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Obtaining F_{msy} from L_{oo}, K, and age-at-50% maturity.

By

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For data-poor stocks some life history parameters like L_{oo}, K, and age-at-50% maturity, are often available. These can be used to get Fmsy, based on the observed relation for data-rich stocks between Fmsy and life history parameters. For instance, if only a short time series of catch-at-age is available for a stock so that ordinary methods for calculation Fmsy is not possible, the approach proposed here might be used to obtain an sound Fmsy value to use in management.

Fmsy has often been linked to life history parameters such as natural mortality and growth rate. We used General Linear Models (GLM) coded in R, for this purpose. Based on the Fmsy estimates from the Fmsy-project (www.fmsyproject.net, Sparholt *et al.* 2019a-c) of 53 data-rich ICES stocks we tested a set of relevant life history parameters. We tested: age at 50% maturity – "a50mat", natural mortality of mature fish – "natM", $L_\infty \times K$ from the von Bertalanffy growth models – "Linf_K", preferred temperature –"prefT", trophic level of adult fish – "troph"). The life history parameter values were based on ICES current input data to fish stocks assessments (ICES, 2018 and reference therein) supplemented with data from FishBase (Froese and Pauly, 2018). We tested a few relevant groupings of species and found that a five-category grouping of species "taxg3" [cod and hake, other gadoids, flatfish, herring, and sprat, and others] worked well with the model. Only a few parameters can be included in the model as we only have 53 Fmsy "observations". We tested several relevant GLM models (see Supplementary material for detailed information). Across most of the models, we found (a) a positive influence on Fmsy of "natM" and, to a lesser degree, of "Linf_K"; (b) a negative influence on Fmsy of "a50mat" and, to a lesser degree, of "prefT"; and (c) "troph" was correlated with both "a50mat" and "Linf_K" and did not add much to the model when both of these were included. "Linf_K" was preferred to "natM" because it is easier to estimate with good precision for most stocks. The final GLM model was:

log(Fmsy) = log(a50mat) + log(Linf_K) + taxg3

It was assumed that Fmsy is log-normally distributed. The above GLM models were fitted to Fmsy estimates, one datapoint for each stock obtained as the mean by stock from the SPMs (Surplus Production Models), ecosystem, multispecies, and dynamic pool models (column "i" in Table 1).

The GLM model based on life history parameters explained 59% of the variation in the Fmsy values. A model without the "taxg3" factor was almost as good, explaining 46% of the variation, while requiring only two parameters (see Supplementary material). However, the AICc was higher (50.9 vs. 45.8) than for the model including "taxg3". Linf_K was not significant at the 5% level, but leaving it out gave higher AICc scores (47.0), and the above-mentioned two-parameter model gave highly significant effects of Linf_K, indicating it was an influential parameter. Diagnostics from the run can be found in Table 2. Plots of model-predicted estimates of Fmsy vs. "observed" Fmsy and residuals vs. "observed" Fmsy are presented in Figure 1.

Table 1. Estimates of F_{msy} by stock and method. Stock names from ICES Stock Assessment Database. [19/11-2019]. http://standardgraphs.ices.dk. From the Fmsy project (www.fmsyproject.net).

#	Column identifier	a	b	c	d	e	f	g	h	i	j	
#	Stock name - short	ICES 2018	Froese *et al.* SPM	RAM Legacy Data-base. Schaefer	RAM Legacy Data-base. Thorson "Taxo-nomic"	RAM Legacy Data-base. Thorson "general"	Eco-system model	Dynamic pool mo-dels, e.g. PROST	Average of b, average (c-e), f and g	GLM of h, based on life history para-meters	Final recom-mended Fmsy values - column i unless there are ecosystem or dynamic pool estimates then a mean of column h and i	Full stock name (truncated to save space)
1	reb.27.1-2		0.06	0.14	0.20	0.15			0.11	0.13	0.13	Beaked redfish in subareas 1 and 2 (Northeast Arctic)
2	bli.27.5b67	0.12	0.11						0.11	0.22	0.22	Blue ling in subareas 6-7 and Division 5.b (Celtic Seas, English ...
3	whb.27.1-91214	0.32	0.37	0.31		0.28			0.33	0.44	0.44	Blue whiting in subareas 1-9, 12, and 14 (Northeast Atlantic and ...
4	cod.27.5a		0.63	0.45	0.39	0.44		0.70	0.59	0.43	0.51	Cod in Division 5.a (Iceland grounds
5	cod.27.7a	0.44	0.95	0.75		0.66			0.83	0.76	0.76	Cod in Division 7.a (Irish Sea)
6	cod.27.7e-k	0.35	0.56	0.51		0.47			0.52	0.63	0.63	Cod in divisions 7.e-k (eastern English Channel and southern ...
7	cod.27.47d20	0.31	0.70	0.73	0.41	0.68	0.87	0.70	0.72	0.71	0.71	Cod in Subarea 4, Division 7.d, and Subdivision 20 (North Sea, ...
8	cod.27.1-2	0.40	0.55	0.51	0.46	0.50		0.60	0.55	0.38	0.47	Cod in subareas 1 and 2 (Northeast Arctic)
9	cod.27.5b1	0.32	0.36	0.57	0.52	0.57			0.46	0.60	0.60	Cod in Subdivision 5.b.1 (Faroe Plateau)
10	cod.27.22-24	0.26	0.62						0.62	0.51	0.51	Cod in subdivisions 22-24, western Baltic stock
11	ldb.27.8c9a	0.193	0.33	0.33	0.24	0.32			0.31	0.44	0.44	Four-spot megrim in divisions 8.c and 9.a (southern Bay of Biscay ...
12	reg.27.1-2	0.0525	0.10						0.10	0.14	0.14	Golden redfish in subareas 1 and 2 (Northeast Arctic)
13	reg.27.561214	0.097	0.14	0.11	0.08	0.10			0.12	0.14	0.14	Golden redfish in subareas 5, 6, 12, and 14 (Iceland and Faroes ...
14	had.27.5a		0.47	0.33		0.31			0.40	0.38	0.38	Haddock in Division 5.a (Iceland grounds)
15	had.27.5b	0.165	0.28	0.39	0.36	0.39			0.33	0.46	0.46	Haddock in Division 5.b (Faroes grounds)
16	had.27.6b	0.20	0.31						0.31	0.39	0.39	Haddock in Division 6.b (Rockall)
17	had.27.7a	0.27	0.41						0.41	0.43	0.43	Haddock in Division 7.a (Irish Sea)
18	had.27.7b-k	0.40	0.87						0.87	0.67	0.67	Haddock in divisions 7.b-k (southern Celtic Seas and English ...
19	had.27.46a20	0.19		0.47	0.71	0.51	0.58		0.57	0.35	0.46	Haddock in Subarea 4, Division 6.a, and Subdivision 20 (North Sea, ...
20	had.27.1-2	0.35	0.43	0.30	0.24	0.29			0.35	0.26	0.26	Haddock in subareas 1 and 2 (Northeast Arctic)
21	hke.27.8c9a	0.25	0.59	0.51	0.43	0.50			0.54	0.65	0.65	Hake in divisions 8.c and 9.a, Southern stock (Cantabrian Sea and ...
22	hke.27.3a46-8abd	0.28	0.82	0.42	0.28	0.40			0.59	0.64	0.64	Hake in subareas 4, 6, and 7, and divisions 3.a, 8.a-b, and 8.d, ...
23	her.27.5a	0.22	0.23	0.25	0.29	0.26			0.25	0.28	0.28	Herring in Division 5.a, summer-spawning herring (Iceland grounds)
24	her.27.nirs	0.27	0.43	0.57	0.66	0.58			0.52	0.32	0.32	Herring in Division 7.a North of 52°30'N (Irish Sea)
25	her.27.irls	0.26	0.34	0.30	0.41	0.32			0.34	0.40	0.40	Herring in divisions 7.a South of 52°30'N, 7.g-h, and 7.j-k (Irish Sea, ...
26	her.27.3a47d	0.26	0.58	0.23	0.29	0.24	0.50		0.45	0.32	0.38	Herring in Subarea 4 and divisions 3.a and 7.d, autumn spawners ...
27	her.27.1-24a514a	0.157		0.16	0.13	0.16			0.15	0.23	0.23	Herring in subareas 1, 2, 5 and divisions 4.a and 14.a, Norwegian ...
28	her.27.28	0.32	0.34	0.53	0.52	0.53			0.43	0.31	0.31	Herring in Subdivision 28.1 (Gulf of Riga)
29	her.27.20-24	0.31	0.33	0.29		0.27			0.30	0.30	0.30	Herring in subdivisions 20-24, spring spawners (Skagerrak, ...
30	her.27.25-2932	0.22	0.21	0.18	0.15	0.18	0.35		0.24	0.25	0.25	Herring in subdivisions 25-29 and 32, excluding the Gulf of Riga ...
31	her.27.3031	0.21		0.19	0.17	0.19			0.19	0.30	0.30	Herring in subdivisions 30 and 31 (Gulf of Bothnia)
32	lin.27.5a	0.286	0.34	0.43					0.39	0.32	0.32	Ling in Division 5.a (Iceland grounds)
33	mac.27.nea	0.21	0.36	0.37	0.39	0.37		0.40	0.38	0.39	0.39	Mackerel in subareas 1-8 and 14 and Division 9.a (the Northeast ...
34	meg.27.7b-k8abd	0.191	0.37	0.35	0.34	0.35			0.36	0.33	0.33	Megrim in divisions 7.b-k, 8.a-b, and 8.d (west and southwest of ...
35	meg.27.8c9a	0.191	0.15	0.18					0.17	0.34	0.34	Megrim in divisions 8.c and 9.a (Cantabrian Sea and Atlantic ...
36	ple.27.7a	0.169	0.21	0.42	0.57	0.45			0.35	0.29	0.29	Plaice in Division 7.a (Irish Sea)
37	ple.27.7d	0.25	0.27						0.27	0.29	0.29	Plaice in Division 7.d (eastern English Channel)
38	ple.27.420	0.21	0.47	0.36	0.30	0.35			0.40	0.35	0.35	Plaice in Subarea 4 (North Sea) and Subdivision 20 (Skagerrak)
39	ple.27.21-23	0.37	0.55						0.55	0.28	0.28	Plaice in subdivisions 21-23 (Kattegat, Belt Seas, and the Sound)
40	pok.27.5a		0.31	0.19		0.17			0.25	0.31	0.31	Saithe in Division 5.a (Iceland grounds)
41	pok.27.5b	0.30	0.37	0.34	0.25	0.32			0.34	0.34	0.34	Saithe in Division 5.b (Faroes grounds)
42	pok.27.1-2		0.49	0.32	0.30	0.32			0.40	0.32	0.32	Saithe in subareas 1 and 2 (Northeast Arctic)
43	pok.27.3a46	0.36	0.54				0.33		0.44	0.33	0.38	Saithe in subareas 4, 6 and Division 3.a (North Sea, Rockall and ...
44	sol.27.7a 1.2	0.20	0.18	0.27	0.17	0.26			0.21	0.36	0.36	Sole in Division 7.a (Irish Sea)
45	sol.27.7d	0.256	0.48	0.63		0.68			0.57	0.34	0.34	Sole in Division 7.d (eastern English Channel)
46	sol.27.7e	0.29	0.26	0.21		0.20			0.23	0.33	0.33	Sole in Division 7.e (western English Channel)
47	sol.27.7fg	0.27	0.31	0.44	0.60	0.47			0.41	0.31	0.31	Sole in divisions 7.f and 7.g (Bristol Channel, Celtic Sea)
48	sol.27.8ab	0.33	0.43	0.38	0.27	0.36			0.39	0.32	0.32	Sole in divisions 8.a-b (northern and central Bay of Biscay)
49	sol.27.4	0.20	0.38	0.40	0.38	0.40			0.39	0.32	0.32	Sole in Subarea 4 (North Sea)
50	sol.27.20-24	0.23	0.38	0.28	0.22	0.27			0.32	0.32	0.32	Sole in subdivisions 20-24 (Skagerrak and Kattegat, western Baltic ...
51	spr.27.22-32	0.26	0.42	0.30	0.34	0.31	0.40	0.45	0.40	0.38	0.39	Sprat in subdivisions 22-32 (Baltic Sea)
52	mon.27.78abd	0.28	0.41						0.41	0.30	0.30	White anglerfish in Subarea 7 and divisions 8.a-b and 8.d (Celtic ...
52	mon.27.8c9a	0.24	0.63	0.27	0.21	0.26			0.44	0.30	0.30	White anglerfish in divisions 8.c and 9.a (Cantabrian Sea and ..

Table 2. Diagnostics of the GLM model log(F_{msy}) = log(a50mat) + log(Linf_K) + taxg3, used to link life history parameters to F_{msy}.

Variable name	**Coefficient**	**Standard error**	***t*-value**	***P*-value**
Intercept	–0.3807	0.3881	–0.981	0.3318
taxg3 (flatfish)	–0.6295	0.1906	–3.302	0.0019**
taxg3 (forage fish)	–0.7003	0.1880	–3.724	0.0005***
taxg3 (other gadoids)	–0.3984	0.1513	–2.634	0.0115*
taxg3 (other taxonomic groups)	–0.5154	0.2258	–2.258	0.0271*
Linf_K	0.2091	0.1145	1.826	0.0744
a50mat	–0.5800	0.1125	–5.156	0.0000***
Null deviance	12.7648 on 52 degrees of freedom			
Residual deviance	5.2618 on 46 degrees of freedom			
AIC	43.987			
AICc	45.813			
Significance codes: * < 0.05, **<0.01, ***<0.001				

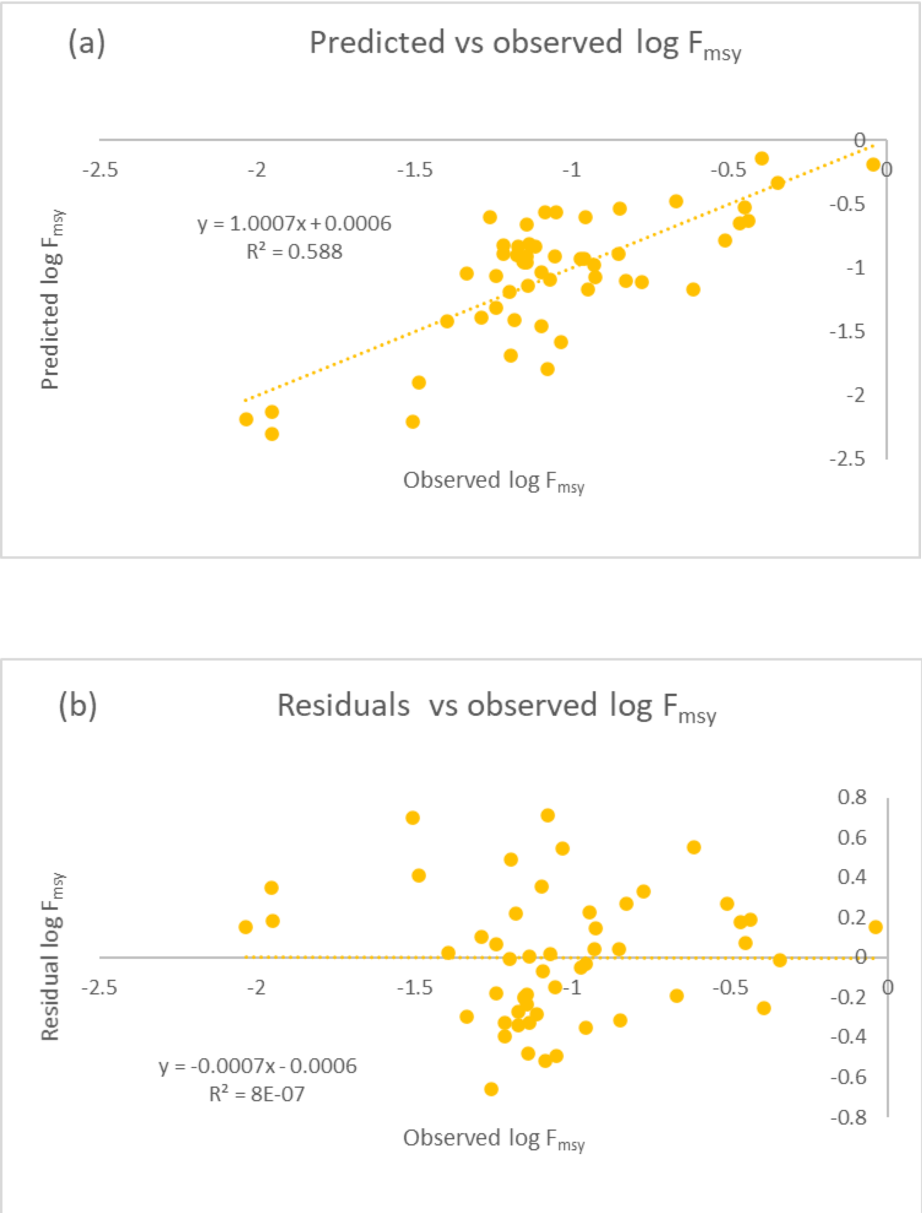

Figure 1. Model predicted log(F_{msy}) vs. "observed" log(F_{msy}) from a GLM model: log(F_{msy}) = log(a50mat) + log(Linf_K) + taxg3, used to link life history parameters to F_{msy} (a), and residual vs. "observed" log(F_{msy}) values (b).

Conclusion: The above formula and the parameter values given in Table 2 can be used to obtain a scientifically sound estimate of Fmsy, for data-poor stocks where L_{oo}, K and age-at-50%-maturity are available.

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Supplementary information.

F_{msy} has often been linked to life history parameters such as natural mortality and growth rate. We used General Linear Models (GLM) coded in R for the purpose. We tested a set of relevant life history parameters (age at 50% maturity – "a50mat", natural mortality of mature fish – "natM", $L_\infty \times K$ from the von Bertalanffy growth models - "Linf_K", preferred temperature -"prefT", trophic level of adult fish - "troph") against the F_{msy} values obtained from the methods mentioned above. The parameter values were based on ICES current input data to fish stock assessments (ICES, 2018, and reference therein) supplemented with data from FishBase (Froese and Pauly, 2018). We tested a few relevant groupings of species and found that a five-category grouping of species "taxg3" (cod and hake, other gadoids, flatfish, herring and sprat, and others) worked well with the model. Only a few parameters can be included in the model as we only have 53 F_{msy} "observations". We tested several relevant GLM models (see www.fmsyproject.net for detailed information). The final GLM model used were: log(Fmsy) ~ log(a50mat) + log(Linf_K) + taxg3.

The model explained 59% of the variation in the F_{msy} values. A model without taxg3 was almost as good, explaining 46% of the variation and had only two parameters. However, the AIC and AICc were better for the six-parameters model. Diagnostics from the final GLM run can be found in Table 2 and for these two others in Tables S1 and S2. Inclusion of Linf_K is just not significant, however, the AIC and the AICc indicate that the model should still include Linf_K. It is sensible to do also because it probably makes the predictions more robust using two rather than one life history parameter and because a GLM without taxg3 and only with these two parameters gives a quite good fit and with both parameters being highly significant.

Table S1. Diagnostics of the GLM model log(Fmsy) ~ log(a50mat) + taxg3 used to link life history parameters to F_{msy} i.e. logLinf_K omitted.

Variable name	**Coefficient**	**Standard error**	***t*-value**	***P*-value**
Intercept	0.2383	0.1935	1.232	0.2242
taxg3 (flatfish)	–0.8360	0.1573	–5.316	0.0000***
taxg3 (forage fish)	–0.8774	0.1650	–5.318	0.0000***
taxg3 (other gadoids)	–0.4797	0.1481	–3.239	0.0022**
taxg3 (other taxonomic groups)	–0.7476	0.1912	–3.910	0.0003***
a50mat	–0.5645	0.1149	–4.912	0.0000***
Null deviance	12.7648 on 52 degrees of freedom			
Residual deviance	5.6431 on 47 degrees of freedom			
AIC	45.695			
AICc	46.972			

Significance codes: * < 0.05, **<0.01, ***<0.001

Table S2. Diagnostics of the GLM model log(Fmsy) ~ log(a50mat) + log(Linf_K) used to link life history parameters to F_{msy} i.e. taxg3 omitted.

Variable name	**Coefficient**	**Standard Error**	**t-value**	**P value**
Intercept	–1.5432	0.2382	–6.479	0.0000***
Linf_K	0.4586	0.0917	5.001	0.0000***
A50mat	–0.4969	0.1009	–4.926	0.0000***
Null deviance	12.7648 on 52 degrees of freedom			
Residual deviance	6.9457 on 50 degrees of freedom			
AIC	50.702			
AICc	50.942			
Significance codes: * < 0.05, **<0.01, ***<0.001				