Copenhagen, 10th October 2020.

WKGMSE Doc HS1

Default density-dependent M in Fmsy calculations - based on the ecosystem model by Pope et al 2006.

By

Henrik Sparholt

There are four density dependent (DD) mechanisms in fish population dynamics that are important for Fmsy calculations. These are:

- Density dependent recruitment
- Density dependent individual fish growth
- Density dependent natural mortality (M)
- Density dependent maturity.

Currently, only the first one is taken into account in the Fmsy calculations, except for a few cases (Northeast Arctic cod and haddock and cod at Iceland). It is a mathematical fact that ignoring any one of these four DD factors will give an underestimated Fmsy (at least in deterministic calculations; in the few cases where uncertainties have been taken into account they have confirmed the “mathematical fact”).

The scientific objective is to come up with unbiased estimates of Fmsy. This demands that a DD model of each of the four DD factor is developed. The most difficult of these is probably the DD in natural mortality. In a few rare cases multispecies models can provide such DD models for specific ecosystems (e.g. cod in the Barents Sea). We propose an approach that works for all stocks and is builds on the generalised ecosystem models by Pope *et al.* (2006).

Pope *et al.* (2006) constructed a generalised and simple multispecies model using only 15 parameters to describe a 13-‘‘species’’ fish community, where species are defined by their maximum body size and the general relationship between size and life-history characteristics. They build in a convincing way on all the past decades of intensive research on multispecies interactions, length-based ecosystems models, and links between life history parameters and size. They simulated a North Sea-like ecosystem. Simulations allowed them to assess the role of changes in the strength and type of density dependence in controlling the response to fishing, and to investigate the trade-off between catches and population dynamic parameters of the different “species”. The outputs showed that the linear slope of the size spectrum was a function of community exploitation rate. DD-controls, specifically predation mortality and the extent of compensation in the stock-recruit relationship, were key mechanisms in maintaining a linear spectrum. The approach allows us to explore the effects of different fishing mortality schedules on M of the various size groups of fish. Figure 1 is showing the result from the simulations in terms of M2 (predation mortality) by fish size for various levels of F. To this needs to be added M1 (non-predation natural mortality) to get total natural mortality (M).

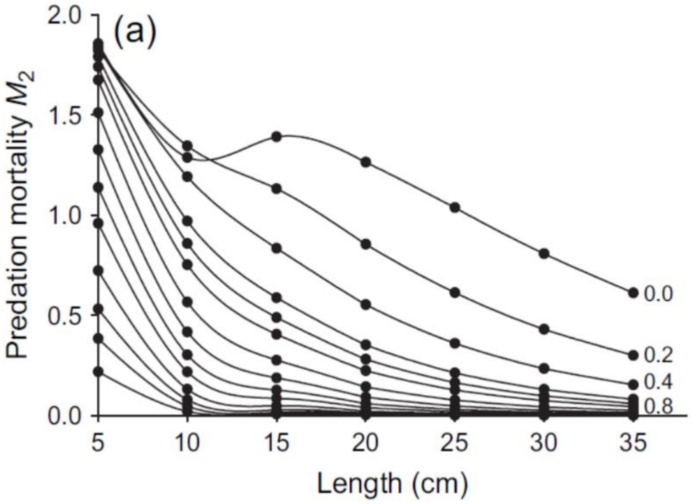


Figure 1. Predation mortality vs length of fish for various levels of F. From Pope et al 2006.

In each simulations Pope *et al.* (2006) used the same F on all stocks. They made simulation for many levels of F. This is of course a rough simulation of reality, but as long as managers are not in a position to prioritise between stocks it is probably a useful and roughly realistic approach.

Based on the result presented in Figure 1 one can fit each curve to an exponential decreasing function:

$$M2(F) = \alpha(F) *\exp(\beta(F)*L)$$

Table 1 shows the fitted parameters for five levels of F. These parameters are then fitted each to a linear curve with F as the independent variable (Figures 2 and 3). In that way we obtain α and β values corresponding to any F value.

Table 1. Parameter values for the exponential decreasing function of M2 with size of fish for various F levels.

	F				
	0	0.2	0.4	0.6	0.8
α	1.96	2.33	2.57	2.75	2.74
β	-0.03	-0.05	-0.07	-0.10	-0.11

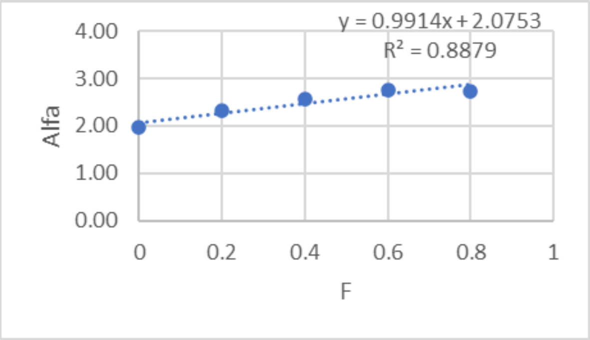


Figure 2. The α (Alfa) factor as a linear function of F.

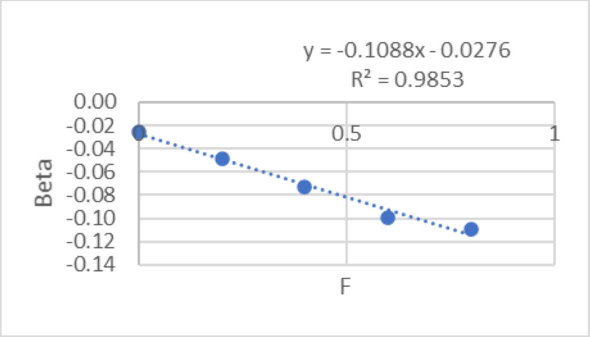


Figure 3. The β (Beta) factor as a linear function of F.

M1 is kept constant in each simulation and is modelled by Pope *et al.* (2006) as related to L_{oo} based partly on Charnov (1993, in his Figure 4.17, who derives a theoretical value for the slope of the ln(L_{oo}) on ln(K) relationship for gadoids):

$$M1 = 0.8*a*\ L_{oo}^{-b}$$

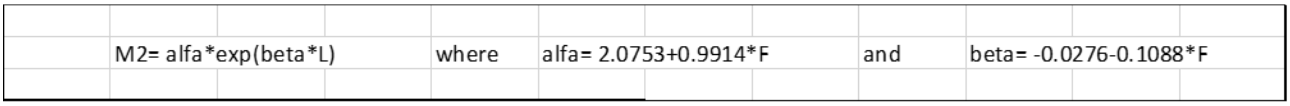
Where a = 4.5 and b = 0.67. Table 2 shows the resultant M1 values for L_{oo} values of 10, 20, …, 130cm.

Table 2. M1 as a function of L_{oo} (in the plot called Linf).

Linf	M1
10	0.78
20	0.49

30	0.37
40	0.31
50	0.27
60	0.23
70	0.21
80	0.19
90	0.18
100	0.17
110	0.16
120	0.15
130	0.14

For MSE and Fmsy calculations use the formula below to related M2 to F-level by size of each length/age group. This is not strictly a model for DD, but relate M2 to the F-level. As the F-level is related to population size in a monotonous way it is indirectly related to population size. As the MSE and Fmsy runs usually use loops in Fs, there is no need to find the relation of M2 to population size, a model relating M2 to F will work fine within these runs.



M2= alfa*exp(beta*L) where alfa= 2.0753+0.9914*F and beta= -0.0276-0.1088*F

Conclusion: From the approach above we now have M1 and M2 for each age/size group of a given species for any F value. These formulas for M1 and M2 can be used directly in MSE and Fmsy calculations and DD in natural mortality thus included to avoid some of the potential bias in Fmsy calculations.

Example: Northeast Atlantic mackerel. Linf and K is obtained from Fishbase, but could also be obtained from ICES WGWIDE reports. Thye will vary slightly by F as growth is density dependent, but a mean value over the years represented in data are probable OK, as the M1 and M2 are not very sensitive to realistic variations in Linf and K. The table below gives the M2 by age group for F = 0, 0.1, 0.2, …, 0.6. For use in MSE and Fmsy calculations use the formula in the bottom to relate M2 to F level by size of each age group. As the MSE and Fmsy runs usually use loops in F, a model relating M2 to F will work fine within these runs. As stated above this is implicitly a DD model of M2. M1 (equal to 0.31, based on the Linf and K for mackerel and M1 = K*0.8 according to Pope et al. 2006) has to be added to M2 to get total M.

			t0=	0				
mackerel			Linf =	39.9	cm		l (age)=	Linf*(1-exp(-k*age)))
			K=	0.36				
M1 =		0.31	Pope et al 2006 assumes one M1 values for all sizes of a species!!!					
M2= alfa*exp(beta*L)								
M2					F			
		0	0.1	0.2	0.3	0.4	0.5	0.6
	alfa:	2.0753	2.17444	2.27358	2.37272	2.47186	2.571	2.67014
	beta:	-0.0276	-0.03848	-0.04936	-0.06024	-0.07112	-0.082	-0.09288
age	mean lgd(cm)							
1	12.06	1.49	1.37	1.25	1.15	1.05	0.96	0.87
2	20.48	1.18	0.99	0.83	0.69	0.58	0.48	0.40
3	26.35	1.00	0.79	0.62	0.49	0.38	0.30	0.23
4	30.45	0.90	0.67	0.51	0.38	0.28	0.21	0.16
5	33.30	0.83	0.60	0.44	0.32	0.23	0.17	0.12
6	35.30	0.78	0.56	0.40	0.28	0.20	0.14	0.10
7	36.69	0.75	0.53	0.37	0.26	0.18	0.13	0.09
8	37.66	0.73	0.51	0.35	0.25	0.17	0.12	0.08
9	38.34	0.72	0.50	0.34	0.24	0.16	0.11	0.08
10	38.81	0.71	0.49	0.33	0.23	0.16	0.11	0.07

M2= alfa*exp(beta*L) where alfa= 2.0753+0.9914*F and beta= -0.0276-0.1088*F

References.

Charnov, E. L. 1993. Life History Invariants: Some Explorations of Symmetry in Evolutionary Ecology. Oxford University Press, Oxford. 167 pp.

Froese, R., and Pauly, D. (Eds). 2018. FishBase. World Wide Web electronic publication. www.fishbase.org, version (10/2018).

ICES. 2018. Report of the ICES Advisory Committee. ICES Advice 2018, Books 1–16. Individual advice sheets available at http://www.ices.dk/community/advisory-process/Pages/Latest-Advice.aspx.

Pope, J. G., Rice, J. C., Daan, N., Jennings, S., and Gislason, H. 2006. Modelling an exploited marine fish community with 15 parameters—results from a simple size-based model. ICES Journal of Marine Science, 63: 1029–1044.

Sparholt, H., Bogstad, B., Christensen, V., Collie, J., Gemert, R.v., Hilborn, R., Horbowy, J., Howell, D., Melnychuk, M.C., Pedersen, S.A., Sparrevohn, C.R., Stefansson, G., Steingrund, P. 2019a. Report of the 3rd working group meeting on optimization of fishing pressure in the Northeast Atlantic, Rhode Island March 2018. NORDIC WORKING PAPERS http://dx.doi.org/10.6027/NA2019-906 NA2019:902, ISSN 2311-0562. www.norden.org/en/publication/report-3rd-working-group-meeting-optimization-fishing-pressure-northeast-atlantic-rhode

Sparholt, H., Bogstad, B., Christensen, V., Collie, J., van Gemert, R., Hilborn, R., Horbowy, J., *et al.* 2019b. Report of the 1st working group meeting on optimization of fishing pressure in the Northeast Atlantic, Copenhagen, June 2017. NORDIC WORKING PAPERS http://dx.doi.org/10.6027/NA2019-904 NA2019:902, ISSN 2311-0562. https://www.norden.org/en/publication/report-1st-working-group-meeting-optimization-fishing-pressure-northeast-atlantic

Sparholt, H., Bogstad, B., Christensen, V., Collie, J., van Gemert, R., Hilborn, R., Horbowy, J., *et al.* 2019c. Report of the 2nd working group meeting on optimization of fishing pressure in the Northeast Atlantic, Vancouver November 2017. NORDIC WORKING PAPERS http://dx.doi.org/10.6027/NA2019-905 NA2019:902, ISSN 2311-0562. https://www.norden.org/en/publication/report-2nd-working-group-meeting-optimization-fishing-pressure-northeast-atlantic-0