SUPPLEMENTARY INFORMATION: METHODS IN ECOLOGY AND EVOLUTION

Evaluation and management implications of uncertainty in a multi-species size-structured model of population and community responses to fishing

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Table S1. Parameter values in the unfiltered ensemble. The first value of each parameter listed is the default option and the following values are the alternatives. Parameter variants were applied to all species in the model unless stated. If parameter variants were separately applied to 'small' and 'large' fish, the length threshold was 50cm. [1] Empirical diet data from Pinnegar & Platts (2011). [2]Mpref is the preferred prey to predator mass ratio. [3]Lpref is the preferred prey to predator length ratio. Codes correspond to the codes in Table 1 of the accompanying paper.

Parameter	Code	Value/treatment	Reference
Diet matrix	1 2 3 4 5	As Rochet *et al*. (2011) Everything eats everything Eat if > 0.001 occurrence Eat if > 0.01 occurrence Demersal eats demersal & pelagic eats pelagic	Rochet *et al*. (2011) Pinnegar & Platts (2011) (see Tables S2, S3 and S4, S5 for options 1, 3, 4 and 5 respectively)
Predation size selection	1 2 3 4 5	Mpref[2]= 1/12.2, Lpref[3] =0.43 (μ=-2.25, σ=0.5) Mpref= 1/54.6 , Lpref=0.26 (μ =-3.75, σ=0.5) Mpref= 1/150, Lpref=0.19 (μ =-4.95, σ=0.25) Mpref= 1/334, Lpref=0.14 (μ =-5.75, σ=0.25) Mpref= 1/1340, Lpref=0.09 (μ =-6.95, σ=0.5)	Scharf *et al*. (2000)
Natural Mortality (M1)	1 2 3 4 5	Largest 25% size class M=0.4, else M=0.0 Largest 25% size class M=0.28, else M=0.0 Largest 25% size class M=0.56, else M=0.0 0-0.3 yr^{-1} linearly increasing with L/L_∞ Constant 0.1 yr^{-1}	Quiroz *et al*. (2010)
Spawner-recruit (β)	1 2 3 4 5	0.20 x SSB_{max} 0.16 x SSB_{max} 0.12 x SSB_{max} 0.08 x SSB_{max} 0.04 x SSB_{max}	Option 1 set using ICES S-R database (ICES, 2013), others see 'Methods'
Growth Efficiency (Ge)	1 2 3 4 5	Decreasing length function Constant value of 0.5 Constant value of 0.1 As #1, but reduced by 40% As #1, but increased by 40%	Madenjian *et al*. (2006)
Asymptotic length (L_∞)	1 2 3 4 5	Default values (Table 2, accompanying paper) All L_∞ 20% larger (+20%) Small fish, L_∞-20%; large fish, +20% Small fish, L_∞+20%; large fish, -20% All L_∞ 20% smaller (-20%)	Katsanevakis & Maravelias (2008)

Table S1. Continued

Parameter		**Value/treatment**	**Reference**
Spawner-recruit (α)	1	$1.33{\times}10^6 / L_\infty^{3.0022}$	Kehler *et al*. (2002)
	2	$1.46{\times}10^8 / L_\infty^{4.1242}$	Denney *et al*. (2002)
	3	$3.71{\times}10^7 / L_\infty^{3.7924}$	
	4	$2.37{\times}10^6 / L_\infty^{3.0022}$	
	5	$1.91{\times}10^6 / L_\infty^{3.0022}$	

Table S2. Diet matrix option 1 (Rochet *et al*. 2011). A value of 1 indicates that the predator species will eat the prey species, 0 that it will not.

		Predator																				
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Prey	**1**	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1	0	1	1	1
	2	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1	0	1	1	1
	3	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	1	1	1	1	1	1
	4	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1	0	1	1	1
	5	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	1	0
	6	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	1	0
	7	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	1
	8	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	1
	9	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	1	0
	10	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	1	0
	11	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	1
	12	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	1	1	1	1	1	1
	13	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	1	1	0
	14	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	1	0
	15	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	1	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	17	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1	0	1	1	1
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	1	1	0
	20	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1	0	1	1	1
	21	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1

Table S3. Diet matrix option 3 with a cut-off diet fraction by numbers of 0.001 (Pinnegar & Platts, 2011). A value of 1 indicates that the predator species will eat the prey species, 0 that it will not.

		Predator																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Prey	1	0	0	1	0	0	1	0	1	0	0	1	1	0	1	0	0	1	0	1	1	1
	2	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0	1	1
	3	0	0	1	1	0	1	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1
	4	0	0	0	1	0	0	0	1	0	0	0	1	0	1	0	0	1	1	1	1	1
	5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	0
	6	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	1	0	0	1	1	1
	7	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	1	1
	8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	1	0	0	1	0	1	1	0	0	0	1	0	1	0	0	1	0	1	1	1
	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	17	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0	1	1	1
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	20	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	1	0	0	1	1	0
	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table S4. Diet matrix option 4 with a cut-off diet fraction by numbers of 0.01 (Pinnegar & Platts, 2011). A value of 1 indicates that the predator species will eat the prey species, 0 that it will not.

		Predator																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Prey	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	1	1
	2	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0	1	1
	3	0	0	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	0	1	1	1
	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1
	5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	1	0
	6	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	1	0	0	1	1	0
	7	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	1	0
	8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	1	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	1	1	1
	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	17	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	20	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0
	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table S5. Diet matrix option 5. A value of 1 indicates that the predator species will eat the prey species, 0 that it will not.

		Predator																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Prey	1	1	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
	2	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	3	1	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
	4	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	5	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	6	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	7	1	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
	8	1	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
	9	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	10	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	11	1	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
	12	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	13	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	14	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	15	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	16	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	17	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	18	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	19	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	20	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
	21	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1

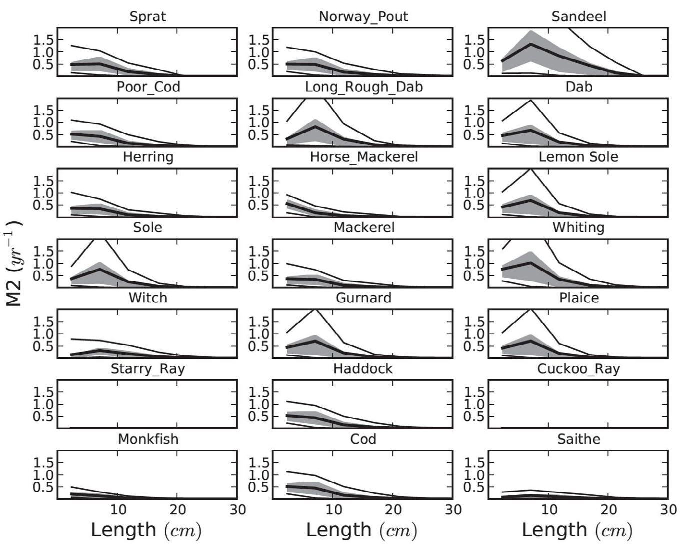

Figure S1. Estimated predation mortality rates (*M*2) in the unfished system based on outputs from model variants in the filtered ensemble (FE) with 10^{10} g 'other food'. Thicker solid lines are means, thinner solid lines show 90% uncertainty intervals and shaded area show 50% uncertainty intervals. There are no estimates for starry ray and cuckoo ray because they have no predators represented in FE models. The 10^{10} g 'other food' is available to each predator species and size class, and equates to 2.5×10^6 tonnes in total. The 90% and 50% uncertainty intervals are calculated in the same way in all figures and spanned the 5th to 95th and the 25th to 75th percentiles of the frequency distribution of output values generated by the FE respectively.

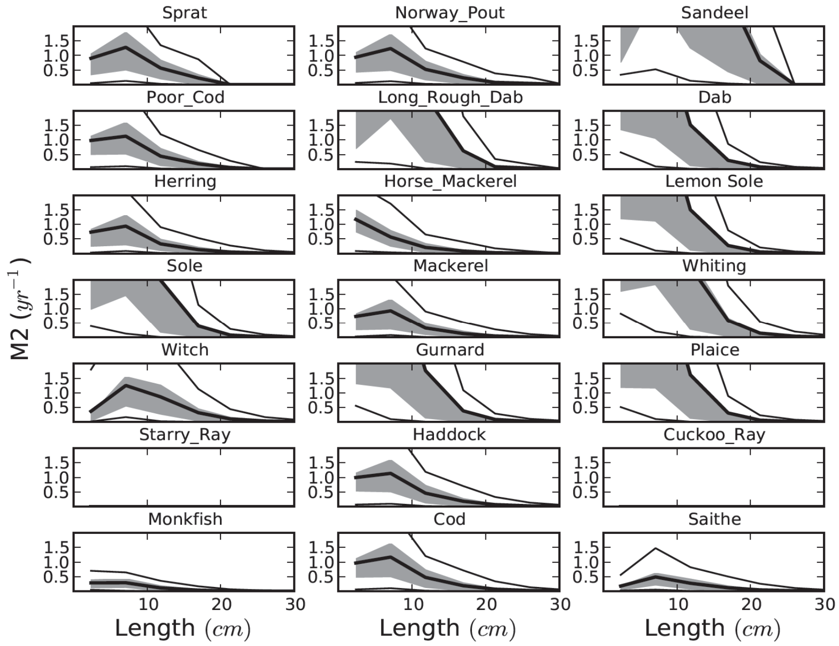

Figure S2. Estimated predation mortality rates ($M2$) in the unfished system based on outputs from model variants in the filtered ensemble (FE) with 10^9 g 'other food'. Thicker solid lines are means, thinner solid lines show 90% uncertainty intervals and shaded area show 50% uncertainty intervals. There are no estimates for starry ray and cuckoo ray because they have no predators represented in FE models. The 10^9 g 'other food' is available to each predator species and size class, and equates to 2.5×10^5 tonnes in total.

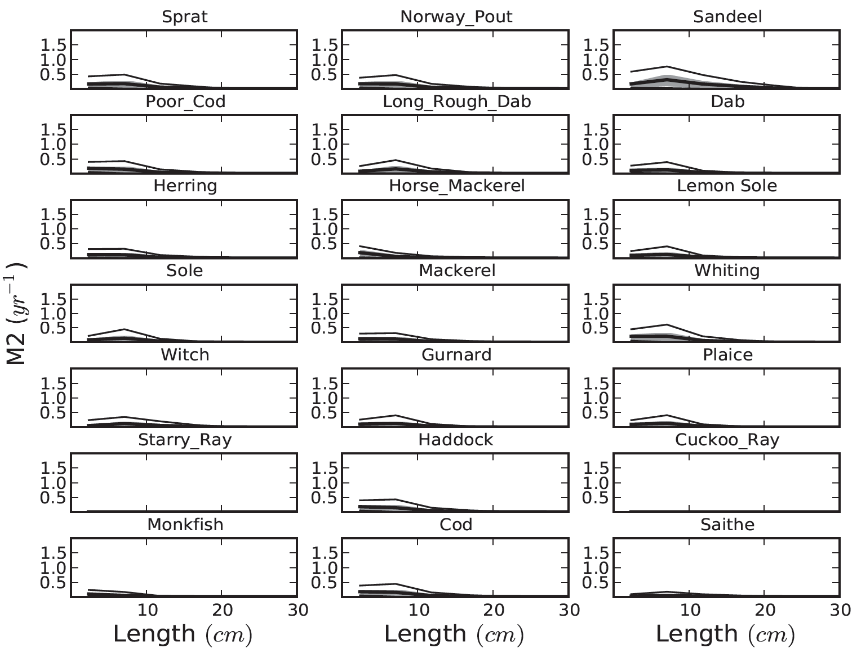

Figure S3. Estimated predation mortality rates ($M2$) in the unfished system based on model variants in the filtered ensemble (FE) with 10^{11} g 'other food'. Thicker solid lines are means, thinner solid lines show 90% uncertainty intervals and shaded area show 50% uncertainty intervals. There are no estimates for starry ray and cuckoo ray because they have no predators represented in FE models. The 10^{11} g 'other food' is available to each predator species and size class, and equates to 2.5×10^7 tonnes in total.

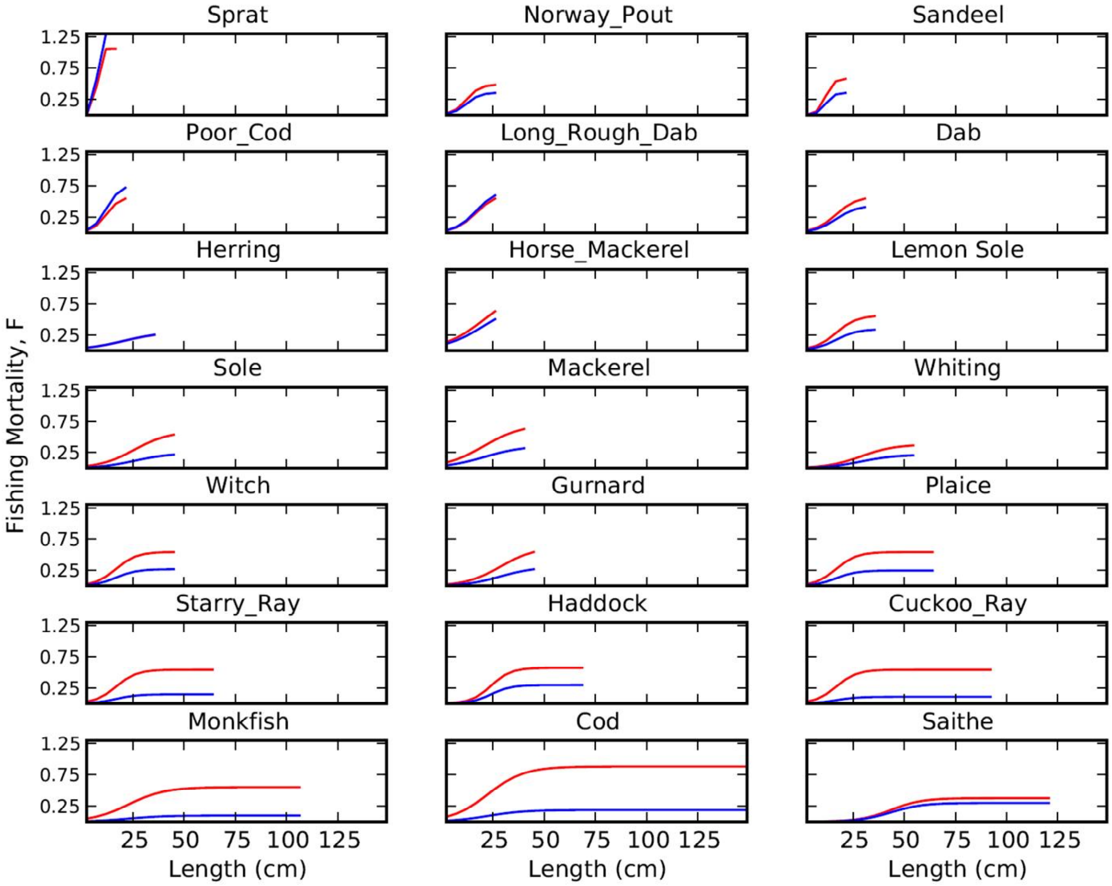

Figure S4. Fishing mortality as a function of length for the F_{HIST} (historic average 1990-2010, red line) and F_{MSY} (single species MSY estimates, blue line) scenarios.

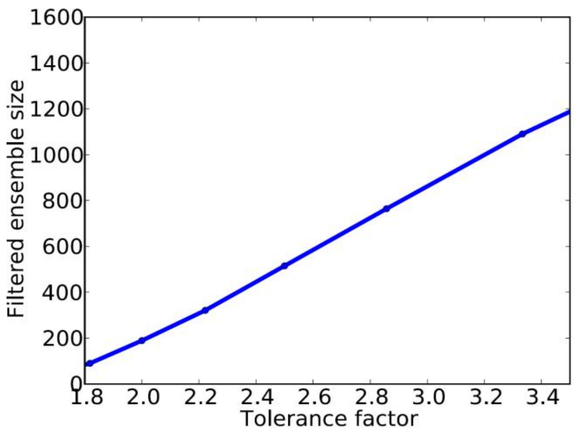

Figure S5. The number of models in the filtered ensemble (FE) as a function of the tolerance factor accepted when screening model outputs against ICES stock assessment data. A tolerance factor of two was adopted to define a FE of 189 models that was used to generate the uncertainty estimates presented in the accompanying paper.

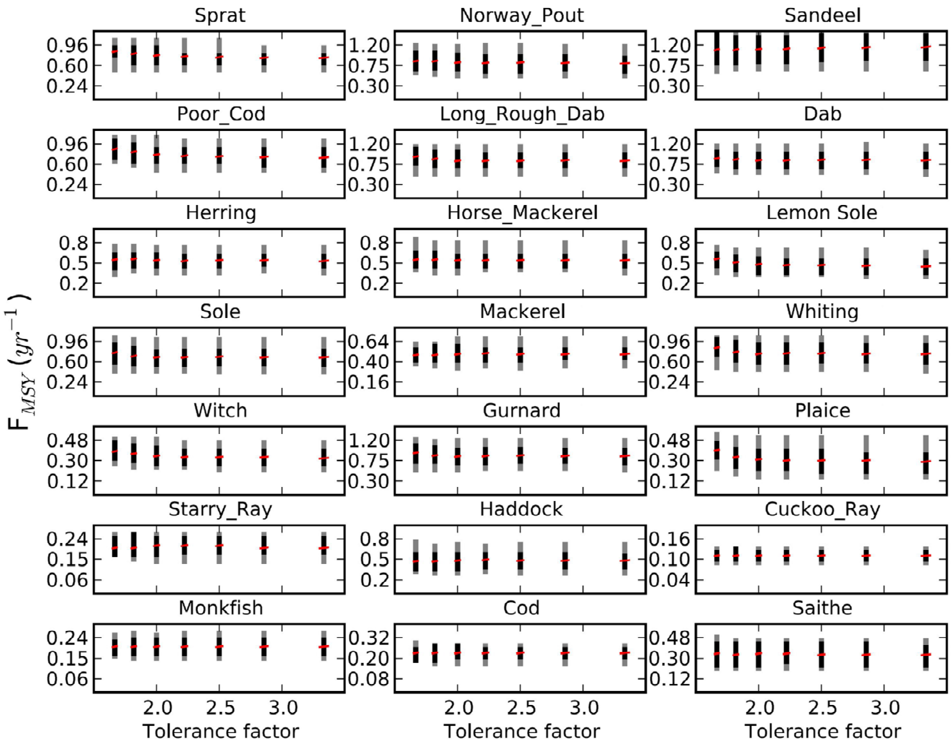

Figure S6. The effects of changes to the tolerance factor on mean F_{MSY} (red) and associated uncertainty (50% uncertainty intervals: black bars; 90% uncertainty intervals: open bars).

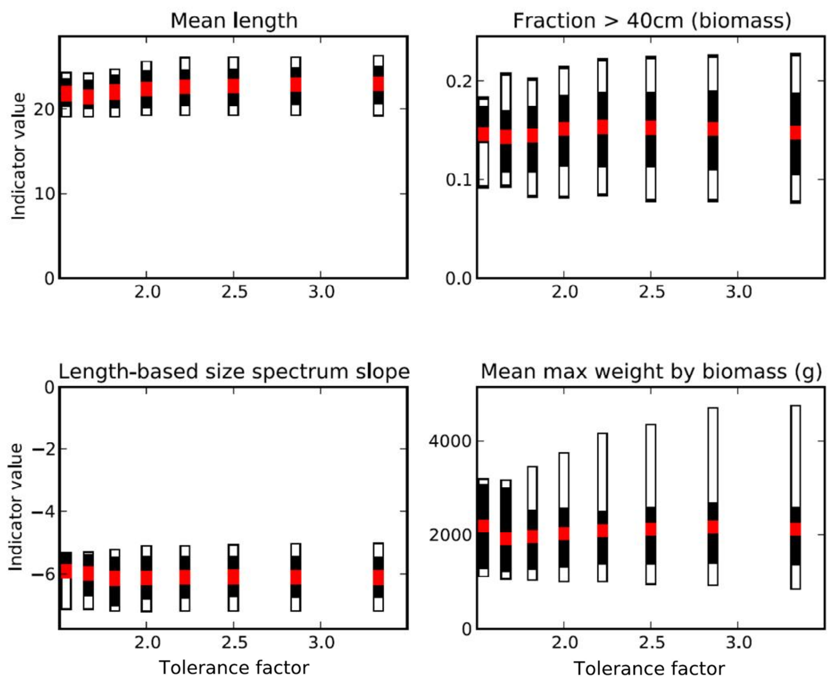

Figure S7. The effects of changes to the tolerance factor on values of four indicators and the associated uncertainty (50% uncertainty intervals: black bars; 90% uncertainty intervals: open bars).

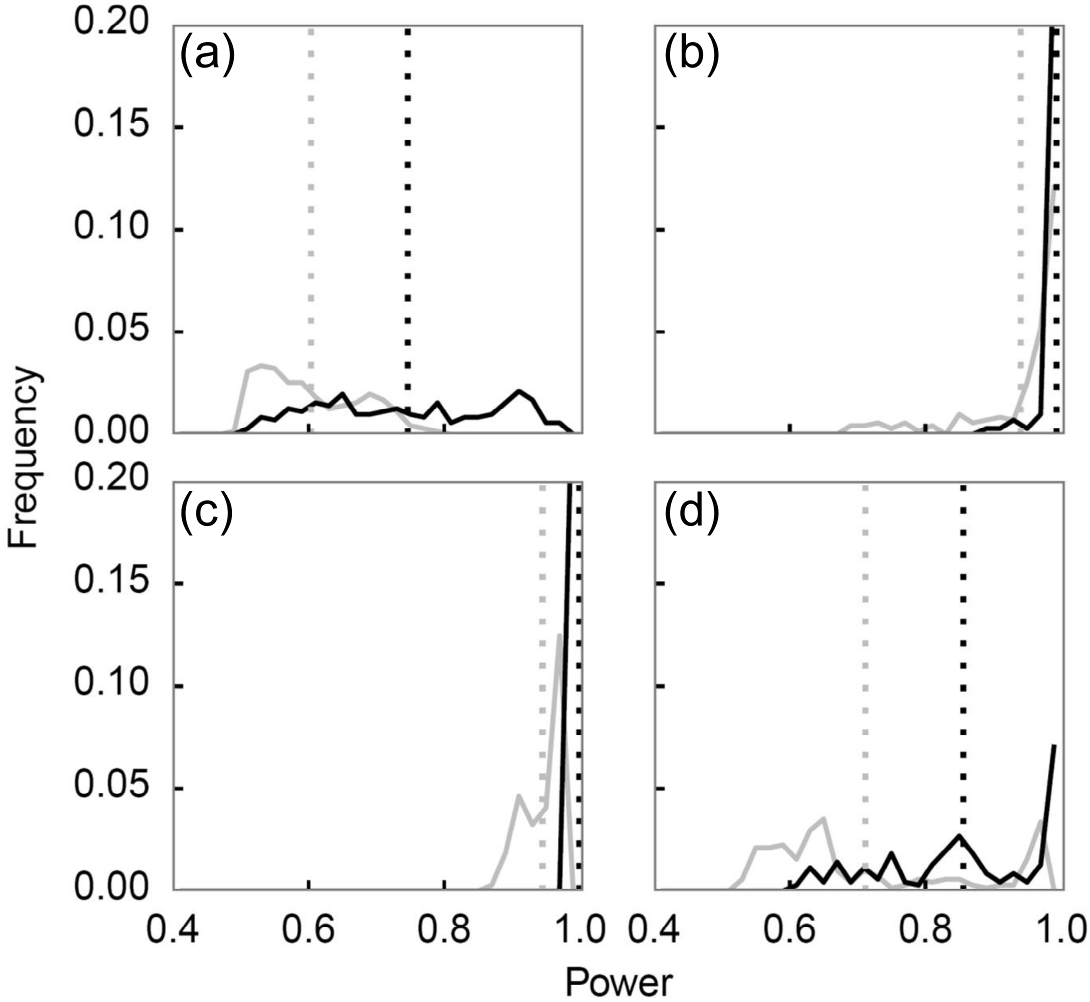

Figure S8. Frequency distributions for the predicted power of the North Sea International Bottom Trawl Survey (IBTS) to detect modelled changes in the values of community metrics for strictly demersal fishes (Category D2, Table 1, accompanying paper) when fishing mortality is reduced from F_{HIST} to F_{MSY} over 5 year (grey) and 15 year (black) periods. Metrics are (a) mean length, (b) proportion of large fish, (c) size spectrum slope and (d) mean maximum weight. Vertical lines denote mean power for all model variants in the filtered ensemble (FE).

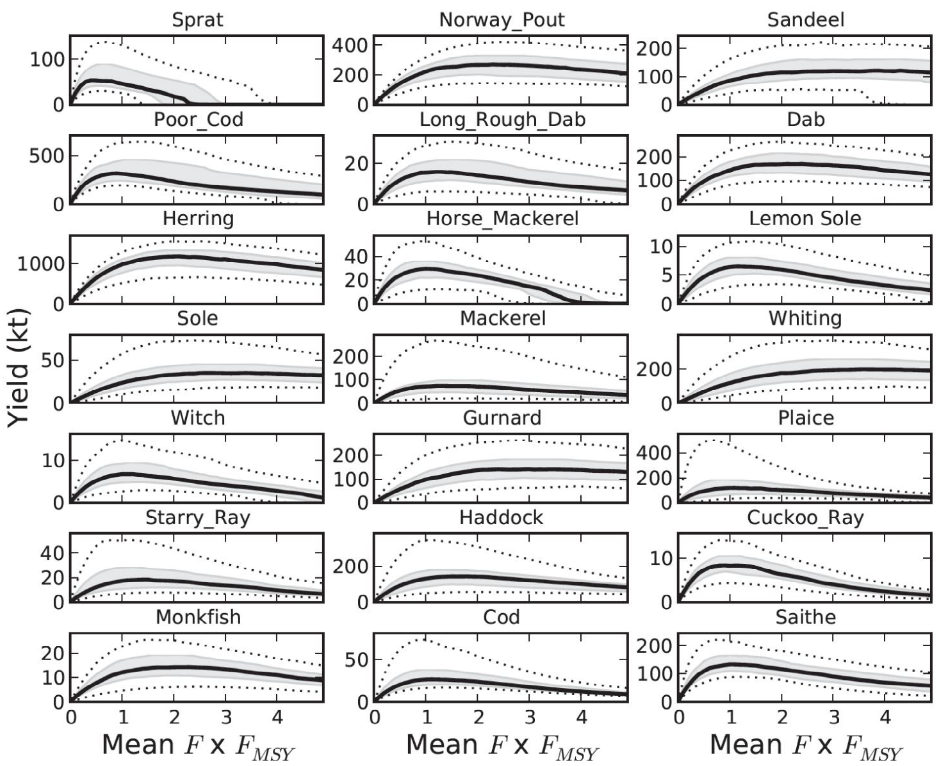

Figure S9 . Species' yields as a function of fishing mortality, as predicted with model variants in the filtered ensemble. Continuous lines denote means, shaded areas 50% uncertainty intervals and broken lines 90% uncertainty intervals.

References

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