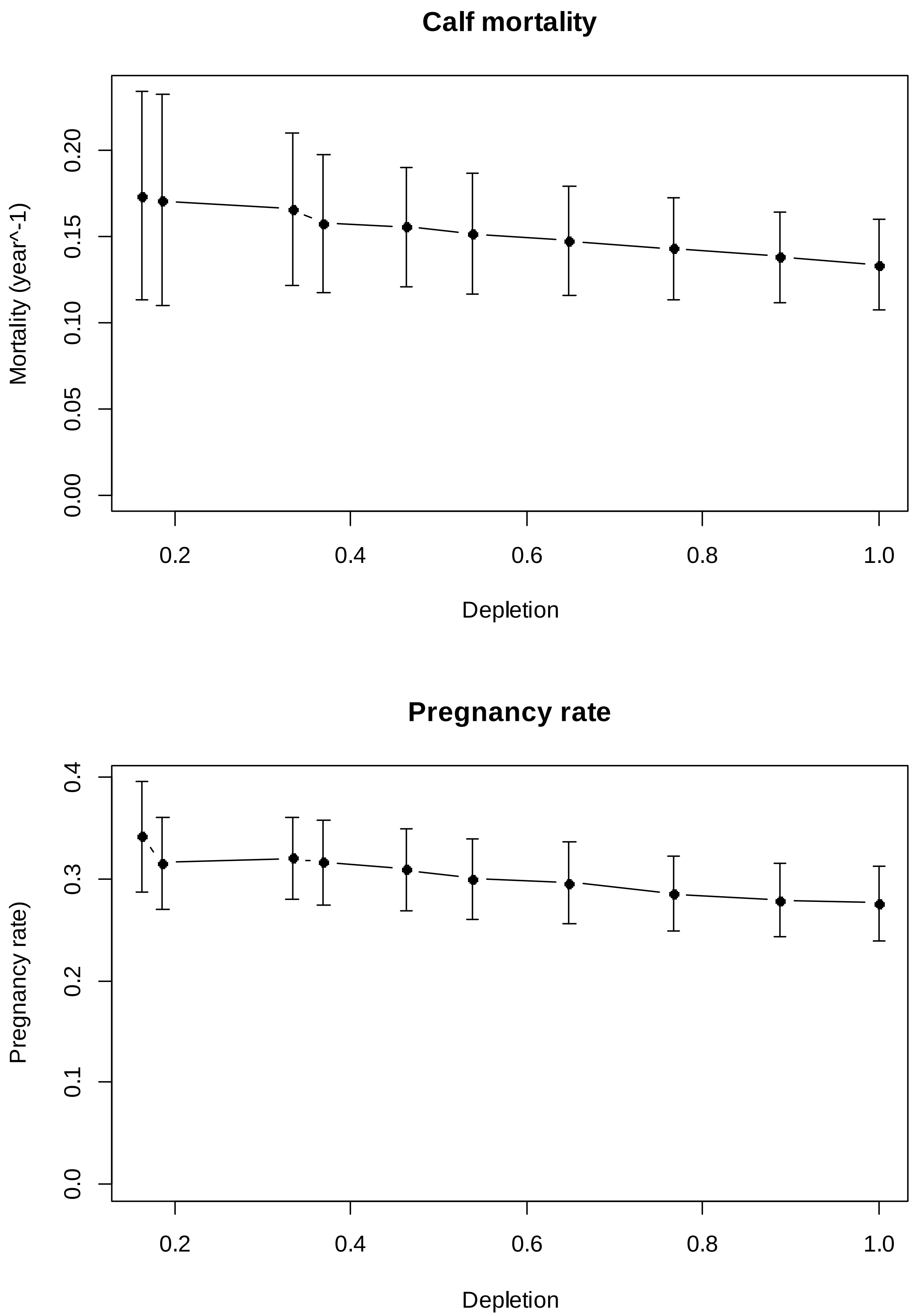
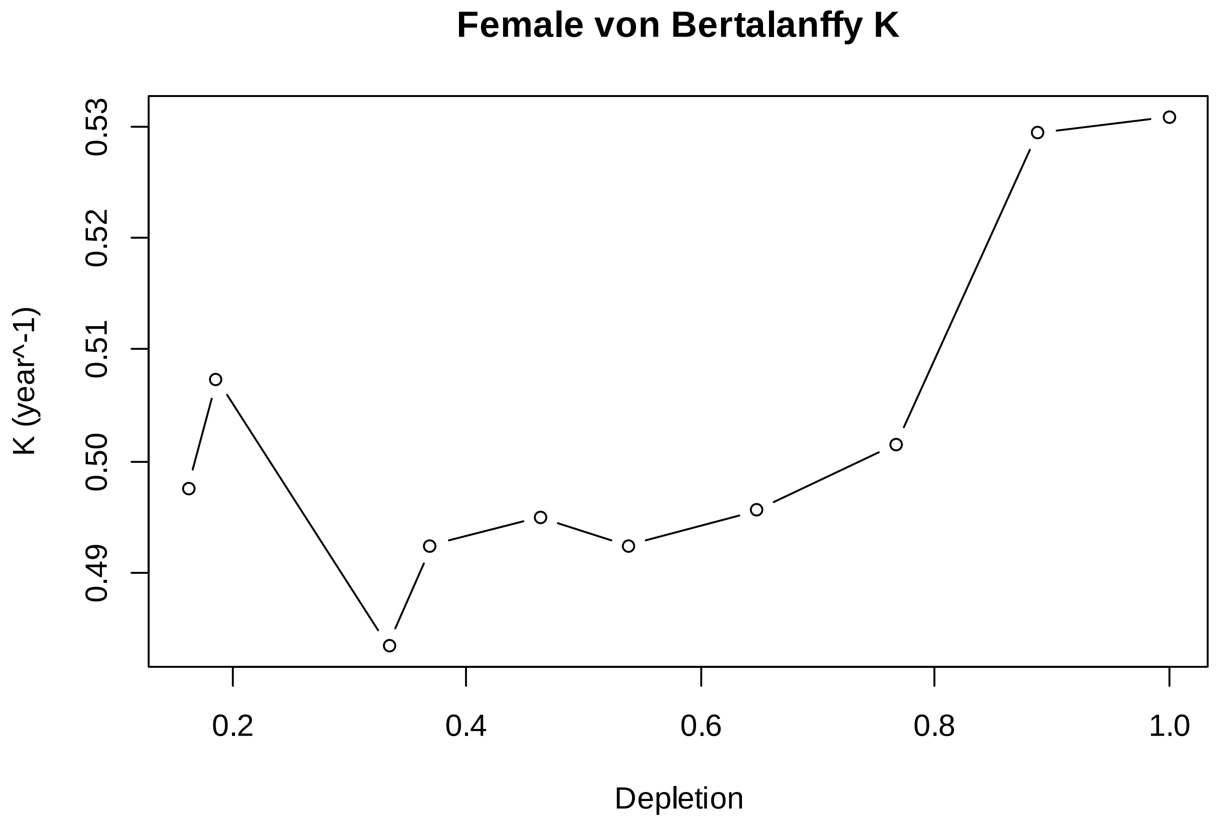


Fig 4. Density dependent response in calf mortality and pregnancy (model 12). Error bars are ± 1 std dev.



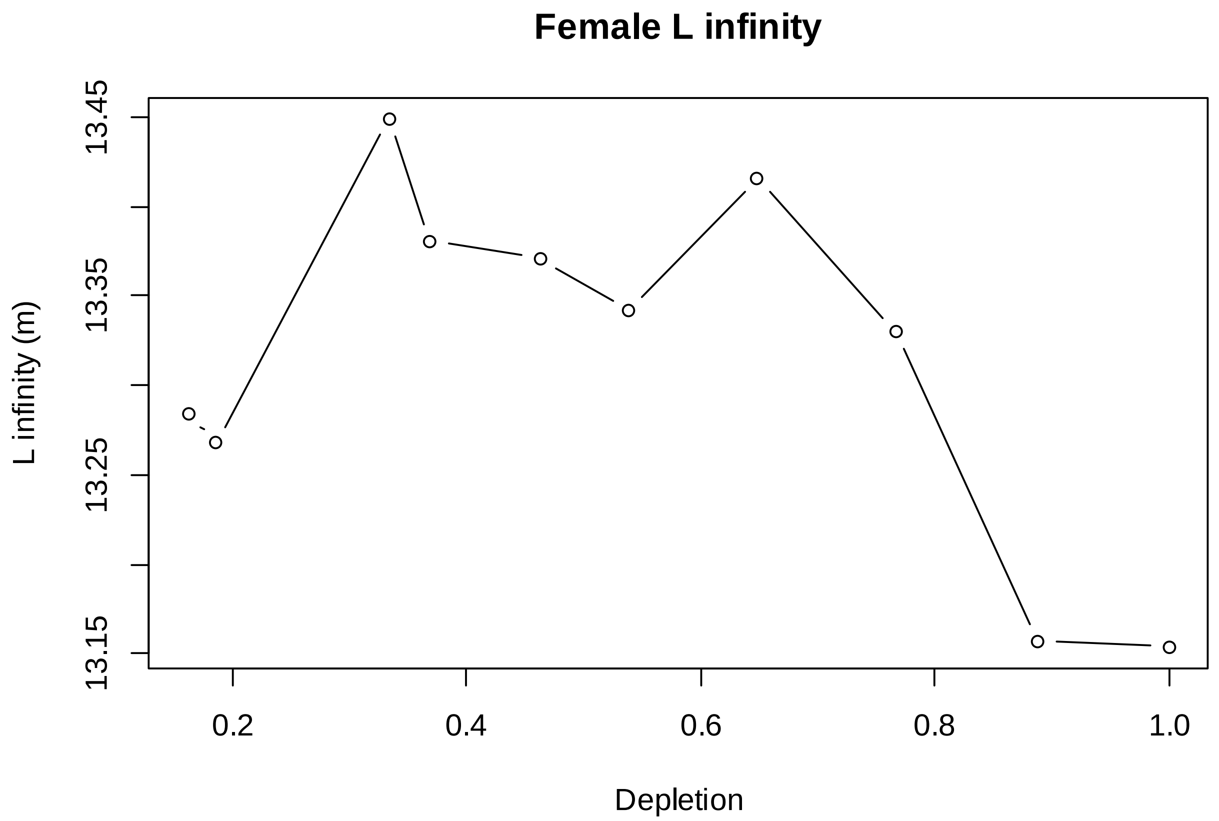


Fig 5. Apparent changes in female growth curve parameters (model 12).