

## Supplementary Materials for

### **Spatio-temporal patterns in the distribution of albacore, bigeye, skipjack and yellowfin tuna species within Exclusive Economic Zones of Tonga for the years 2002 to 2018.**

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**Table S1.** Summary of numerical index of relative importance of predictors for the four tuna species in the EEZ, of Tonga.

<i>Species</i>	<i>Predictors</i>	<i>mean</i>	<i>sd</i>	<i>n</i>	<i>se</i>	<i>New_predictors</i>
<i>Albacore</i>	chl_grad	0.015	0.000	50	5.08E-05	z_chlorophyll_grad
	depth	0.064	0.002	50	3.05E-04	depth
	log_chl	0.036	0.001	50	1.42E-04	chlorophyll
	month	0.580	0.010	50	1.36E-03	month
	sst	0.230	0.006	50	8.21E-04	sst
	sst_grad	0.006	0.000	50	2.75E-05	z_sst_grad
	year	0.284	0.006	50	8.58E-04	year
<i>Bigeye</i>	chl_grad	0.014	0.001	50	8.38E-05	z_chlorophyll_grad
	depth	0.088	0.002	50	2.46E-04	depth
	log_chl	0.031	0.002	50	2.42E-04	chlorophyll
	month	0.301	0.005	50	6.60E-04	month
	sst	0.121	0.005	50	7.22E-04	sst
	sst_grad	0.004	0.000	50	1.60E-05	z_sst_grad
	year	0.501	0.011	50	1.56E-03	year
<i>Skipjack</i>	chl_grad	0.016	0.001	50	1.52E-04	z_chlorophyll_grad
	depth	0.047	0.003	50	4.75E-04	depth
	log_chl	0.002	0.000	50	1.87E-05	chlorophyll
	month	0.527	0.019	50	2.73E-03	month
	sst	0.044	0.005	50	6.92E-04	sst
	sst_grad	0.007	0.000	50	6.92E-05	z_sst_grad
	year	0.740	0.023	50	3.28E-03	year
<i>Yellowfin</i>	chl_grad	0.006	0.000	50	2.86E-05	z_chlorophyll_grad
	depth	0.034	0.001	50	1.66E-04	depth
	log_chl	0.021	0.001	50	1.05E-04	chlorophyll
	month	0.398	0.008	50	1.18E-03	month
	sst	0.017	0.000	50	5.89E-05	sst
	sst_grad	0.001	0.000	50	3.28E-06	z_sst_grad
	year	0.564	0.010	50	1.38E-03	year

**Table S2.** Model summary for the best GAM model for the four species. Smooth effects; estimated degrees of freedom (*edf*), degrees of freedom (*df*), *F*-statistics and *p*-values and deviance explained are presented.

<i>Species</i>	<i>term</i>	<i>edf</i>	<i>df</i>	<i>F</i> -statistic	<i>p</i> -value	<i>Deviance explained</i>
<i>Albacore</i>	s(sst)	2.980	3.000	89.105	***0.000	0.278
	s(log_chl)	2.225	2.634	11.449	***0.000	
	s(sst_grad)	1.004	1.009	7.745	***0.005	
	s(chl_grad)	2.372	2.737	6.734	***0.000	
	s(depth)	2.945	2.997	35.972	***0.000	
	s(month)	7.495	8.000	111.290	***0.000	
<i>Bigeye</i>	s(sst)	2.935	2.997	28.143	***0.000	0.122
	s(log_chl)	2.849	2.983	5.423	***0.001	
	s(sst_grad)	1.002	1.004	2.073	0.150	
	s(chl_grad)	2.380	2.744	3.054	***0.021	
	s(depth)	1.021	1.042	44.307	***0.000	
	s(month)	5.552	8.000	20.255	***0.000	
<i>Skipjack</i>	s(sst)	2.646	2.915	3.828	***0.006	0.250
	s(log_chl)	1.001	1.001	0.574	0.449	
	s(sst_grad)	1.988	2.400	1.069	0.266	
	s(chl_grad)	2.213	2.607	2.555	**0.053	
	s(depth)	2.810	2.973	6.609	***0.001	
	s(month)	6.600	8.000	28.836	***0.000	
<i>Yellowfin</i>	s(sst)	2.631	2.908	7.218	***0.000	0.257
	s(log_chl)	2.634	2.910	8.221	***0.000	
	s(sst_grad)	1.005	1.010	0.791	0.376	
	s(chl_grad)	1.006	1.013	4.788	***0.028	
	s(depth)	2.907	2.993	13.736	***0.000	
	s(month)	7.223	8.000	52.405	***0.000	

\*\*\**p*-value < 0.005 is highly significant

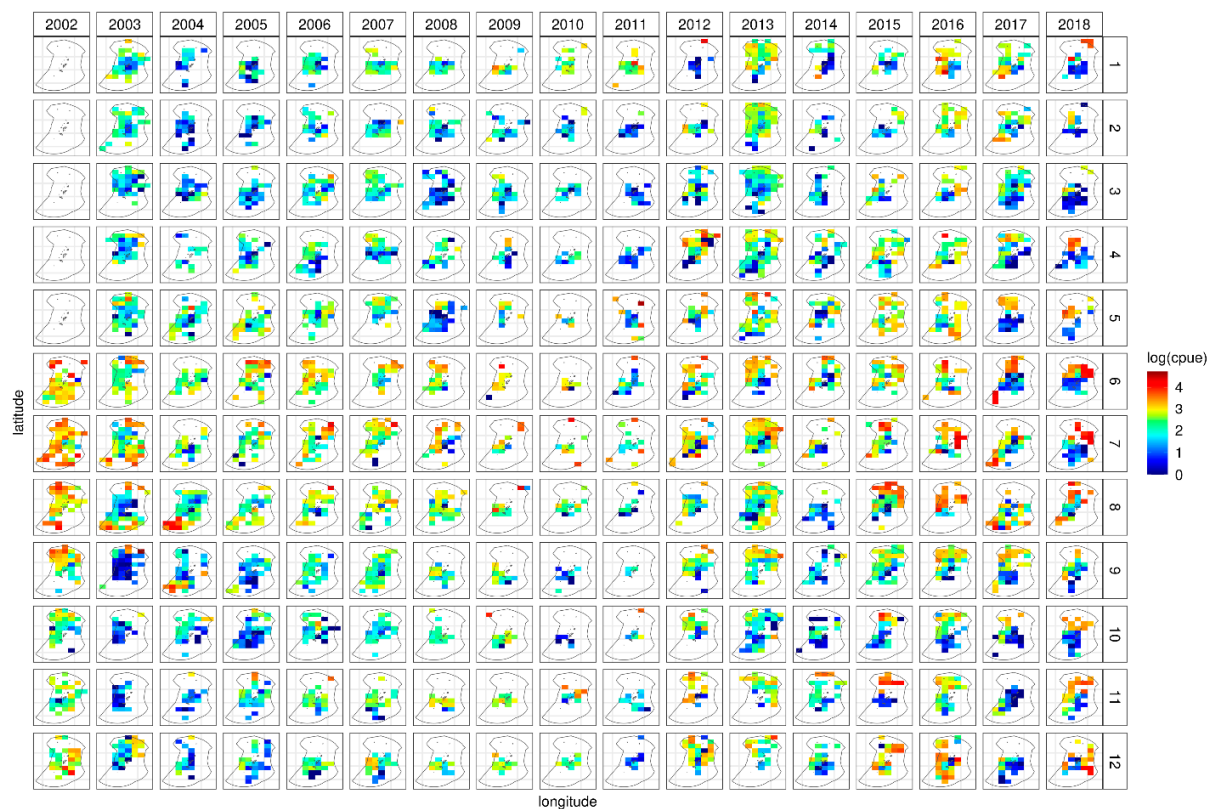
**Table S3.** Model summary for the best GAM model for the four species. Parametric effects; estimate, standard error, F-statistics and p-values are presented.

<i>Species</i>	<i>term</i>	<i>estimate</i>	<i>std.error</i>	<i>F-statistic</i>	<i>p-value</i>
<i>Albacore</i>	Intercept	2.774	0.050	55.056	***0.000
	Year 2003	-0.689	0.067	-10.277	***0.000
	Year 2004	-0.807	0.074	-10.874	***0.000
	Year 2005	-0.798	0.072	-11.141	***0.000
	Year 2006	-0.548	0.071	-7.716	***0.000
	Year 2007	-0.495	0.071	-6.930	***0.000
	Year 2008	-0.561	0.077	-7.269	***0.000
	Year 2009	-0.223	0.084	-2.634	***0.008
	Year 2010	-0.352	0.094	-3.734	***0.000
	Year2011	-0.558	0.089	-6.252	***0.000
	Year 2012	-0.347	0.072	-4.816	***0.000
	Year 2013	-0.516	0.064	-8.030	***0.000
	Year 2014	-0.868	0.078	-11.088	***0.000
	Year 2015	-0.135	0.068	-1.970	***0.049
	Year 2016	0.044	0.066	0.663	0.507
	Year 2017	-0.410	0.068	-6.016	***0.000
	Year 2018	-0.167	0.070	-2.392	***0.017
<i>Bigeye</i>	Intercept	1.160	0.067	17.440	***0.000
	Year 2003	-0.764	0.090	-8.467	***0.000
	Year 2004	-0.585	0.095	-6.133	***0.000
	Year 2005	-0.278	0.088	-3.175	***0.002
	Year 2006	-0.139	0.087	-1.589	0.112
	Year 2007	-0.023	0.087	-0.266	0.791
	Year 2008	-0.134	0.092	-1.447	0.148
	Year 2009	-0.077	0.105	-0.731	0.465
	Year 2010	-0.313	0.117	-2.681	***0.007
	Year2011	-0.883	0.121	-7.277	***0.000
	Year 2012	-0.646	0.098	-6.596	***0.000
	Year 2013	-0.754	0.087	-8.684	***0.000
	Year 2014	-0.935	0.104	-9.021	***0.000
	Year 2015	-0.169	0.088	-1.916	***0.055
	Year 2016	-0.358	0.089	-4.015	***0.000
	Year 2017	-0.517	0.090	-5.727	***0.000
	Year 2018	-0.463	0.094	-4.941	***0.000
<i>Skipjack</i>	Intercept	-2.377	0.185	-12.874	***0.000

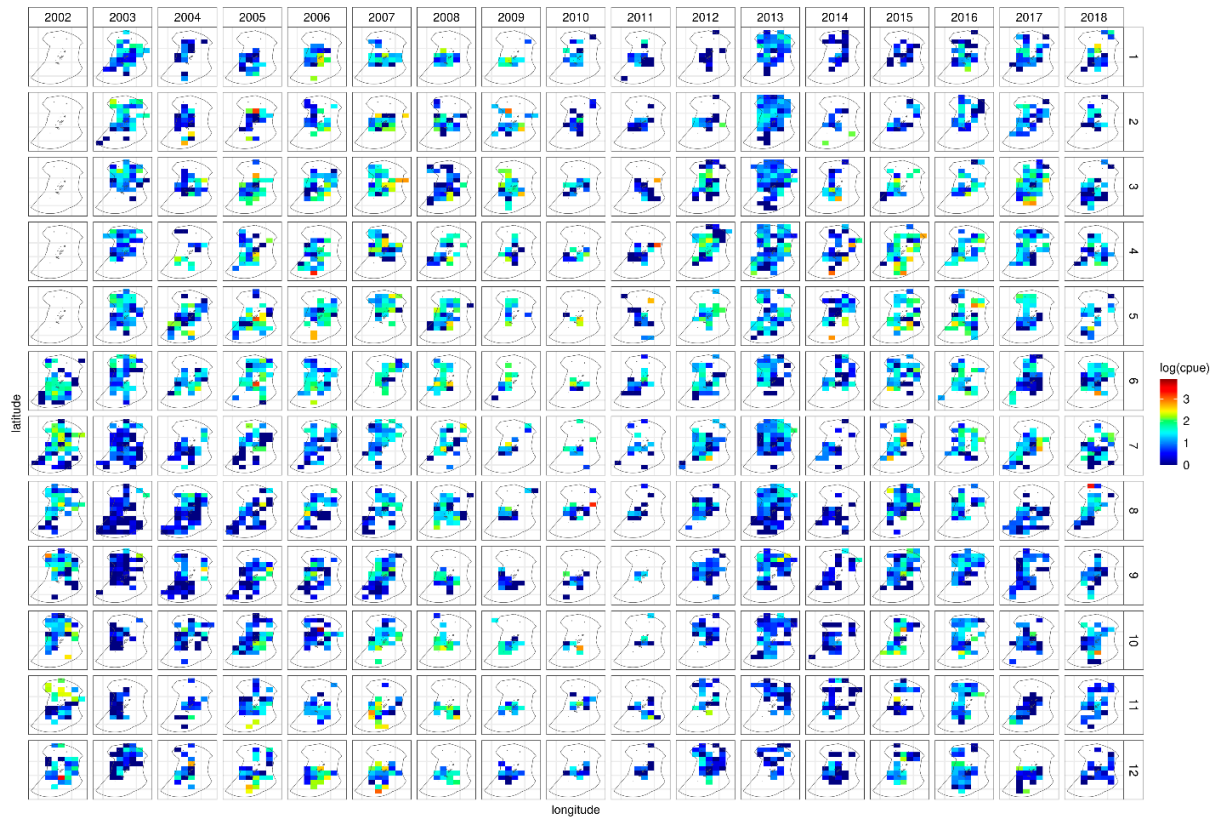
Yellowfin	Year 2003	0.191	0.229	0.834	0.404
	Year 2004	-0.095	0.253	-0.373	0.709
	Year 2005	-0.251	0.251	-1.000	0.317
	Year 2006	-0.996	0.280	-3.560	***0.000
	Year 2007	-1.124	0.289	-3.892	***0.000
	Year 2008	-1.825	0.346	-5.277	***0.000
	Year 2009	-1.500	0.388	-3.867	***0.000
	Year 2010	-0.370	0.355	-1.041	0.298
	Year2011	0.182	0.302	0.603	0.546
	Year 2012	0.041	0.258	0.159	0.874
	Year 2013	-0.322	0.236	-1.366	0.172
	Year 2014	0.970	0.239	4.053	***0.000
	Year 2015	0.701	0.236	2.972	***0.003
	Year 2016	2.001	0.215	9.307	***0.000
	Year 2017	1.707	0.215	7.941	***0.000
	Year 2018	1.388	0.226	6.138	***0.000
	Intercept	1.669	0.071	23.415	***0.000
	Year 2003	-0.300	0.089	-3.356	***0.001
	Year 2004	0.347	0.090	3.844	***0.000
	Year 2005	-0.110	0.092	-1.196	0.232
	Year 2006	-0.074	0.092	-0.803	0.422
	Year 2007	0.393	0.089	4.397	***0.000
	Year 2008	0.520	0.092	5.673	***0.000
	Year 2009	0.422	0.103	4.089	***0.000
	Year 2010	-0.026	0.115	-0.227	0.820
	Year2011	0.650	0.100	6.522	***0.000
	Year 2012	0.403	0.092	4.389	***0.000
	Year 2013	-0.004	0.086	-0.046	0.964
	Year 2014	0.655	0.090	7.267	***0.000
	Year 2015	0.876	0.086	10.210	***0.000
	Year 2016	0.990	0.085	11.711	***.000
	Year 2017	0.937	0.084	11.167	***0.000
	Year 2018	0.571	0.089	6.427	***0.000

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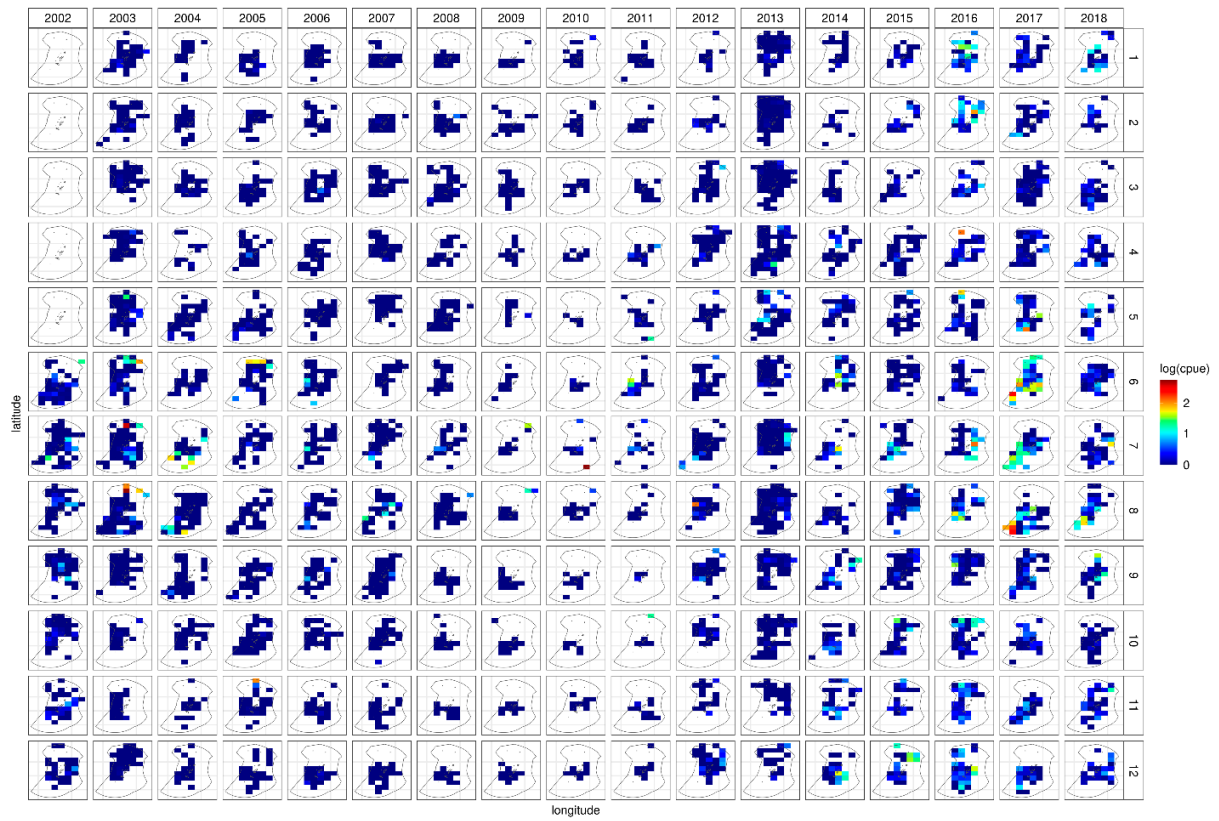
\*\*\**p-value < 0.005 is highly significant*



**Figure S1.** Spatio-temporal pattern in the distribution of *albacore* tuna within the EEZ, longitude 14.5°S–20.22°S, longitude 171.31°W–179.10°W of Tonga. Data aggregated to coarser resolution of 0.3 degree (~5NM).

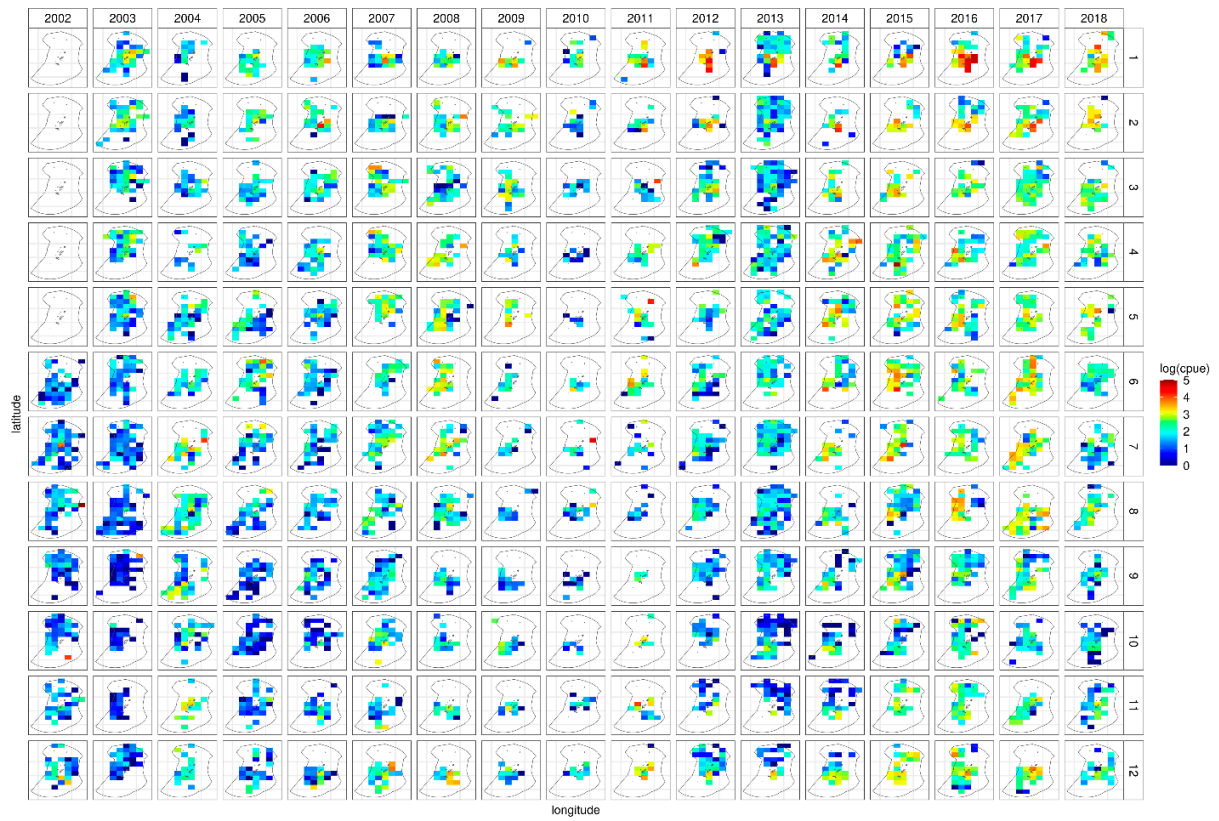


**Figure S2.** Spatio-temporal pattern in the distribution of bigeye tuna in the EEZ, longitude  $14.5^{\circ}\text{S}$ – $20.22^{\circ}\text{S}$ , longitude  $171.31^{\circ}\text{W}$ – $179.10^{\circ}\text{W}$  of Tonga. Data aggregated to coarser resolution of 0.3 degree ( $\sim 5\text{NM}$ ).

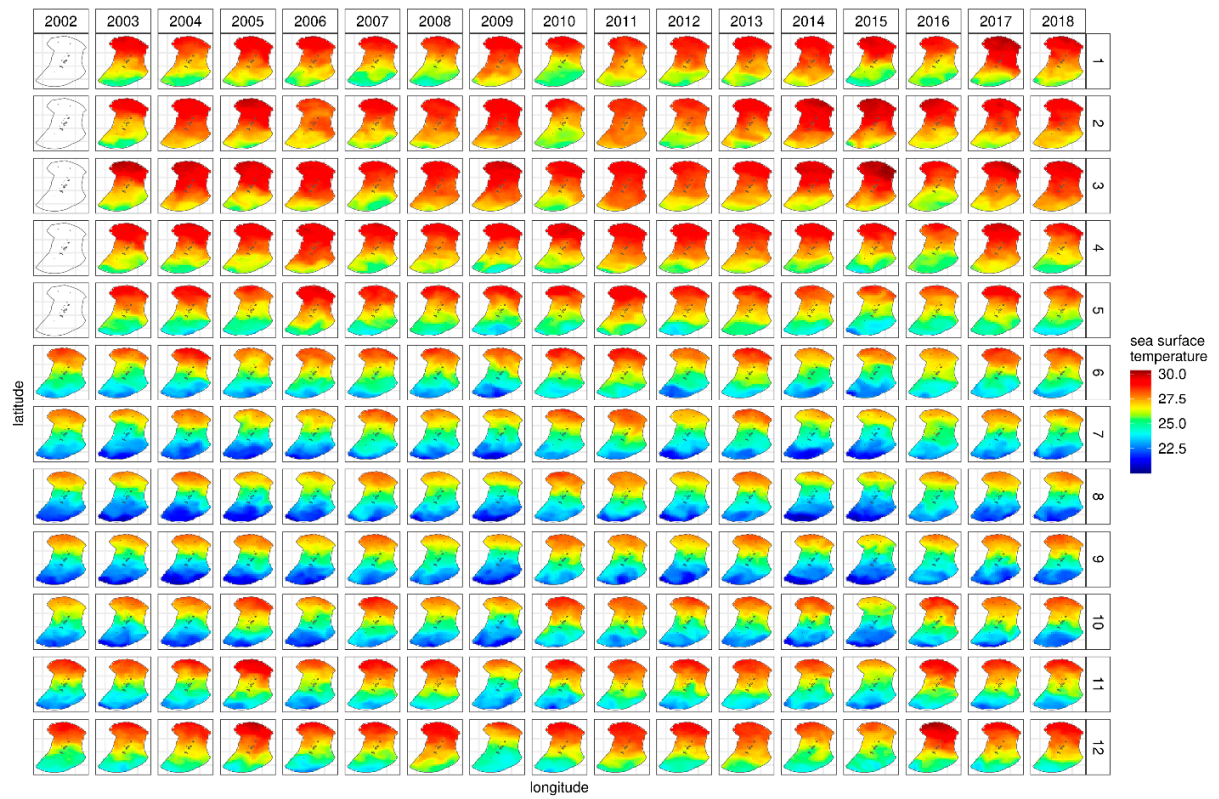


**Figure S3.** Spatio-temporal pattern in the distribution of skipjack tuna in the EEZ, longitude  $14.5^{\circ}\text{S}$ –  $20.22^{\circ}\text{S}$ , longitude  $171.31^{\circ}\text{W}$ –  $179.10^{\circ}\text{W}$  of Tonga. Data aggregated to coarser resolution of 0.3 degree ( $\sim 5\text{NM}$ ).

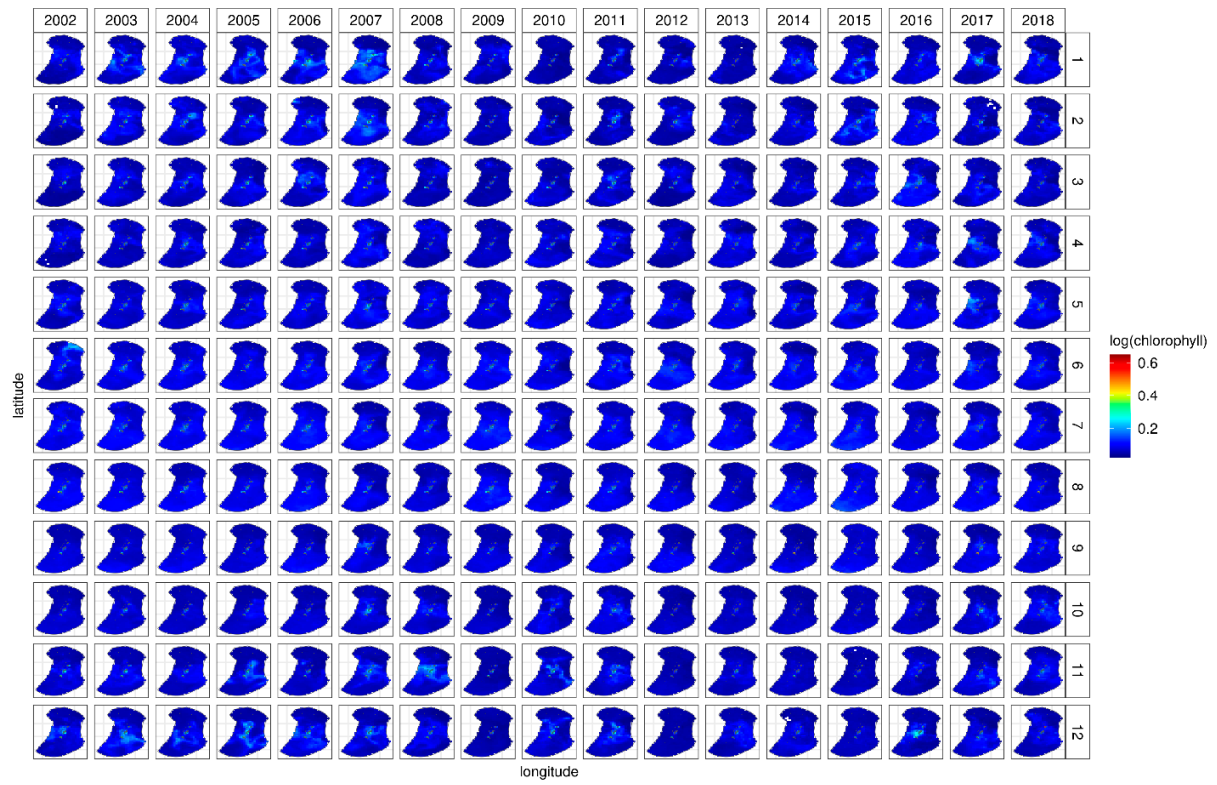




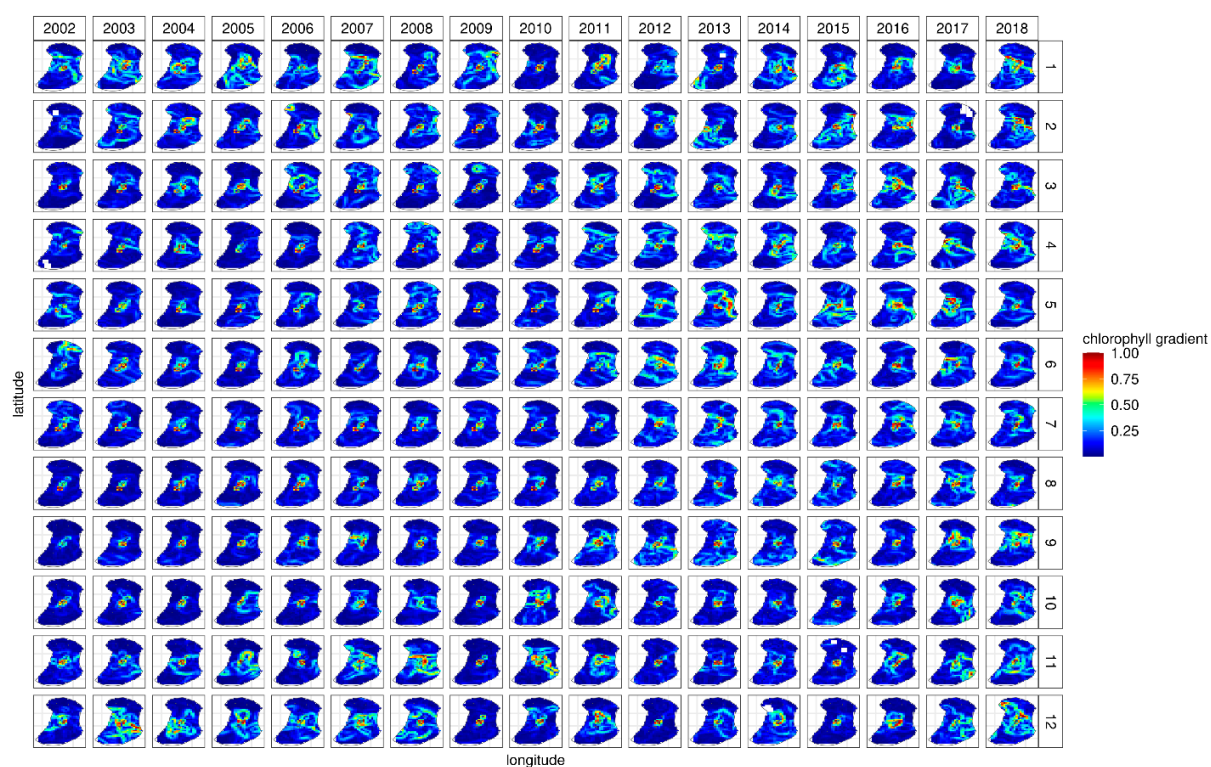
**Figure S4.** Spatio-temporal pattern in the distribution of yellowfin tuna in the EEZ, longitude 14.5°S–20.22°S, longitude 171.31°W–179.10°W of Tonga. Data aggregated to coarser resolution of 0.3 degree (~5NM).



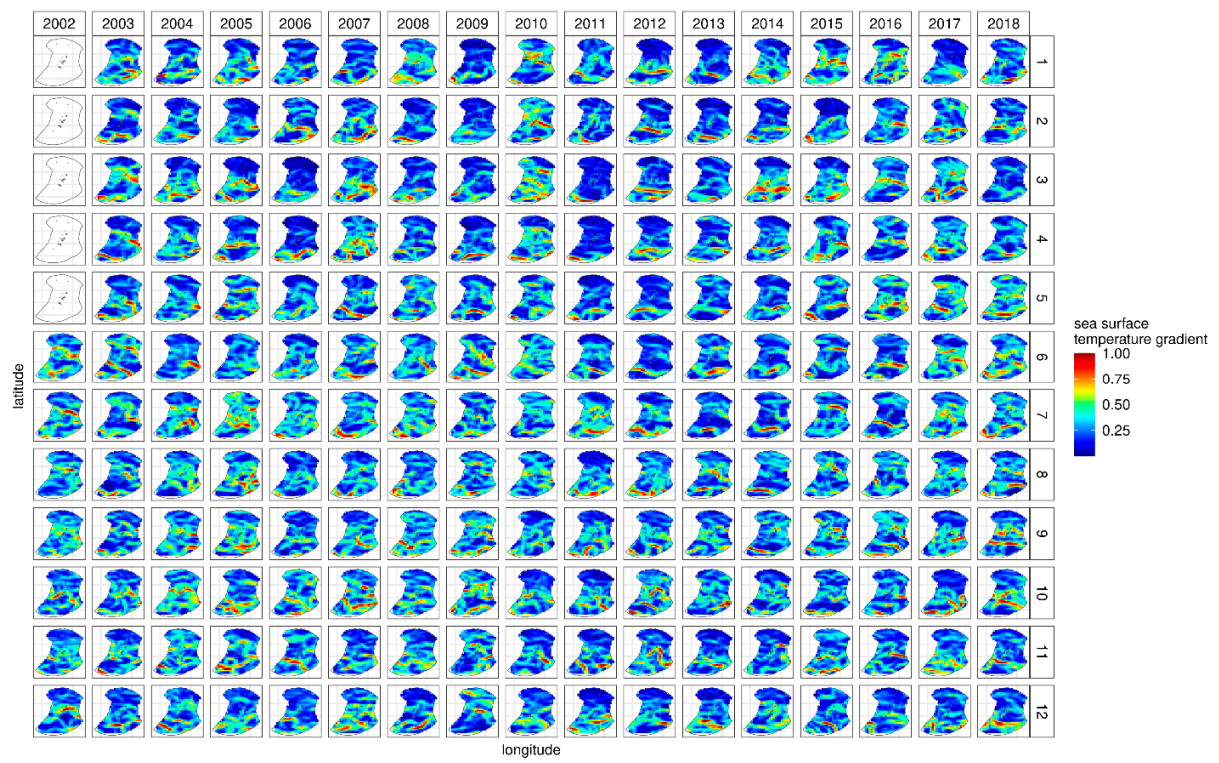
**Figure S5.** Annual and monthly variability of sea surface temperature for the EEZ, longitude  $14.5^{\circ}\text{S}$ – $20.22^{\circ}\text{S}$ , longitude  $171.31^{\circ}\text{W}$ – $179.10^{\circ}\text{W}$  of Tonga. Data aggregated to coarser resolution of 0.3 degree ( $\sim 5\text{NM}$ ).



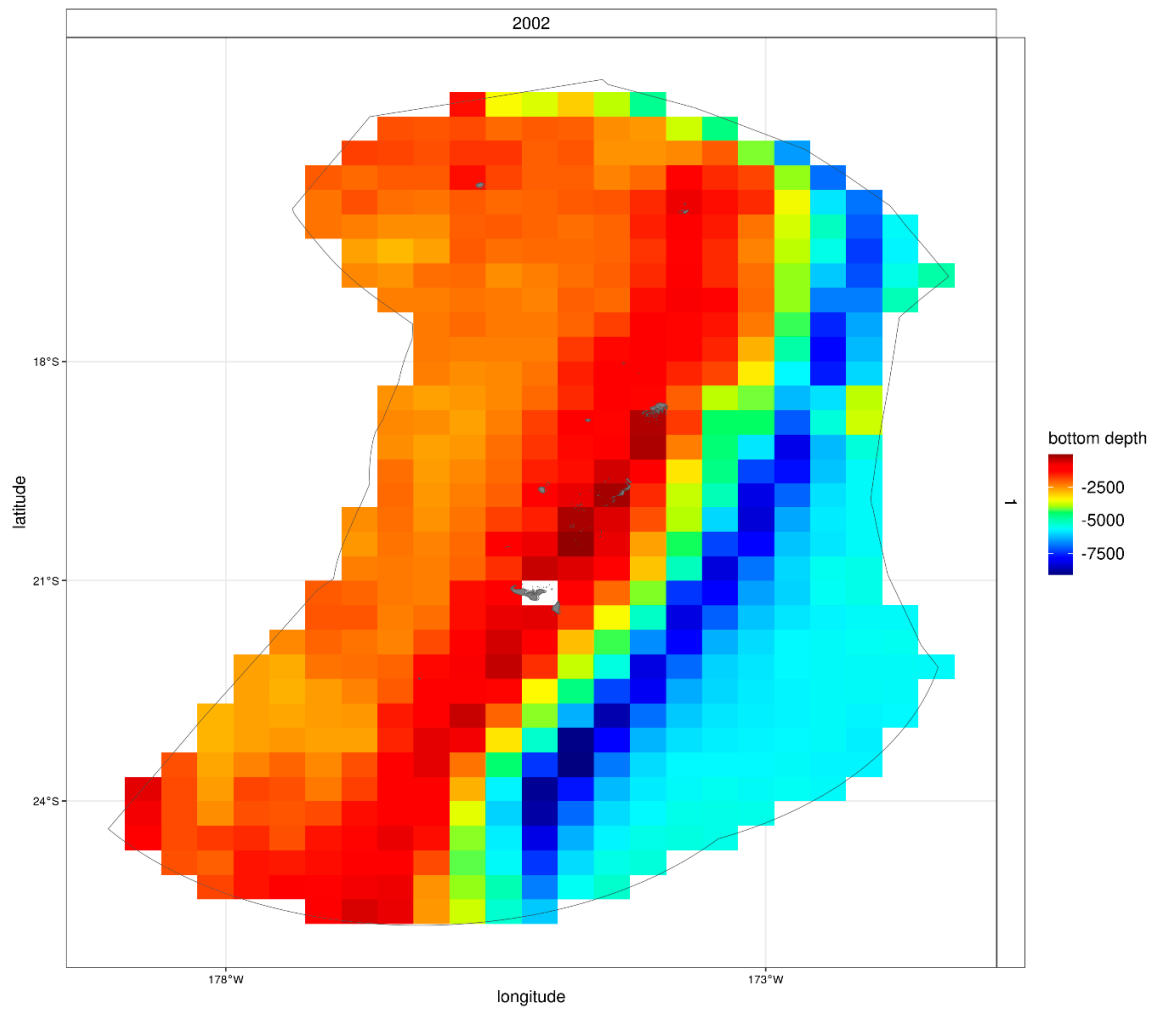
**Figure S6.** Annual and monthly variability of sea surface chlorophyll for the EEZ, longitude  $14.5^{\circ}\text{S}$ – $20.22^{\circ}\text{S}$ , longitude  $171.31^{\circ}\text{W}$ – $179.10^{\circ}\text{W}$  of Tonga.



**Figure S7.** Annual and monthly variability of sea surface chlorophyll gradient for the EEZ, longitude  $14.5^{\circ}\text{S}$ – $20.22^{\circ}\text{S}$ , longitude  $171.31^{\circ}\text{W}$ – $179.10^{\circ}\text{W}$  of Tonga.

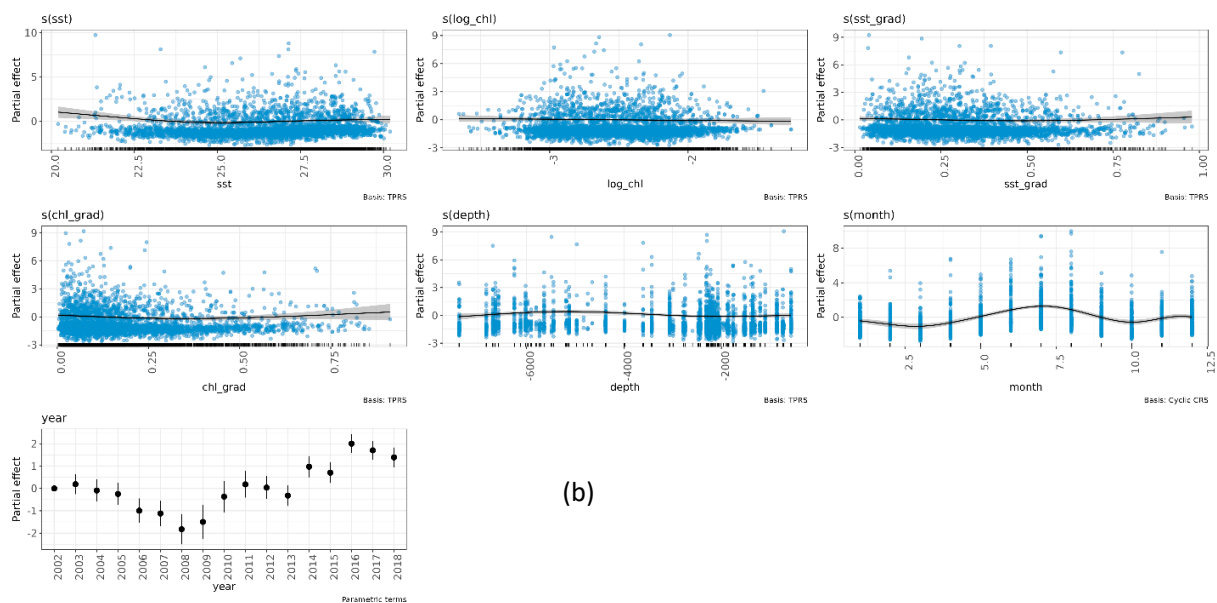
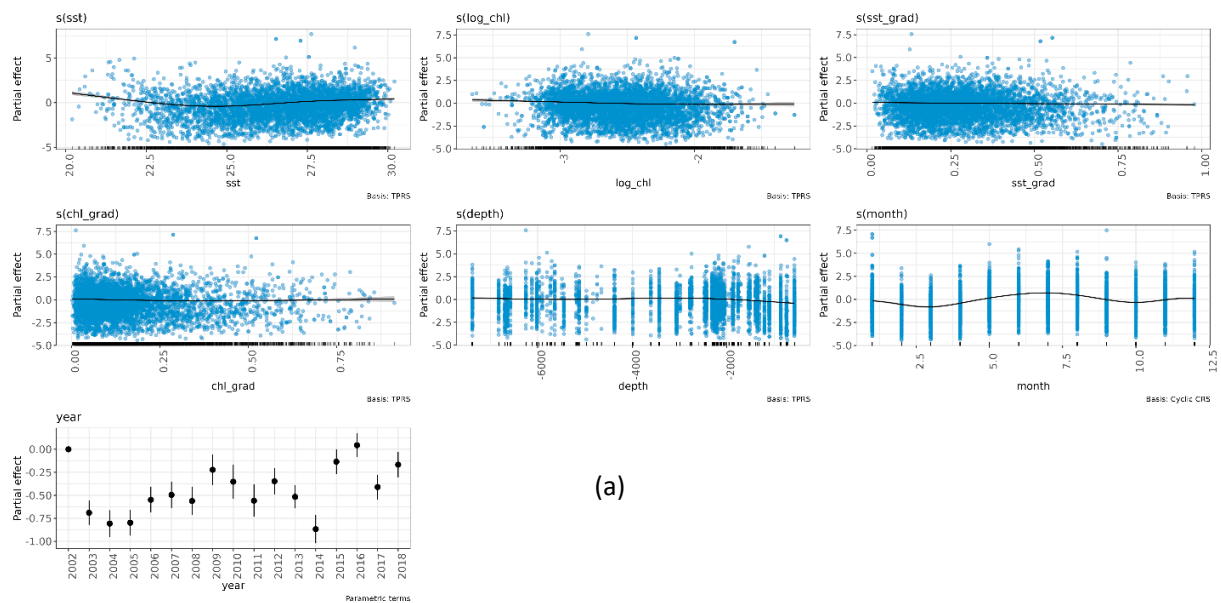


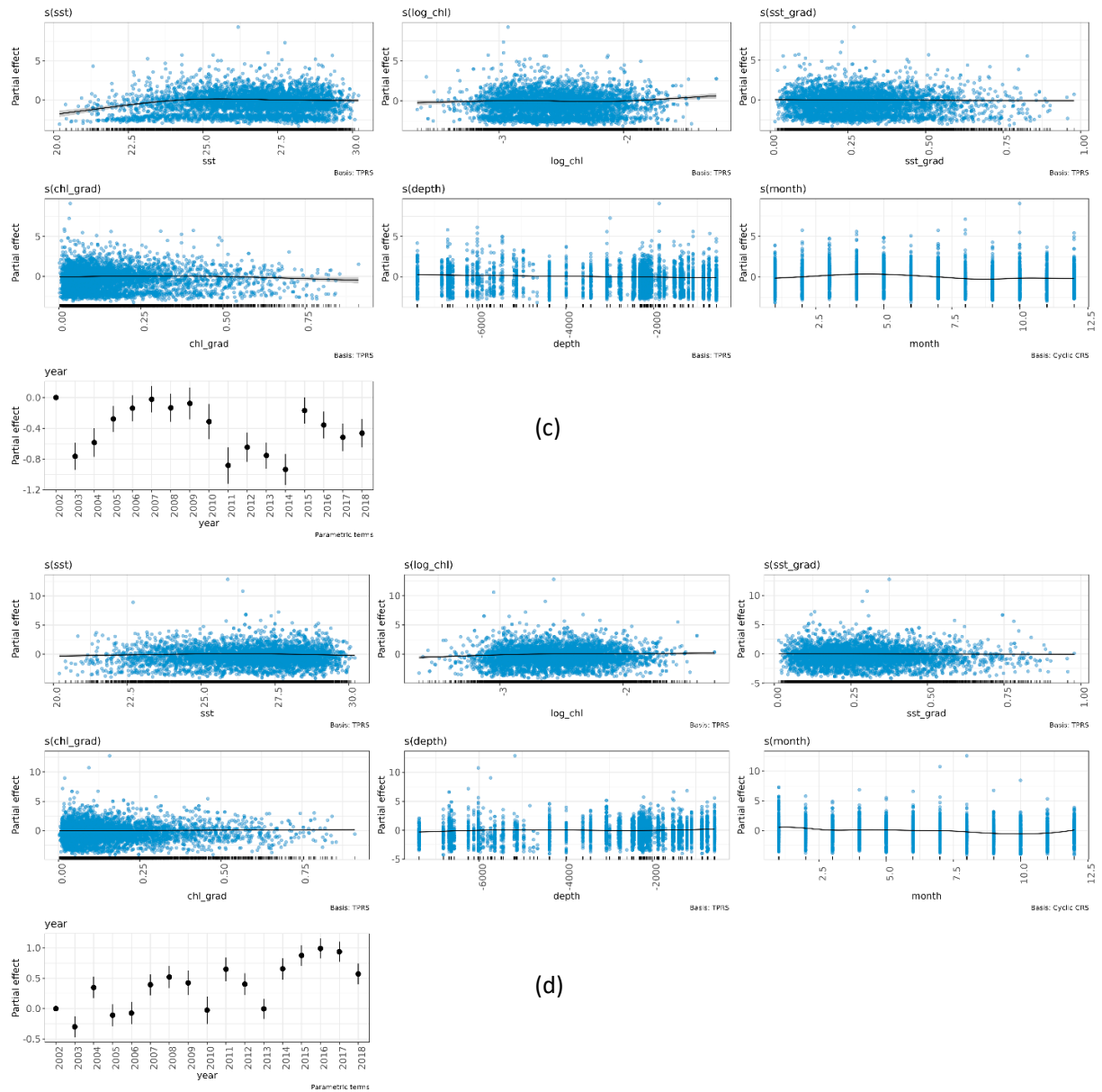
**Figure S8.** Annual and monthly variability of sea surface temperature gradient for the EEZ, longitude  $14.5^{\circ}\text{S}$ – $20.22^{\circ}\text{S}$ , longitude  $171.31^{\circ}\text{W}$ – $179.10^{\circ}\text{W}$  of Tonga.



**Figure S9.** Bathymetry for the EEZ, longitude 14.5°S–20.22°S, longitude 171.31°W–179.10°W of Tonga.

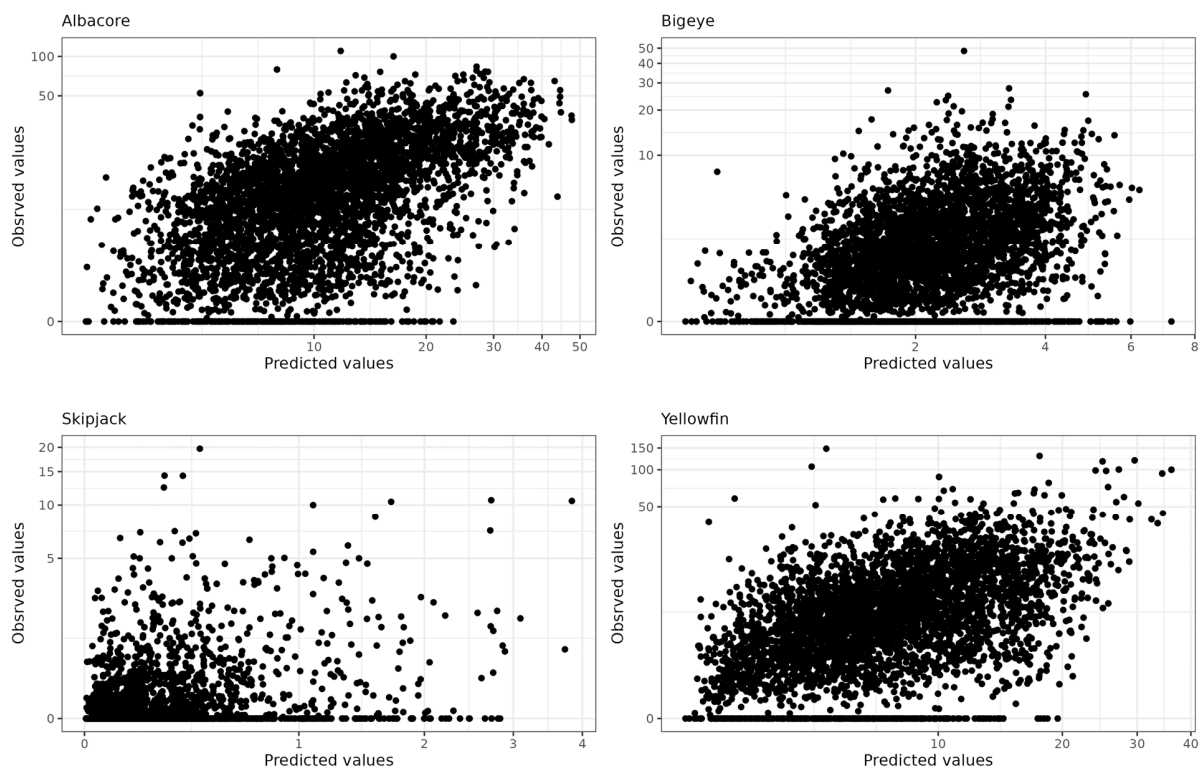




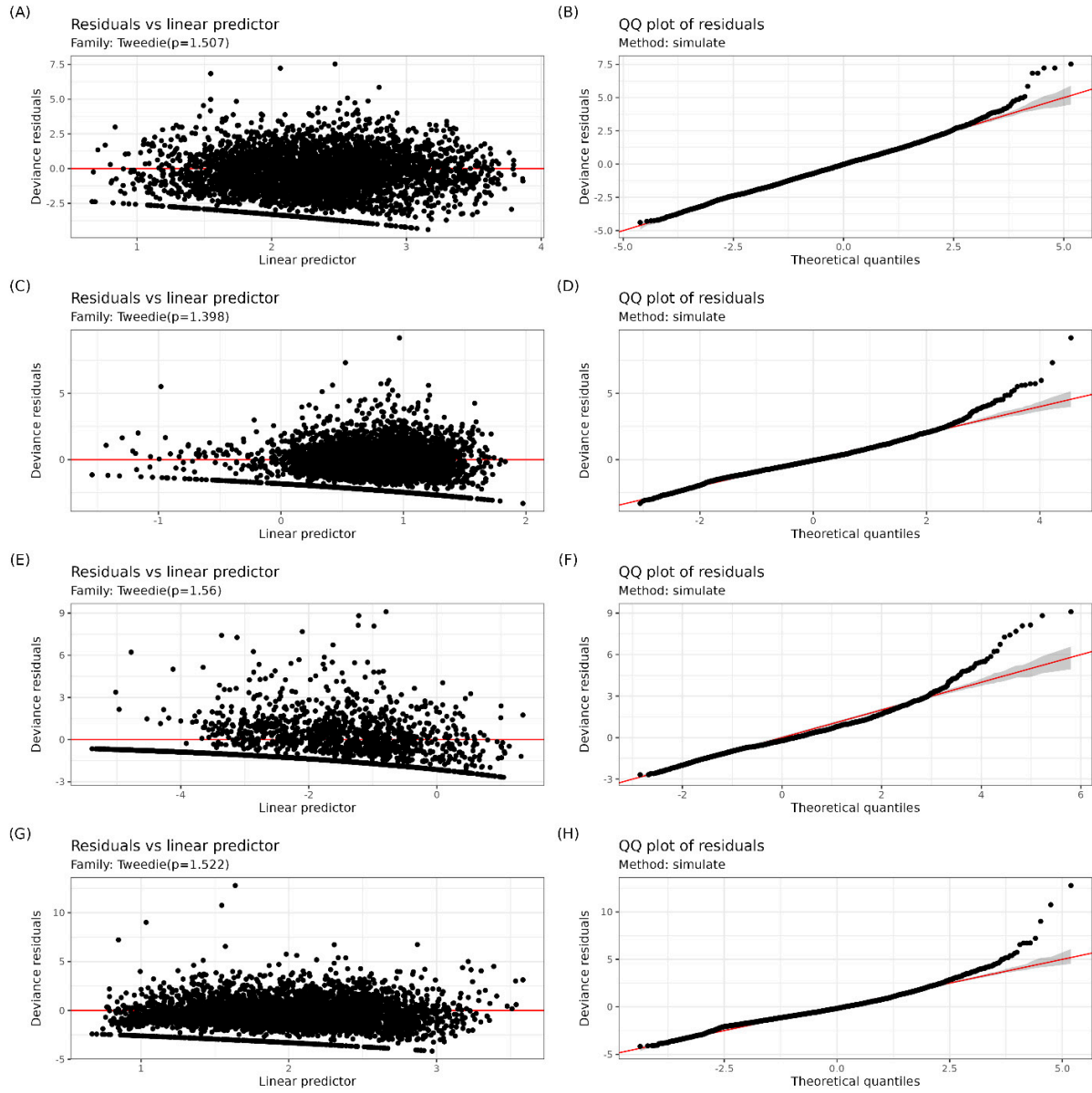


**Figure S10.** The partial effects with partial residuals for covariates *chl\_grad*, *depth*, *Chl-a*, *SST*, *sst\_grad*, *month* and *year* for (a) albacore, (b) bigeye, (c) skipjack and (d) yellowfin respectively, within the EEZ, longitude 171.31° W–179.10° W of Tonga.





**Figure S11.** Model diagnostic plots of predicted values vs observed values for each species presented in log-scale for visual purpose.



**Figure S12.** Model diagnostics plot of linear predictors vs deviance residuals and quantile-quantile plots of theoretical values vs deviance residuals for albacore (panels A and B), bigeye (panels C and D), skipjack (panels E and F) and yellowfin (panels G and H) in the EEZ, longitude  $14.5^{\circ}\text{S}$ – $20.22^{\circ}\text{S}$ , longitude  $171.31^{\circ}\text{W}$ – $179.10^{\circ}\text{W}$  of Tonga.