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Supplementary information

Reply to: Shark mortality cannot be assessed by fishery overlap alone

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Supplementary Information

Reply to: Shark mortality cannot be assessed by fishery overlap alone
Queiroz *et al*.

Supplementary Methods

Shark catch data

Pelagic shark catch per unit effort (CPUE) per $1 \times 1^{\circ}$ grid cell was calculated for the species tracked by summing total shark biomass (kg) retained (recorded in skipper's logbooks) by the Spanish pelagic longline fleet in the North Atlantic divided by the number of fishing days. Catch data were available for the period January 2013 to November 2017, and were included for the following tracked sharks: blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*), longfin mako (*I. paucus*), tiger shark (*Galeocerdo cuiver*), white shark (*Carcharodon carcharias*), porbeagle shark (*Lamna nasus*), silky shark (*Carcharhinus falciformis*), smooth hammerhead shark (*Sphyrna zygaena*), bigeye thresher shark (*Alopias superciliosus*), copper shark (*Carcharhinus brachyurus*) and the sandbar shark (*C. plumbeus*). Sharks included in fishing exposure index (FEI) values were calculated using North Atlantic fishing effort of all AIS-monitored Spanish longline fishing vessels operating in that ocean. Data were $\log_{10}$ transformed prior to regression analysis.

Linear regression modelling

We compared the models (Table S1) using the Akaike and Bayesian information criterion (AIC) and assessed the models strength of evidence using the AIC weights (*w*AIC) (Burnham & Anderson, 2002). We then used r^2 to quantify the models goodness of fit, and repeated the same procedure when removing 1, 5, 10 and 25 % of the data.

Supplementary Tables

Supplementary Table 1. Linear regression model results. A model set was developed with pelagic shark catch per unit effort (CPUE) as the response variable and FEI, fishing effort (Effort) and number of longline sets (nSets) as explanatory variables with and without interactions with year (**a**) and month (**b**). All variables were $\log_{10}$ transformed. Best model when testing interaction with year is shown in bold [log(cpue) ~ log(FEI) * year], with slightly better percentage of deviance explained than Effort [log(cpue) ~ log(effort) * year]. *w*AIC, Akaike Information Criteria weights. Similar results were obtained for General Linear Models (GLM) with a Poisson distribution and a log link function.

(a) Linear regression model results with interactions with year.

Model	*w*AIC	r^2
log(cpue) ~ log(FEI) * year	**0.898**	**0.11**
log(cpue) ~ log(effort)	0.045	0.07
log(cpue) ~ log(FEI)	0.040	0.07
log(cpue) ~ log(effort) * year	0.017	**0.10**
log(cpue) ~ log(nsets) * year	0.000	0.08
log(cpue) ~ 1	0.000	0.00

(b) Linear regression model results with interactions with month.

Model	*w*AIC	r^2
log(cpue) ~ log(effort) * month	**1.000**	**0.46**
log(cpue) ~ log(nsets) * month	0.000	**0.43**
log(cpue) ~ log(FEI) * month	0.000	**0.42**
log(cpue) ~ log(effort)	0.000	0.07
log(cpue) ~ log(FEI)	0.000	0.07
log(cpue) ~ 1	0.000	0.00

Supplementary Table 2. Summary statistics for linear regression of the best fit model. There was a significant and positive correlation between log(CPUE) and log(FEI). Significance codes: 0 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '.

log(cpue) ~ log(FEI) * year					
Residuals:					
	Min	1Q	Median	3Q	Max
	-2.50423	-0.36673	0.01353	0.40220	2.15328
Coefficients:					
	Estimate Std.	Error	t value	Pr(>|t|)	
(Intercept)	8.14117	0.34450	23.632	< 2e-16 ***	
log(FEI)	0.15692	0.04790	3.276	0.00112 **	
year2014	-0.06699	0.43145	-0.155	0.87668	
year2015	0.37507	0.47575	0.788	0.43084	
year2016	-1.10595	0.59818	-1.849	0.06505	
year2017	-0.75244	0.49138	-1.531	0.12632	
log(FEI):year2014	-0.03877	0.06075	-0.638	0.52362	
log(FEI):year2015	0.05783	0.06525	0.886	0.37591	
log(FEI):year2016	-0.17141	0.09086	-1.886	0.05980	
log(FEI):year2017	-0.10672	0.06680	-1.598	0.11072	
Residual standard error: 0.6553 on 513 degrees of freedom					
Multiple R-squared: 0.1118, Adjusted R-squared: 0.09621					
F-statistic = 7.174 on 9 and 513 DF, p-value = 7.773e-10					

Supplementary Table 3. Summary statistics for linear regression of the second fit model. There was a significant and positive correlation between log(CPUE) and log(effort). Significance codes: 0 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '.

log(cpue) ~ log(effort) * year					
Residuals:					
	Min	1Q	Median	3Q	Max
	-2.76544	-0.37784	0.01735	0.40268	2.19458
Coefficients:					
	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	6.26505	0.25837	24.248	< 2e-16 ***	
log(effort)	0.18037	0.05830	3.094	0.00208 **	
year2014	0.51919	0.32912	1.577	0.11530	
year2015	-0.16804	0.34674	-0.485	0.62816	
year2016	0.31073	0.54134	0.574	0.56622	
year2017	0.27706	0.33500	0.827	0.40860	
log(effort):year2014	-0.07096	0.07297	-0.972	0.33128	
log(effort):year2015	0.03070	0.08067	0.381	0.70368	
log(effort):year2016	-0.06168	0.11656	-0.529	0.59692	
log(effort):year2017	-0.05782	0.07814	-0.740	0.45965	
Residual standard error: 0.6603 on 513 degrees of freedom					
Multiple R-squared: 0.09829, Adjusted R-squared: 0.08247					
F-statistic = 6.213 on 9 and 513 DF, p-value = 2.417e-08					

Supplementary Table 4. Linear regression models used in bootstrapping tests. The models tested included the $\log_{10}$ transformations of both response and explanatory variable. CPUE denotes catch per unit effort (response variable); FEI, fishing exposure index; effort, fishing effort (days); nsets, number of longline sets.

Model	**Variables included**
Model 1	log(cpue) ~ log(FEI)
Model 2	log(cpue) ~ log(effort)
Model 3	log(cpue) ~ log(FEI) * year
Model 4	log(cpue) ~ log(effort) * year
Model 5	log(cpue) ~ log(nsets) * year
Model 6	log(cpue) ~ 1

Supplementary Table 5. Akaike Information Criteria weights (wAIC) for each model tested after removing 1% of data (bootstrapping). Columns labelled 1-10 denote each of 10 iterations randomly removing 1% of the data. wAIC was always best for Model 3 (bold).

Model	1	2	3	4	5	6	7	8	9	10
1	0.029	0.057	0.044	0.029	0.064	0.039	0.018	0.011	0.020	0.030
2	0.023	0.051	0.050	0.027	0.066	0.026	0.005	0.012	0.055	0.032
3	**0.939**	**0.875**	**0.889**	**0.932**	**0.854**	**0.925**	**0.973**	**0.967**	**0.883**	**0.923**
4	0.009	0.016	0.016	0.011	0.016	0.010	0.004	0.010	0.042	0.015
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table 6. Bayesian Information Criteria weights (wBIC) for each model tested after removing 1% of data. wBIC always choses the most parsimonious model (i.e. the models without interactions) and best fit alternates between effort and FEI.

Model	1	2	3	4	5	6	7	8	9	10
1	**0.562**	**0.528**	**0.469**	**0.519**	**0.494**	**0.599**	**0.791**	**0.481**	**0.261**	**0.487**
2	**0.438**	**0.472**	**0.531**	**0.481**	**0.506**	**0.401**	**0.209**	**0.519**	**0.739**	**0.513**
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table 7. Percentage deviance explained (%DE) for each model tested after removing 1% of data. %DE was always higher for model 3 and followed closely by model 4.

Model	1	2	3	4	5	6	7	8	9	10
1	7.128	6.917	6.553	6.749	6.923	7.362	9.288	7.631	7.484	7.142
2	7.038	6.877	6.598	6.722	6.932	7.218	8.821	7.658	7.855	7.160
3	**11.224**	**10.764**	**10.510**	**10.855**	**10.724**	**11.344**	**13.461**	**12.048**	**11.678**	**11.219**
4	**9.617**	**9.372**	**9.120**	**9.322**	**9.342**	**9.775**	**11.597**	**10.498**	**10.637**	**9.797**
5	7.865	7.497	7.282	7.455	7.508	8.132	10.259	8.599	8.566	7.930
6	-0.512	-0.300	-0.683	-0.318	-0.306	0.020	2.630	0.351	-0.034	0.000

Supplementary Table 8. Akaike Information Criteria weights (wAIC) for each model tested after removing 5% of data (bootstrapping). Columns labelled 1-10 denote each of 10 iterations randomly removing 5% of the data. wAIC was always best for Model 3.

Model	1	2	3	4	5	6	7	8	9	10
1	0.124	0.048	0.006	0.010	0.204	0.017	0.014	0.096	0.079	0.082
2	0.147	0.058	0.004	0.015	0.222	0.034	0.003	0.043	0.039	0.069
3	**0.698**	**0.869**	**0.980**	**0.964**	**0.565**	**0.900**	**0.977**	**0.848**	**0.875**	**0.827**
4	0.031	0.025	0.010	0.010	0.009	0.042	0.006	0.013	0.007	0.022
5	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table 9. Bayesian Information Criteria weights (wBIC) for each model tested after removing 5% of data. wBIC always choses the most parsimonious model (i.e. the models without interactions) and best fit alternates between effort and FEI.

Model	1	2	3	4	5	6	7	8	9	10
1	**0.458**	**0.454**	**0.569**	**0.406**	**0.479**	**0.330**	**0.824**	**0.692**	**0.667**	**0.541**
2	**0.542**	**0.546**	**0.431**	**0.594**	**0.521**	**0.670**	**0.176**	**0.308**	**0.333**	**0.459**
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table 10. Percentage deviance explained (%DE) for each model tested after removing 5% of data. %DE was always higher for model 3 and followed closely by models 4, 1 and 2.

Model	1	2	3	4	5	6	7	8	9	10
1	10.933	12.471	13.627	10.918	12.162	11.171	13.466	11.828	11.287	11.871
2	10.993	12.537	13.529	11.055	12.192	11.425	12.928	11.540	11.039	11.812
3	**14.425**	**16.297**	**18.144**	**15.379**	**15.366**	**15.429**	**17.700**	**15.441**	**14.999**	**15.528**
4	13.344	15.091	16.609	13.821	13.928	14.381	15.990	14.020	13.333	14.281
5	11.832	13.058	14.767	12.181	12.197	13.785	14.225	12.286	11.485	12.157
6	3.512	5.926	6.247	3.799	5.345	4.333	6.987	5.022	4.159	4.567

Supplementary Table 11. Akaike Information Criteria weights (wAIC) for each model tested after removing 10% of data (bootstrapping). Columns labelled 1-10 denote each of 10 iterations randomly removing 10% of the data. wAIC was best for Model 3 most often but also model 2 and 4.

Model	1	2	3	4	5	6	7	8	9	10
1	0.008	0.037	0.168	0.047	0.224	0.248	0.019	0.016	0.015	0.130
2	0.319	0.073	0.078	0.045	**0.426**	0.204	**0.591**	**0.589**	0.025	0.059
3	0.265	**0.822**	**0.745**	**0.883**	0.292	**0.505**	0.208	0.257	**0.940**	**0.805**
4	**0.407**	0.067	0.009	0.025	0.057	0.043	0.182	0.139	0.020	0.006
5	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table 12. Bayesian Information Criteria weights (wBIC) for each model tested after removing 10% of data. wBIC always choses the most parsimonious model (i.e. the models without interactions) and alternating between models 1 and 2.

Model	1	2	3	4	5	6	7	8	9	10
1	0.025	0.338	**0.681**	**0.508**	0.345	**0.549**	0.031	0.026	0.384	**0.689**
2	**0.975**	**0.662**	0.319	**0.492**	**0.655**	**0.451**	**0.969**	**0.974**	**0.616**	0.311
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table 13. Percentage deviance explained (%DE) for each model tested after removing 10% of data. %DE was always higher for model 3 and followed closely by models 4, and 5 (also 1 and 2).

Model	1	2	3	4	5	6	7	8	9	10
1	16.432	16.009	16.678	16.647	20.120	15.362	16.503	18.938	13.719	16.944
2	17.724	16.249	16.408	16.635	20.337	15.291	17.716	20.170	13.893	16.663
3	**20.485**	**19.951**	**20.046**	**20.508**	**22.949**	**18.514**	**20.187**	**22.638**	**18.124**	**20.413**
4	**20.630**	**19.094**	**18.519**	**19.298**	**22.412**	**17.656**	**20.143**	**22.436**	**16.774**	**18.711**
5	18.604	17.645	17.345	17.297	19.925	15.091	17.981	20.357	15.192	17.222
6	10.528	10.539	9.966	9.111	13.601	7.857	8.947	13.035	6.585	9.623

Supplementary Table 14. Akaike Information Criteria weights (wAIC) for each model tested after removing 25% of data (bootstrapping). Columns labelled 1-10 denote each of 10 iterations randomly removing 25% of the data. wAIC was best for Model 3 most often but also model 2 and 1.

Model	1	2	3	4	5	6	7	8	9	10
1	**0.307**	0.087	0.058	0.117	0.117	0.101	**0.494**	0.174	**0.636**	**0.508**
2	**0.378**	**0.868**	0.228	**0.549**	0.182	0.008	0.017	0.089	0.005	0.203
3	**0.295**	0.025	**0.502**	0.226	**0.643**	**0.886**	**0.486**	**0.721**	**0.359**	0.287
4	0.020	0.020	0.205	0.108	0.055	0.004	0.003	0.009	0.000	0.003
5	0.000	0.000	0.007	0.000	0.003	0.000	0.000	0.006	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table 15. Bayesian Information Criteria weights (wBIC) for each model tested after removing 25% of data. wBIC always choses the most parsimonious model (i.e. the models without interactions) and alternating between models 1 and 2.

Model	1	2	3	4	5	6	7	8	9	10
1	**0.448**	0.091	0.202	0.175	0.392	**0.925**	**0.966**	**0.663**	**0.992**	**0.715**
2	**0.552**	**0.909**	**0.798**	**0.825**	**0.608**	0.075	0.034	0.337	0.008	0.285
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table 16. Percentage deviance explained (%DE) for each model tested after removing 25% of data. %DE was always higher for model 3 followed closely by models 4, 5, 1 and 2.

Model	1	2	3	4	5	6	7	8	9	10
1	24.519	26.911	27.814	30.505	29.906	29.374	28.707	30.513	35.991	35.470
2	24.600	27.765	28.319	31.052	30.062	28.466	27.478	30.274	34.389	35.167
3	**27.624**	**29.491**	**31.557**	**33.602**	**33.384**	**33.039**	**31.648**	**33.866**	**38.457**	**37.957**
4	**26.631**	**29.402**	**31.244**	**33.350**	**32.544**	**31.206**	**29.852**	**32.380**	**35.831**	**36.493**
5	24.049	28.063	30.027	31.209	31.482	29.528	28.128	32.256	35.922	33.455
6	19.037	22.033	23.333	25.804	25.470	23.064	23.465	25.199	31.232	27.904

Supplementary Reference

Burnham, K.P., Anderson,D.R. Multimodel inference – understanding AIC and BIC in model selection. *Sociological Methods and Research* **33**, 261–304 (2004).