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Supplementary information

Bycatch rates in fisheries largely driven by variation in individual vessel behaviour

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Supplementary Information

Title: Fisheries bycatch rates largely driven by variation in individual vessel behaviour

*Leslie A. Roberson[1,2], Chris Wilcox[1]

1. *CSIRO Oceans and Atmosphere, Hobart, Tasmania, 7000, Australia*
2. *School of Earth and Environmental Sciences, University of Queensland, St Lucia, 4072, Australia*

Correspondence to: leslie.roberson@csiro.au

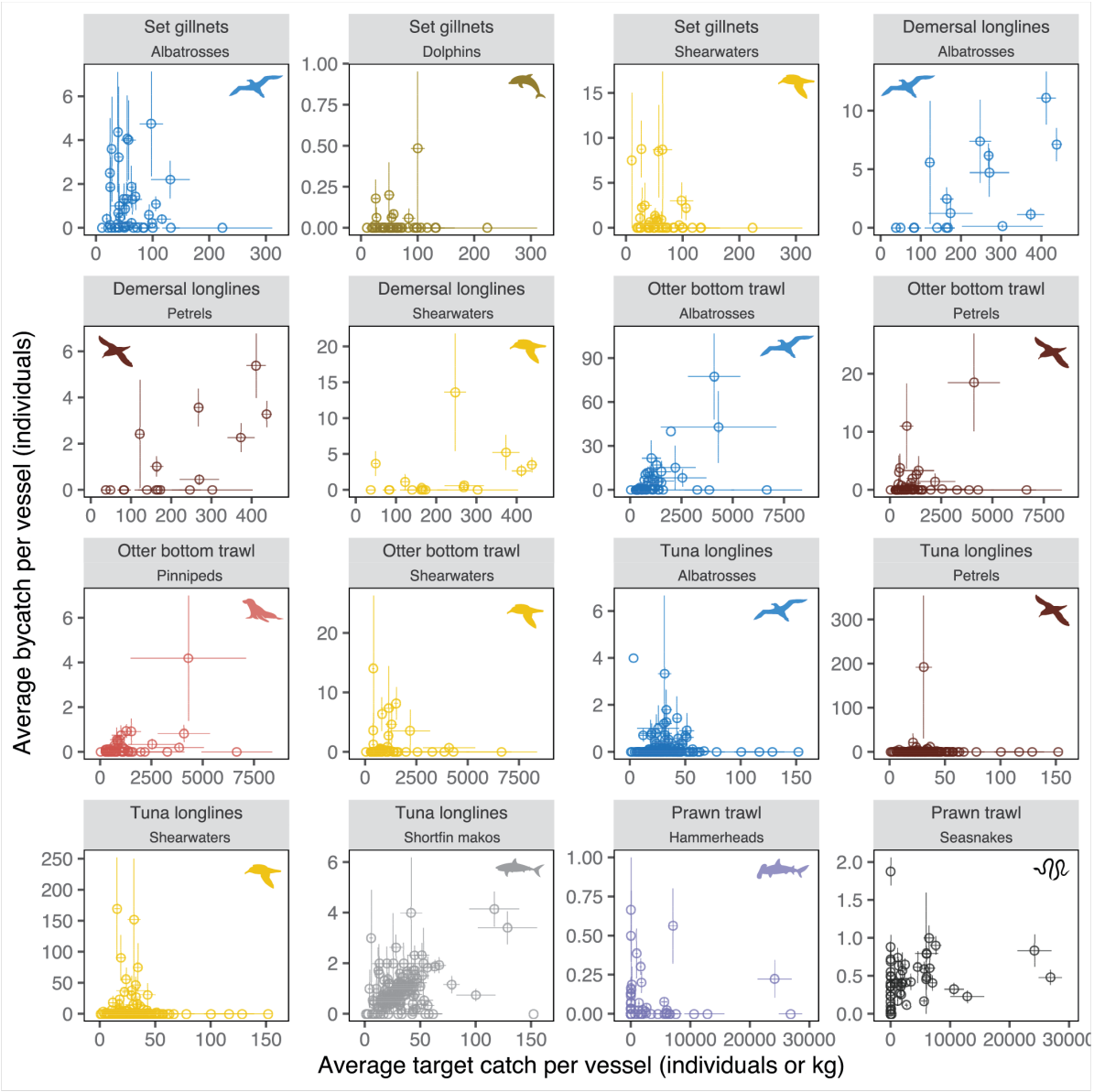

Figure S1: Vessel bycatch and target catch. Bycatch compared to target catch per individual vessel for the 16 fishery-bycatch type interaction, averaged across all fishing events recorded for each vessel. Bycatch includes individuals that were caught or landed as well as interactions where the animal escaped. Lines show standard errors for target and bycatch for each vessel. Species icons from flaticon.com (albatross, petrel), vecteezy.com (shearwater), and thenounproject.com (shortfin mako, hammerhead, dolphin, and sea snake).

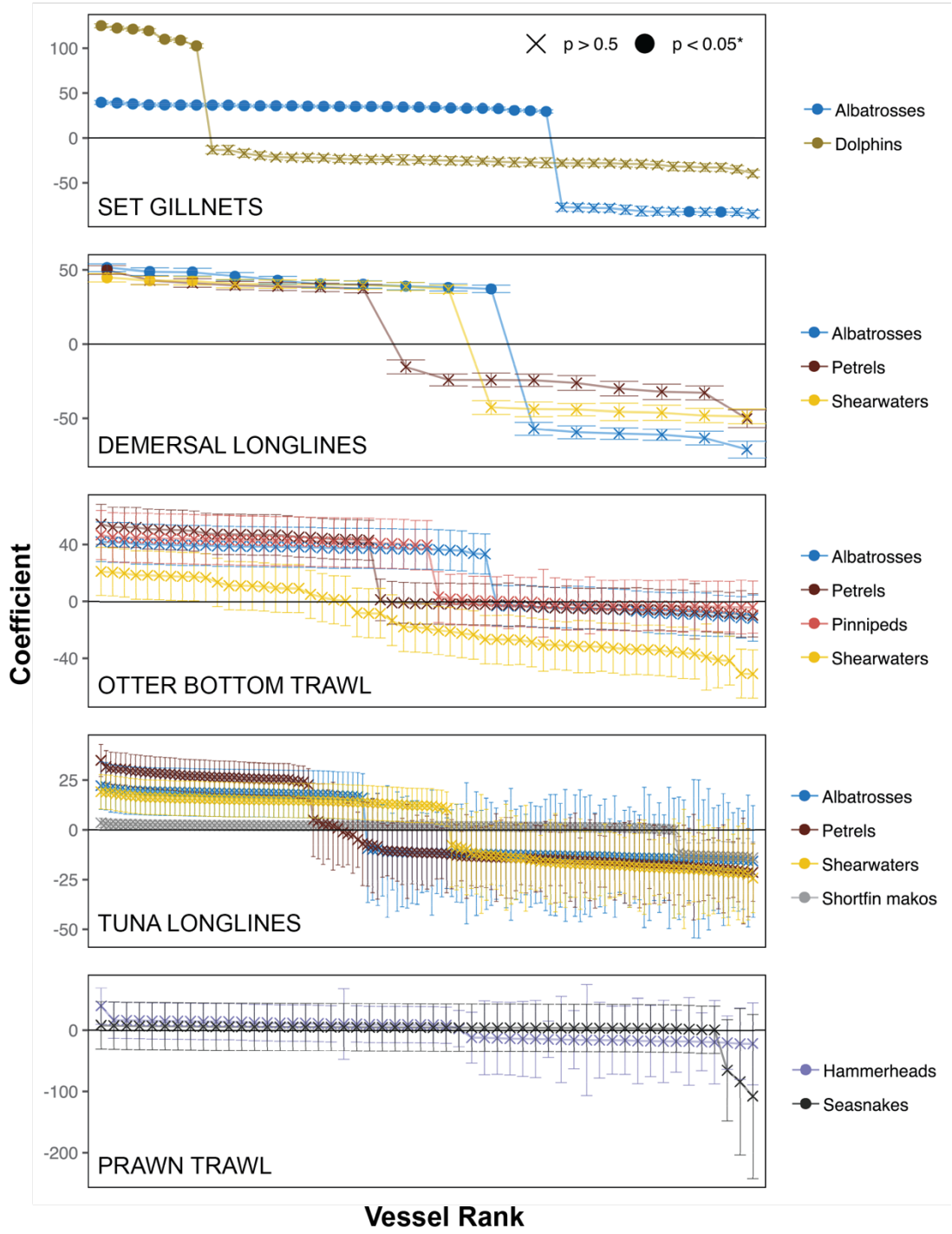

Figure S2: Regression coefficients for individual vessels (as a fixed effect) in the 15 models where vessel was significant. Coefficients are calculated using deviation contrasts instead of the default treatment contrasts, and ordered by descending coefficient value for each species (more positive coefficients on left indicate higher bycatch). Error bars show the cube root of the standard error estimate for each regression coefficient. Round dots show significant ($p<0.05$) regression coefficients and crosses show *p*-values > 0.05. The only significant coefficients are in the set gillnet and demersal longline fisheries.

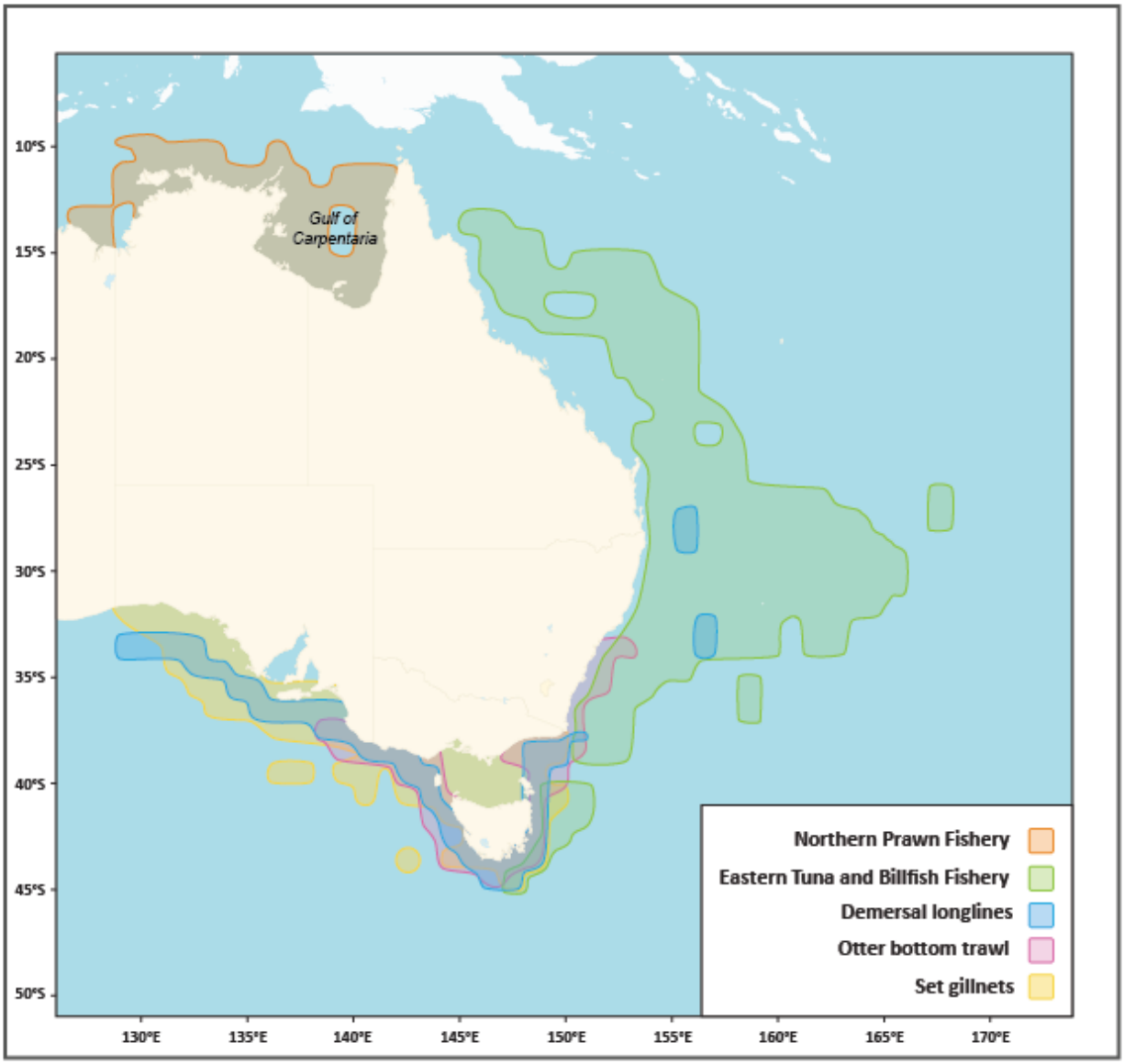

Figure S3: Map of the five Australian Commonwealth fisheries. Area shows each fishery's general area of operation, as shown in reports from the Australian Fisheries Management Authority

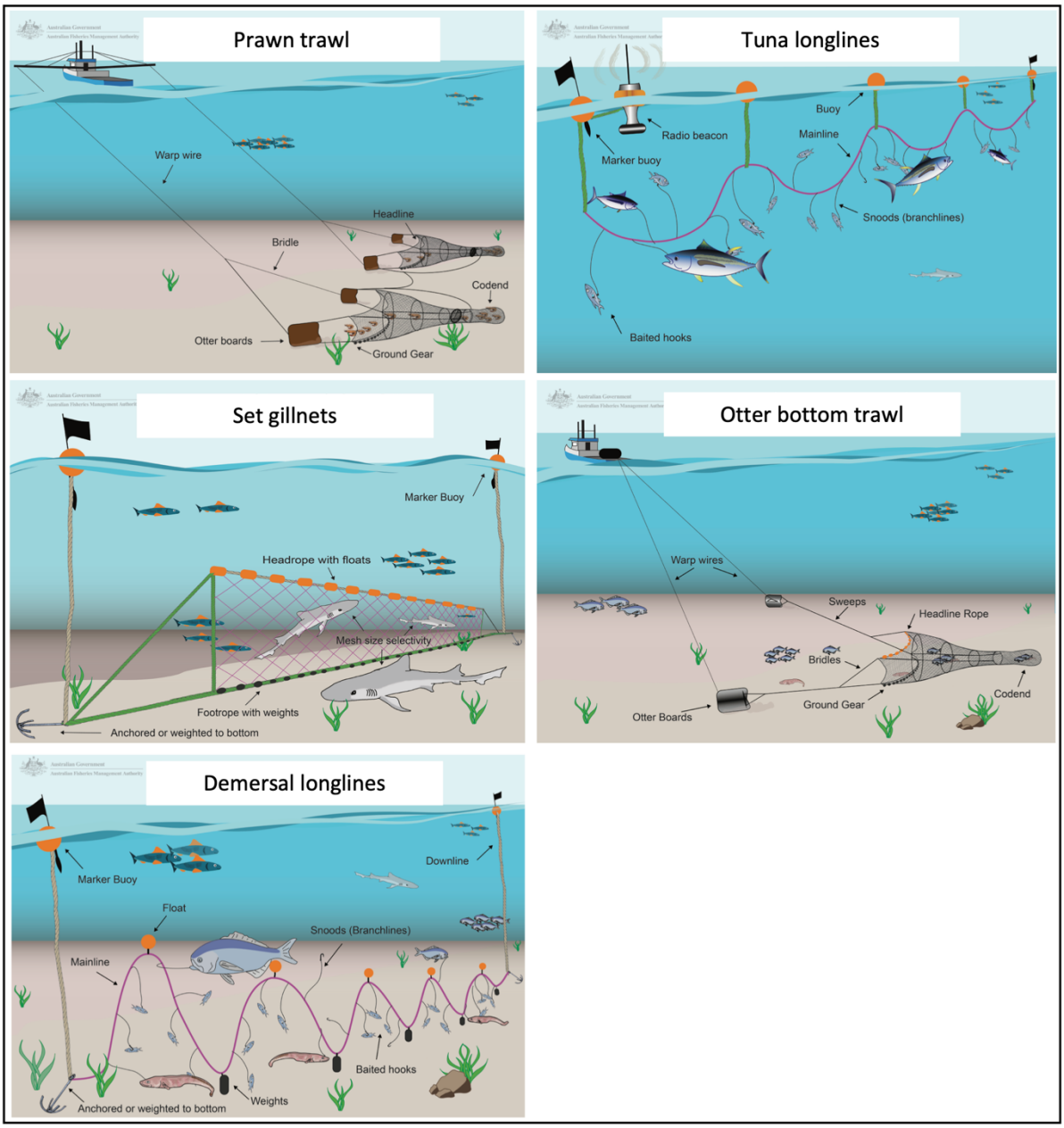

Figure S4: Schematic of gear types used in the five fishing sectors. Illustrations provided by the Australian Fisheries Management Authority (https://www.afma.gov.au/fisheries-management/methods-and-gear).

Table S1: Description of fishing sectors and scientific observer datasets included in analysis.

Fishery	Main target species	Bycatch species or groups	Vessels	Years	Fishing events
Prawn trawl	Banana prawns (*Fenneropenaeus spp*.); Tiger prawns (*Penaeus spp)*	Hammerhead and winghead sharks (Sphyrnidae); Sea snakes (Laticaudidae, Hydrophiidae)	52	2007-2017	4377
Tuna longlines	Yellowfin tuna (*Thunnus. albacares*), bigeye tuna (*T. obesus*), albacore (*T. alalunga*), Southern bluefin tuna (*T. maccoyii*), broadbill swordfish (*Xiphias gladius*)	Shortfin mako shark (*Isurus oxyrinchus*); Albatrosses (*Diomedea exulan*s, *Thalassarche* spp.); Petrels (*Procellaria* spp., *Pterodoma* spp., *Puffinus* spp.); Shearwaters (Mostly *Ardenna carneipes*, some *Puffinus* spp.)	133	2001-2015	4242
Demersal gillnets	Gummy shark (*Mustelus antarcticus*), sawsharks (Pristiophoridae), elephant fish (Callorhinchidae)	Dolphins (mostly *Delphinus delphis*); Albatrosses (mostly *Thalassarche cauta and T. melanophris,* also *T. chlororhynchos* and *T. bulleri); Shearwaters (Mostly Ardenna carneipes,* also *Puffinus tenuirostris, Ardenna grisea)*	43	2007-2016	2115
Demersal longlines	Blue-eye trevalla (*Hyperoglyphe antarctica, Schedophilus labyrinthica*), Pink ling (*Genypterus blacodes*), Ribaldo (*Mora moro),* Ocean perch *(Helicolenus barathri, H. percoides)*	Albatrosses (mostly *Thalassarche cauta*, some *T. melanophris* and *T*. spp.,); Petrels (mostly *Procellaria aequinoctialis*, also other *Procellaria* spp., *Daption capense*); Shearwaters (Mostly *Ardenna carneipes*, some *Puffinus* spp.)	17	2007-2016	5227
Otter bottom trawl	Flathead (*Neoplatycephalus richardsoni*), pink ling (*Genypterus blacodes*), Blue grenadier (*Macruronus novaezelandiae*), Silver warehou (*Seriolella punctata*), Orange roughy (*Hoplostethus atlanticus*), morwong (*Nemadactylus macropterus),* Bight redfish *(Centroberyx gerrardi)*	Pinnipeds (mostly *Arctocephalus pusillus doriferus*); Albatrosses (mostly *Thalassarche cauta*, also *T. melanophris*, *T.* spp.); Petrels (mostly *Procellaria aequinoctialis*, also other *Procellaria* spp.); Shearwaters (Mostly *Ardenna carneipes*, some *Puffinus* spp.)	58	2004-2016	1987

Table S2: Estimated parameters for parametric coefficients, smoothed effects, and fixed effects for the best model for the 16 species-fishery interactions. Perc. in light = Percent of fishing event duration in daylight. Duration= duration of fishing event (setting and hauling gear). Depth= depth of fishing gear (either a min or max depth depending on the fishery). All models included an effort offset. "Importance" is estimated with the dredge function that sums all Akaike weights over all models including the explanatory variable. Dev.=Deviance, No. obs. = Number of observations. ∆AIC is the difference between the best model and the second-best model suggested with the dredge function. AICc weight is the proportion of the total amount of predictive power provided by the full set of models contained in the best model.

Shortfin makos (Tuna longlines)						
Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-1.04E+00	7.95E-02	-13.139	< 2e-16	
	Target catch	1.67E-03	2.64E-04	6.321	2.88E-10	1.0000
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	8.9068	8.997	39.188	< 0.001	1.0000
	s(Month)	9.0796	10	43.630	< 0.001	1.0000
	s(Lat, Lon)	1.9941	2	419.223	< 0.001	1.0000
	s(% in light)	8.1137	8.7745	26.015	< 0.001	1.0000
	s(Shot duration)	7.382	8.3485	8.271	< 0.001	1.0000
Fixed Effects						
	Target cluster					1.0000
	Vessel					1.0000
	Operation type					1.0000
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**∆AICc**	**AICc weight**	
	25.30%	4242	9547.7690	16.6970	0.9997	

Shearwaters (Tuna longlines)						
Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-5.90E+00	1.08051	-5.462	4.98E-08	
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	2.65	3.3369	46.007	< 0.001	1.0000
	s(Month)	7.8977	10	43.916	< 0.001	1.0000
	s(Lat, Lon)	1.9267	2	67.845	< 0.001	1.0000
	s(% in light)	3.4626	4.2049	23.194	< 0.001	1.0000
	s(Vessel)	57.4526	133	2.714	< 0.001	1.0000
Fixed Effects						
	Target cluster					0.3995
	Operation type					0.9997
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**∆AICc**	**AICc weight**	
	82.50%	4242	7437.7263	0.6103	0.3407	

Petrels (Tuna longlines)						
Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-9.78901	2.51329	-3.895	9.98E-05	
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	3.8934	4.6854	17.364	< 0.001	1.0000
	s(Month)	5.4927	10	42.038	< 0.001	1.0000
	s(Lat, Lon)	1.4714	2	17.731	0.021	0.5513
	s(% in light)	2.1926	2.63	13.318	< 0.001	0.9984
	s(Vessel)	47.0819	133	1.666	< 0.001	1.0000
Fixed Effects						
	Operation type					0.4212
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	84.10%	4242	5194.8720	0.0663	0.1443	

Albatrosses (Tuna longlines)						
Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-5.0356	0.4426	-11.376	<2e-16	
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	1	1	58.142	< 0.001	1.0000
	s(Month)	5.915	10	6.175	< 0.001	1.0000
	s(Lat, Lon)	1.7986	2	50.694	< 0.001	1.0000
	s(% in light)	2.2447	2.6794	16.752	< 0.001	0.9999
	s(Vessel)	29.4666	133	0.652	< 0.001	0.7531
Fixed Effects						
	Operation type					0.7289
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	52.30%	4242	4951.2225	0.4750	0.1682	

Sea snakes (Prawn trawl)						
Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-5.26E+00	4.45E-01	-11.820	< 2e-16	
	Target catch	-2.33E-05	6.37E-06	-3.660	0.00026	1.0000
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	8.2682	8.8556	34.596	< 0.001	1.0000
	s(Month)	1.8119	2	9.291	< 0.001	0.9897
	s(Lat, Lon)	3.7762	4	17.131	< 0.001	1.0000
Fixed Effects						
	Target cluster					0.9994
	Vessel					1.0000
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	84.80%	4377	9140.7725	9.1383	0.9891	

Hammerheads (Prawn trawl)

Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-30.8618	24486.875	-0.001	0.999	
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	8.2671	8.7596	15.592	< 0.001	0.9999
	s(Month)	1.9164	2	19.151	< 0.001	0.9999
	s(Lat, Lon)	3.6897	4	19.478	< 0.001	0.0001
	s(Depth)	6.3773	7.3336	6.246	< 0.001	1.0000
Fixed Effects						
	Vessel					1.0000
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	95.40%	4377	4446.9330	18.9154	0.9999	

Shearwaters (Demersal longlines)

Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-7.4016	0.7819	-9.466	<2e-16	
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	**Importance**
	s(Month)	1.7652	2	14.247	0.002	0.9647
	s(Vessel)	4.6623	16	1.058	< 0.001	0.9835
Fixed Effects						
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	16.10%	1987	3186.7039	0.0000	0.1061	

Petrels (Demersal longlines)

Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-1.34E+02	8.10E+01	-1.653	0.0985	
	Target catch	-2.33E-03	9.33E-04	-2.501	0.0125	0.4506
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	0.9543	9	3.998	< 0.001	0.9998
	s(Lat,Lon)	1.8205	2	24.457	< 0.001	0.9959
	s(Depth)	3.9711	9	4.056	< 0.001	1.0000
	s(Vessel)	5.0809	16	3.825	< 0.001	1.0000
Fixed Effects						
	Target cluster					1.0000
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	44.20%	1987	3943.4554	0.0000	0.4295	

Albatrosses (Demersal longlines)

Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**

	Intercept	-6.5939	0.8396	-7.854	6.58E-15	
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	1.3132	9	5.613	< 0.001	0.9869
	s(Month)	1.3614	2	2.489	0.045	0.7323
	s(Lat,Lon)	1.8465	2	28.156	< 0.001	0.8856
	s(Depth)	2.1342	9	5.148	0.002	0.9371
	s(Vessel)	6.8429	16	3.645	< 0.001	1.0000
Fixed Effects						
	Target cluster					0.0285
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	27%	1987	4745.7154	0.8132	0.3557	

Shearwaters (Otter bottom trawl)

Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-1.23E+01	1.58E+00	-7.772	9.23E-15	
	Target catch	2.59E-04	3.51E-05	7.382	1.80E-13	1.0000
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	5.997	9	10.562	< 0.001	1.0000
	s(Month)	3.8623	10	6.581	0.009	0.6815
	s(Lat,Lon)	1.3596	2	90.511	0.059	0.6507
	s(Vessel)	22.4045	57	1.878	< 0.001	1.0000
Fixed Effects						
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	66.80%	5227	6041.2951	1.6504	0.2278	

Pinnipeds (Otter bottom trawl)

Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-9.028192	0.4400382	-20.520	<2e-16	
	Target catch	0.0002452	0.0000241	10.180	<2e-16	1.0000
Smoothed terms	**Term**	**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Month)	2.7034	10	9.234	< 0.001	0.9860
	s(Lat,Lon)	1.8532	2	516.996	< 0.001	0.9941
	s(dpth_min)	0.8767	9	3.201	0.004	0.9766
	s(Vessel)	31.7655	57	2.724	< 0.001	1.0000
Fixed Effects						
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	46.30%	5227	5842.7276	0.0001	0.1534	

Petrels (Otter bottom trawl)

Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**

	Intercept	-9.67E+00	1.27E+00	-7.645	2.48E-14	
	Target catch	2.54E-04	3.85E-05	6.604	4.40E-11	1.0000
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	5.2392	9	46.102	< 0.001	1.0000
	s(Vessel)	26.3911	57	2.375	< 0.001	1.0000
Fixed Effects						
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	70.30%	5227	5842.7407	0.0000	0.1535	

Albatrosses (Otter bottom trawl)

Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-6.13E+00	4.90E-01	-12.510	<2e-16	
	Target catch	2.43E-04	2.40E-05	10.100	<2e-16	1.0000
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	4.989	9	41.606	< 0.001	1.0000
	s(Month)	4.8035	10	11.341	< 0.001	0.8462
	s(dpth_min)	3.7249	9	7.847	< 0.001	0.9801
	s(Vessel)	29.1687	57	2.820	< 0.001	1.0000
Fixed Effects						
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	51.30%	5227	7931.6391	0.2168	0.2628	

Shearwaters (Set gillnets)

Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-7.8705	0.5727	-13.740	<2e-16	
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	0.565	9	0.144	0.12	0.5301
	s(Month)	1.671	2	4.785	0.003	0.9421
	s(Lat,Lon)	0.5504	2	0.548	0.14	0.4981
	s(Vessel)	0	42	0.000	0.64	0.4880
Fixed Effects						
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	12%	2115	3467.4892	0.0000	0.1045	

Dolphins (Set gillnets)

Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-19.97966	2.53933	-7.868	5.72E-15	
	Target catch	-0.04123	0.0137	-3.010	0.00264	0.8492
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Year)	0.7419	9	40.488	0.049	0.7946

	s(Lat,Lon)	1.0618	2	247.512	0.012	0.8933
	s(Vessel)	12.3574	42	1.176	< 0.001	0.9938
Fixed Effects						
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	72.30%	2115	2252.2635	0.0002	0.2931	

Albatrosses (Set gillnets)

Coefficients	**Term**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Importance**
	Intercept	-7.4155	0.5437	-13.640	<2e-16	
Smoothed terms		**Est. df**	**Ref df**	***F***	***P*-value**	
	s(Lat,Lon)	1.1383	2	10.939	0.003	0.6839
	s(Depth)	0.9346	9	1.816	0.007	0.9041
	s(Vessel)	12.3066	42	0.560	0.004	0.9564
Fixed Effects						
Summary stats	**Dev. explained**	**No. obs**	**AICc**	**ΔAICc**	**AICc weight**	
	20%	2115	3467.4892	0.0000	0.1045	