

Properly designed effort management for highly fluctuating small pelagic fish populations: a case study in a purse seine fishery targeting chub mackerel

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Table S1. Results of the model selection and sensitivity analysis in the second operation model. The model selection was performed with AICc by selecting random effects with full fixed effects (1st step) and then selecting the fixed effects with a determined set of the random effects (2nd step). “*” represents the model selected at each step. The results of the sensitivity analysis with alternative variable transformation are also shown (Sensitivity). Within the sensitivity analysis results, a column with grey shading indicates the variable with an alternative variable transformation; if the base model used the log scale, the sensitivity was on a normal scale, and vice versa.

	Fixed effects						Random effects				AICc	ΔAICc	Dispersion factor	
	α_0	α_1	α_2	α_3	α_4	α_5	σ_1	σ_2	σ_3	σ_4				
1st step: selection of random effects														
*	R1	-1.59	1.10	-0.12	0.10	-0.38	-2.65	0.33	0.63	1.03	0.38	6564.4	1.6	1.04
	R2	-1.73	1.17	-0.15	0.02	-0.39	-2.43	-	0.64	1.08	0.38	6569.1	6.3	1.04
	R3	-1.34	0.97	-0.08	0.10	-0.38	-2.41	0.32	-	1.18	0.37	6583.4	20.6	1.04
	R4	-1.58	1.07	-0.10	0.11	-0.35	-2.53	0.33	0.59	1.01	-	6635.9	73.1	1.05
	R5	0.17	0.06	-0.17	0.13	-0.35	-1.39	0.78	1.03	-	0.36	6779.9	217.1	1.06
2nd step: selection of fixed effects														
*	F1	-1.58	1.12	-0.18	-	-0.38	-2.63	0.32	0.63	1.04	0.38	6562.8	0.0	1.04
	F2	-1.70	1.13	-	0.18	-0.38	-2.66	0.34	0.62	1.03	0.38	6563.2	0.4	1.04
	F3	-1.84	1.21	-	-	-0.38	-2.61	0.31	0.62	1.04	0.38	6563.7	0.9	1.04
	F4	-1.59	1.10	-0.12	0.10	-0.38	-2.65	0.33	0.63	1.03	0.38	6564.4	1.6	1.04
	F5	0.78	-	-0.31	-	-0.37	-2.51	0.38	0.58	0.96	0.38	6586.6	23.8	1.04
	F6	0.71	-	-0.21	0.18	-0.37	-2.55	0.40	0.58	0.94	0.37	6587.1	24.3	1.04
Sensitivity: alternative variable transformation														
S1	-0.02	0.09	-0.24	-	-0.38	-2.59	0.34	0.61	1.01	0.38	6576.3	13.5	1.04	
S2	-1.83	0.99	-0.20	-	0.02	-2.15	0.41	0.66	1.02	0.34	6683.1	120.3	1.05	
S3	-3.48	1.13	-0.19	-	-0.38	-0.50	0.50	0.78	0.98	0.38	6567.0	4.2	1.04	

Table S2. Results of the model selection and sensitivity analysis in the third operation model. The model selection was performed with AICc by selecting random effects with full fixed effects (1st step) and then selecting the fixed effects with a determined set of the random effects (2nd step). “*” represents the model selected at each step. The results of the sensitivity analysis with an alternative variable transformation are also shown (Sensitivity). In the sensitivity analysis results, a column with grey shading indicates the variable with an alternative variable transformation; if the base model used the log scale, the sensitivity was on a normal scale, and vice versa.

	Fixed effects						Random effects				AICc	ΔAICc	Dispersion factor	
	φ_0	φ_1	φ_2	φ_3	φ_4	φ_5	τ_1	τ_2	τ_3	τ_4				
1st step: selection of random effects														
R1	-4.35	1.91	-2.99	0.02	-0.52	-2.16	0.01	0.48	0.57	0.36	2406.7	4.0	0.89	
R2	-4.27	1.96	-3.15	0.03	-0.55	-2.18	0.38	0.52	-	0.35	2419.1	16.4	0.90	
R3	-4.47	1.96	-2.89	0.07	-0.54	-1.94	0.09	-	0.80	0.37	2413.6	10.8	0.89	
*	R4	-4.33	1.90	-2.99	0.02	-0.52	-2.16	-	0.48	0.56	0.36	2404.7	2.0	0.89
R5	-4.25	1.86	-2.95	0.00	-0.49	-2.10	0.00	0.47	0.55	-	2415.2	12.5	0.90	
R6	-3.29	1.51	-3.20	-0.03	-0.51	-2.09	-	0.54	-	0.36	2429.1	26.3	0.90	
R7	-4.44	1.95	-2.90	0.06	-0.54	-1.92	-	-	0.80	0.37	2411.6	8.9	0.89	
R8	-4.25	1.86	-2.95	0.00	-0.49	-2.10	-	0.47	0.55	-	2413.2	10.4	0.90	
2nd step: selection of fixed effects														
*	F1	-4.33	1.90	-3.00	-	-0.52	-2.16	-	0.48	0.56	0.36	2402.7	0.0	0.89
F2	-4.33	1.90	-2.99	0.02	-0.52	-2.16	-	0.48	0.56	0.36	2404.7	2.0	0.89	
F3	-4.79	1.79	-2.86	-	-0.47	-	-	0.55	0.75	0.36	2420.6	17.8	0.89	
F4	-4.74	1.78	-2.90	-0.07	-0.47	-	-	0.55	0.74	0.36	2422.5	19.7	0.89	
F5	-0.39	-	-3.15	-	-0.49	-1.73	-	0.50	0.58	0.35	2434.1	31.4	0.90	
F6	-4.72	1.81	-2.94	-	-	-1.74	-	0.51	0.60	0.32	2434.6	31.9	0.90	
Sensitivity: alternative variable transformation														
S1	-2.00	0.20	-3.04	-	-0.52	-2.18	-	0.47	0.58	0.36	2408.3	5.6	0.89	
S2	-4.77	1.83	-2.94	-	-0.15	-1.90	-	0.48	0.58	0.33	2432.1	29.4	0.90	
S3	-5.55	1.84	-2.98	-	-0.51	-0.36	-	0.58	0.60	0.37	2407.4	4.7	0.89	

Table S3. Results of the model selection and sensitivity analysis in the catch model. The model selection was performed with AICc by selecting random effects with full fixed effects (1st step) and then selecting the fixed effects with a determined set of the random effects (2nd step). “*” represents the model selected at each step.

	Fixed effects			Random effects				AICc	ΔAICc	
	λ_0	λ_1	λ_2	ω_1	ω_2	ω_3	ω_4			
1st step: Selection of random effects										
*	R1	1.35	0.08	0.31	-	0.24	0.57	0.09	16978.6	0.0
R2	1.14	0.11	0.41	0.23	0.38	-	0.11	18235.1	1256.5	
R3	1.13	0.09	0.42	-	0.30	-	0.11	18593.7	1615.1	
R4	1.31	0.09	0.33	-	-	0.59	0.09	17081.0	102.4	
R5	1.33	0.08	0.31	-	0.23	0.57	-	17032.5	53.9	
R6	1.13	0.09	0.42	-	0.30	-	0.11	18593.7	1615.1	
R7	0.98	0.09	0.44	0.19	-	-	0.11	18663.3	1684.7	
R8	1.12	0.11	0.41	0.24	0.38	-	-	18286.1	1307.5	
2nd step: Selection of fixed effects										
*	F1	1.35	0.08	0.31	-	0.24	0.57	0.09	16978.6	0.0
F2	1.37	-	0.28	-	0.24	0.57	0.09	16996.4	17.8	
F3	1.37	0.06	-	-	0.24	0.57	0.09	17028.5	49.9	
F4	1.38	-	-	-	0.24	0.57	0.09	17036.6	58.0	

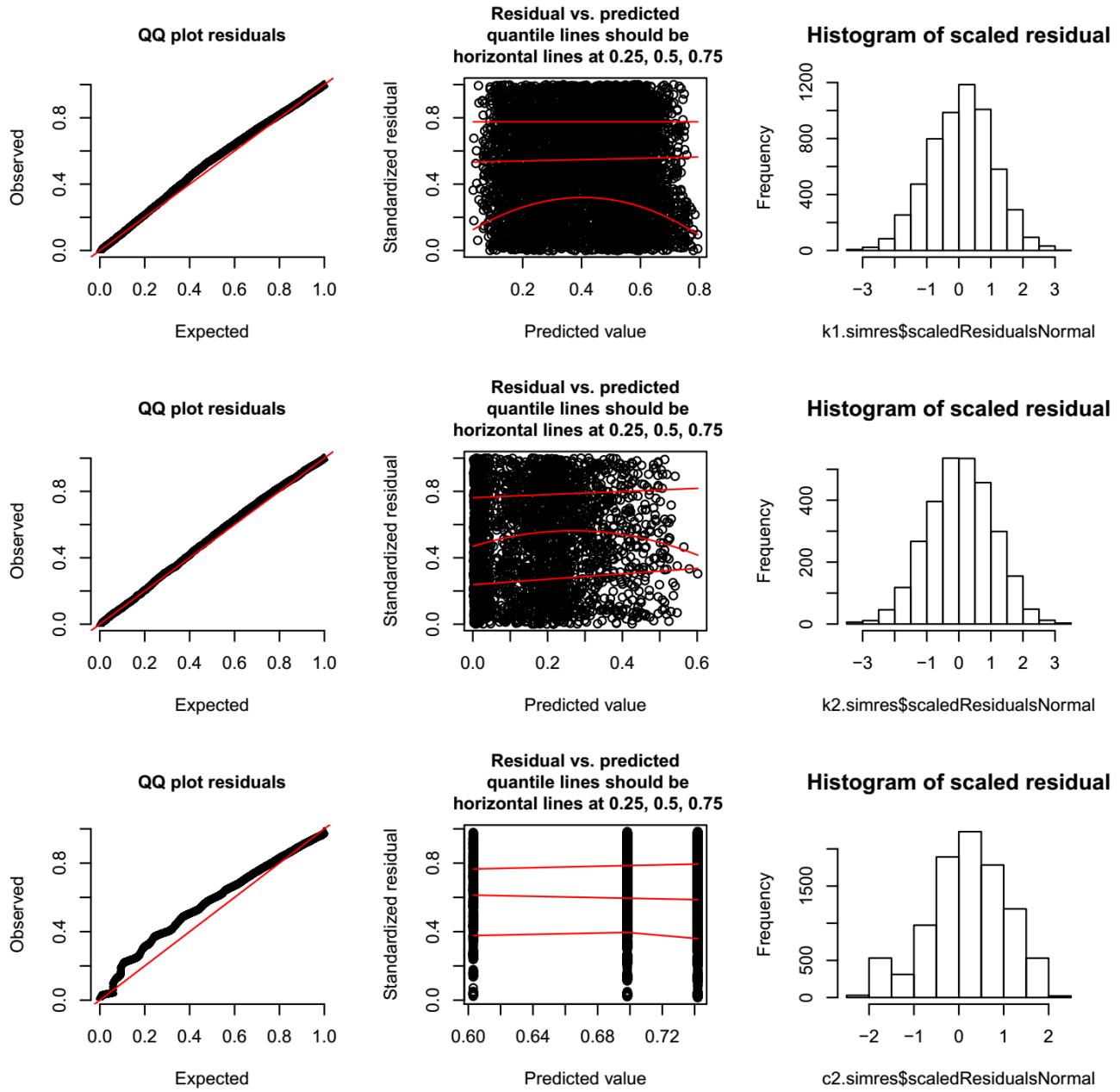


Fig. S1. QQ plot residuals (left rows), residual vs. predicted values (middle rows), and histograms of the residual distributions (right rows) for the second operation (top columns), third operation (middle columns), and catch models (bottom columns). The residuals were scaled and standardized using the R package of DHARMA (Hartig 2017). In the diagnostic plots, the black points should be on red lines (left rows), the red lines should be horizontal lines at 0.25, 0.5, and 0.75 (middle rows), and the histogram should be similar, with normal distribution when the model fits (right rows) are good.

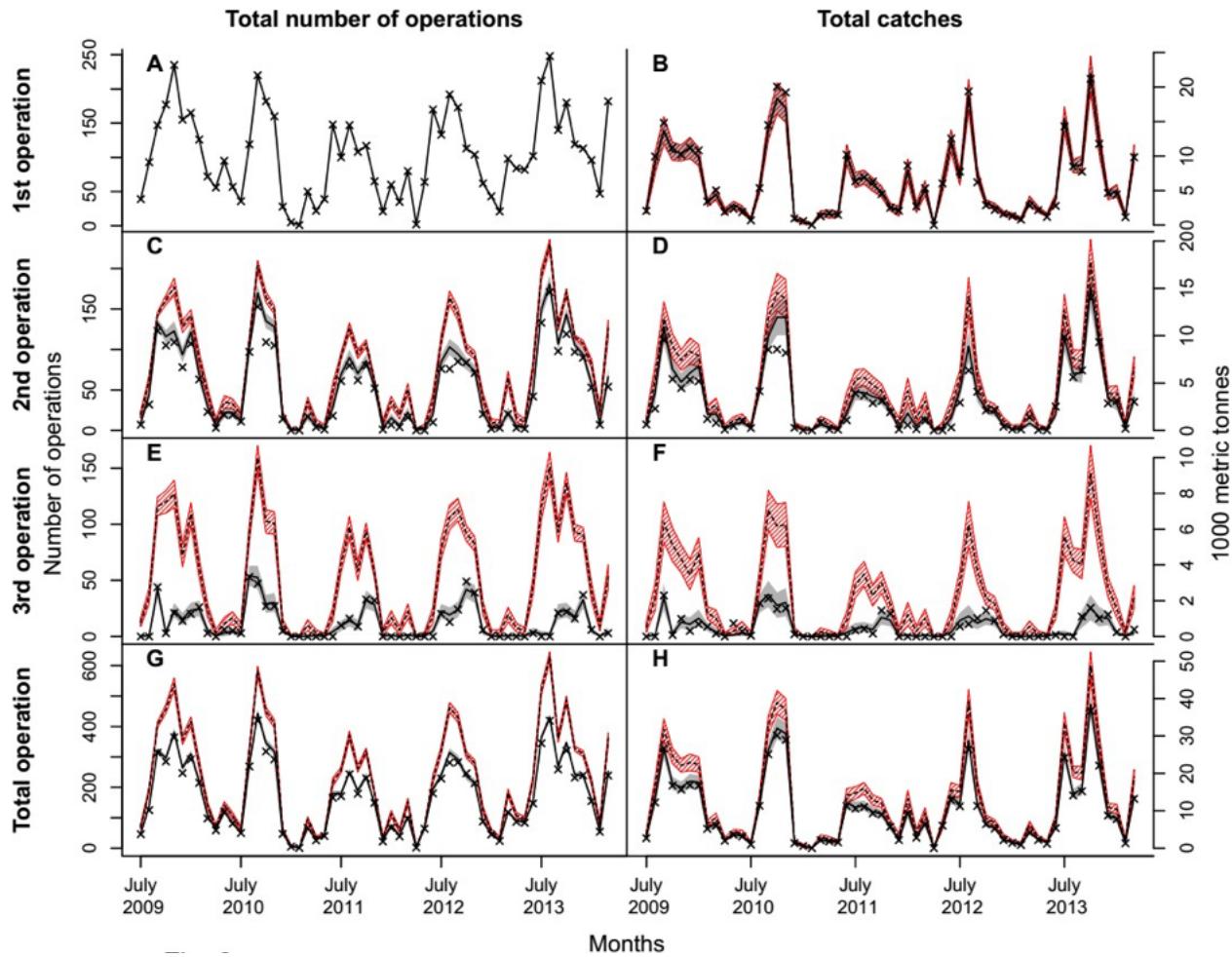


Fig. S2. Results of the sensitivity analysis when assuming a looser-effort management scenario at $h=24$ instead of $h=15$. The figure caption is the same as that in Fig. 6 of the primary text.

References

Hartig F (2017) DHARMA: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. R package. version 0.1.5. <http://florianhartig.github.io/DHARMA/>