Appendices: Use of satellite data for understanding and predicting oil sardine (*Sardinella longiceps*) catch variability along the southwest coast of India

27 February, 2019

Appendix A: Tests for prior season catch as covariate

Table A1. Model selection tests of time-dependency the log catch during spawning months using F-tests of nested linear models. S_t is the catch during the spawning period (Jul-Sep). N_t is the catch during the non-spawning period (Oct-Jun). S_{t-1} and N_{t-1} are the catch during the prior season during and after the spawning period respectively. S_{t-2} and N_{t-2} are the same for two seasons prior. Test A uses catch during the spawning period as the explanatory variable. Test B uses catch during the non-spawning period as the explanatory variable. Test C uses both. For Test C, the nestedness is lines 1-3 and lines 1-2 and 4.

Model	Residual df	Residual deviance	F	p value	AIC
Time dependency test A 1983-2015 data					
$ln(S_t) = \alpha + \epsilon$ (Var(ϵ) = 2.03)	32	65.09			120.07
$ln(S_t) = \alpha + \beta ln(S_{t-1}) + \epsilon$ ($R^2 adj$ = 10%, Var(ϵ) = 1.84)	31	56.91	4.61	0.04	117.63
$ln(S_t) = \alpha + \beta_1 ln(S_{t-1}) + \beta_2 ln(S_{t-2}) + \epsilon$ ($R^2 adj$ = 13%, Var(ϵ) = 1.78)	30	53.27	2.05	0.163	117.45
Time dependency test B 1983-2015 data					
$ln(S_t) = \alpha + \epsilon$ (Var(ϵ) = 2.03)	32	65.09			120.07
$ln(S_t) = \alpha + \beta ln(N_{t-1}) + \epsilon$ ($R^2 adj$ = 23%, Var(ϵ) = 1.56)	31	48.33	10.45	0.003	112.24
$ln(S_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(N_{t-2}) + \epsilon$ ($R^2 adj$ = 21%, Var(ϵ) = 1.6)	30	48.11	0.14	0.714	114.09
Time dependency test C 1983-2015 data					
$ln(S_t) = \alpha + \beta ln(N_{t-1}) + \epsilon$ ($R^2 adj$ = 23%, Var(ϵ) = 1.56)	31	48.33			112.24
$ln(S_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(S_{t-1}) + \epsilon$ ($R^2 adj$ = 22%, Var(ϵ) = 1.59)	30	47.65	0.43	0.517	113.77
$ln(S_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(S_{t-2}) + \epsilon$ ($R^2 adj$ = 22%, Var(ϵ) = 1.6)	30	47.89	0.28	0.601	113.94

Table A2. Model selection tests of time-dependency the catch during spawning months using non-linear responses instead of linear responses as in Table A1 See Table A1 for an explanation of the parameters and model set-up.

Model	Residual df	Residual deviance	F	p value	AIC
Time dependency test A 1983-2015 data					
$ln(S_t) = \alpha + \beta ln(S_{t-1}) + \epsilon$ ($R^2 adj$ = 10%, Var(ϵ) = 1.84)	31	56.91			117.63
$ln(S_t) = \alpha + s(ln(S_{t-1})) + \epsilon$ ($R^2 adj$ = 20%, Var(ϵ) = 1.63)	29	48.2	2.73	0.085	115.01
$ln(S_t) = \alpha + s_1(ln(S_{t-1})) + s_2(ln(S_{t-2})) + \epsilon$ ($R^2 adj$ = 20%, Var(ϵ) = 1.62)	26.2	44.27	0.86	0.466	116.82
Time dependency test B 1983-2015 data					
$ln(S_t) = \alpha + \beta ln(N_{t-1}) + \epsilon$ ($R^2 adj$ = 23%, Var(ϵ) = 1.56)	31	48.33			112.24
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \epsilon$ ($R^2 adj$ = 27%, Var(ϵ) = 1.49)	29.6	44.66	1.71	0.203	111.57
$ln(S_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(N_{t-2})) + \epsilon$ ($R^2 adj$ = 26%, Var(ϵ) = 1.51)	27.3	42.64	0.57	0.594	113.79
Time dependency test C 1983-2015 data					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \epsilon$ ($R^2 adj$ = 27%, Var(ϵ) = 1.49)	29.6	44.66			111.57
$ln(S_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-1})) + \epsilon$ ($R^2 adj$ = 32%, Var(ϵ) = 1.39)	26.9	38.53	1.66	0.202	111.12
$ln(S_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-2})) + \epsilon$ ($R^2 adj$ = 28%, Var(ϵ) = 1.47)	26.8	40.64	0.98	0.414	113.05

Table A3. Model selection tests of time-dependency for the catch during spawning months using 1956-2015 data. See Table A1 for definitions.

Model	Residual df	Residual deviance	F	p value	AIC
Time dependency test B linear 1956-2015 data					
$ln(S_t) = \alpha + \epsilon$	57	80.84			187.85
(R^2adj = 0%, Var(ϵ) = 1.42)					
$ln(S_t) = \alpha + \beta ln(N_{t-1}) + \epsilon$	56	67.58	10.79	0.002	179.46
(R^2adj = 15%, Var(ϵ) = 1.21)					
$ln(S_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(N_{t-2}) + \epsilon$	55	67.58	0	0.97	181.46
(R^2adj = 13%, Var(ϵ) = 1.23)					
Linearity test 1956-2015 data					
$ln(S_t) = \alpha + \beta ln(N_{t-1}) + \epsilon$	56	67.58			179.46
(R^2adj = 15%, Var(ϵ) = 1.21)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \epsilon$	54.6	65.7	1.13	0.312	179.64
(R^2adj = 16%, Var(ϵ) = 1.19)					
$ln(S_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(N_{t-2})) + \epsilon$	52.3	65	0.25	0.811	182.78
(R^2adj = 14%, Var(ϵ) = 1.22)					

Table A4. Model selection tests of time-dependency the N_t model using F-tests of nested models fit to 1983 to 2014 log landings data. The years are determined by the covariate data availability. N_t is the catch during the non-spawning period (Qtrs 4, 1 and 2: Oct-Jun) of season t (Jul-Jun). S_{t-1} and N_{t-1} are the catch during the prior sardine season during and after the spawning period respectively. S_{t-2} and N_{t-2} are the same for two seasons prior. Test A uses catch during the spawning period as the explanatory variable. Test B uses catch during the non-spawning period as the explanatory variable. Test C uses both. For Test C, the nestedness is lines 1-3 and lines 1-2 and 4.

Model	Residual df	Residual deviance	F	p value	AIC
Time dependency test A 1983-2014 data					
$ln(N_t) = \alpha + \epsilon$ (Var(ϵ) = 1.49)	31	46.19			106.56
$ln(N_t) = \alpha + \beta ln(S_{t-1}) + \epsilon$ ($R^2 adj$ = 28%, Var(ϵ) = 1.08)	30	32.39	12.77	0.001	97.2
$ln(N_t) = \alpha + \beta_1 ln(S_{t-1}) + \beta_2 ln(S_{t-2}) + \epsilon$ ($R^2 adj$ = 28%, Var(ϵ) = 1.08)	29	31.31	1	0.325	98.12
Time dependency test B 1983-2014 data					
$ln(N_t) = \alpha + \epsilon$ (Var(ϵ) = 1.49)	31	46.19			106.56
$ln(N_t) = \alpha + \beta ln(N_{t-1}) + \epsilon$ ($R^2 adj$ = 39%, Var(ϵ) = 0.91)	30	27.41	20.17	0	91.85
$ln(N_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(N_{t-2}) + \epsilon$ ($R^2 adj$ = 38%, Var(ϵ) = 0.93)	29	27	0.43	0.517	93.38
Time dependency test C 1983-2014 data					
$ln(N_t) = \alpha + \beta ln(N_{t-1}) + \epsilon$ ($R^2 adj$ = 39%, Var(ϵ) = 0.91)	30	27.41			91.85
$ln(N_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(S_{t-1}) + \epsilon$ ($R^2 adj$ = 37%, Var(ϵ) = 0.94)	29	27.32	0.1	0.759	93.75
$ln(N_t) = \alpha + \beta_1 ln(N_{t-1}) + \beta_2 ln(S_{t-2}) + \epsilon$ ($R^2 adj$ = 37%, Var(ϵ) = 0.94)	29	27.4	0.01	0.93	93.84

Table A5. Model selection tests of time-dependency the N_t model using non-linear responses instead of linear responses as in Table A4 See Table A4 for an explanation of the parameters and model set-up.

Model	Residual df	Residual deviance	F	p value	AIC
Time dependency test A 1983-2014 data					
$ln(N_t) = \alpha + \beta ln(S_{t-1}) + \epsilon$ ($R^2 adj$ = 28%, Var(ϵ) = 1.08)	30	32.39			97.2
$ln(N_t) = \alpha + s(ln(S_{t-1})) + \epsilon$ ($R^2 adj$ = 31%, Var(ϵ) = 1.03)	28.1	29.4	1.68	0.207	96.88
$ln(N_t) = \alpha + s_1(ln(S_{t-1})) + s_2(ln(S_{t-2})) + \epsilon$ ($R^2 adj$ = 38%, Var(ϵ) = 0.93)	25.1	24.35	1.84	0.166	95.69
Time dependency test B 1983-2014 data					
$ln(N_t) = \alpha + \beta ln(N_{t-1}) + \epsilon$ ($R^2 adj$ = 39%, Var(ϵ) = 0.91)	30	27.41			91.85
$ln(N_t) = \alpha + s(ln(N_{t-1})) + \epsilon$ ($R^2 adj$ = 47%, Var(ϵ) = 0.79)	28.5	22.99	4.07	0.04	88.28
$ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(N_{t-2})) + \epsilon$ ($R^2 adj$ = 51%, Var(ϵ) = 0.73)	26.3	19.89	1.87	0.171	87.3
Time dependency test C 1983-2014 data					
$ln(N_t) = \alpha + s(ln(N_{t-1})) + \epsilon$ ($R^2 adj$ = 47%, Var(ϵ) = 0.79)	28.5	22.99			88.28
$ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-1})) + \epsilon$ ($R^2 adj$ = 45%, Var(ϵ) = 0.81)	25.9	21.83	0.55	0.631	90.96
$ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-2})) + \epsilon$ ($R^2 adj$ = 61%, Var(ϵ) = 0.59)	25.6	15.58	4.26	0.015	80.66

Table A6. Table A5 with 1956-2015 data instead of 1983 to 2014 data. See Table A4 for an explanation of the parameters and model set-up.

Model	Residual df	Residual deviance	F	p value	AIC
Time dependency test A 1956-2015 data					
$ln(N_t) = \alpha + \beta ln(S_{t-1}) + \epsilon$	55	43.02			151.71
(R^2adj = 19%, Var(ϵ) = 0.78)					
$ln(N_t) = \alpha + s(ln(S_{t-1})) + \epsilon$	53.4	41.68	1.04	0.348	152.24
(R^2adj = 20%, Var(ϵ) = 0.77)					
$ln(N_t) = \alpha + s_1(ln(S_{t-1})) + s_2(ln(S_{t-2})) + \epsilon$	50.7	40.21	0.71	0.534	154.53
(R^2adj = 20%, Var(ϵ) = 0.78)					
Time dependency test B 1956-2015 data					
$ln(N_t) = \alpha + \beta ln(N_{t-1}) + \epsilon$	55	36.81			142.84
(R^2adj = 31%, Var(ϵ) = 0.67)					
$ln(N_t) = \alpha + s(ln(N_{t-1})) + \epsilon$	53.6	35.24	1.75	0.191	142.2
(R^2adj = 33%, Var(ϵ) = 0.65)					
$ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(N_{t-2})) + \epsilon$	51.3	33.96	0.87	0.439	143.8
(R^2adj = 33%, Var(ϵ) = 0.65)					
Time dependency test C 1956-2015 data					
$ln(N_t) = \alpha + s(ln(N_{t-1})) + \epsilon$	53.6	35.24			142.2
(R^2adj = 33%, Var(ϵ) = 0.65)					
$ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-1})) + \epsilon$	51.2	33.5	1.12	0.342	143.28
(R^2adj = 34%, Var(ϵ) = 0.64)					
$ln(N_t) = \alpha + s_1(ln(N_{t-1})) + s_2(ln(S_{t-2})) + \epsilon$	51	33.97	0.75	0.513	144.43
(R^2adj = 32%, Var(ϵ) = 0.65)					

Table A7. Model selection tests for the N_t model using AIC for models fit to log landings data with catch during the spawning season S_t added as a covariate. Data 1983 to 2014 were used.

Model	Residual df	Residual deviance	AIC
Add current season spawning information			
$ln(N_t) = \alpha + \beta ln(S_t) + \epsilon$	30	15.41	73.43
($R^2 adj$ = 66%, Var(ϵ) = 0.51)			
$ln(N_t) = \alpha + s(ln(S_t)) + \epsilon$	28.2	14.79	74.64
($R^2 adj$ = 65%, Var(ϵ) = 0.51)			
$ln(N_t) = \alpha + \beta ln(S_t) + s(ln(S_{t-1})) + \epsilon$	27.1	11.51	68.8
($R^2 adj$ = 72%, Var(ϵ) = 0.42)			
$ln(N_t) = \alpha + \beta ln(S_t) + s(ln(N_{t-1})) + \epsilon$	27.5	10.93	66.45
($R^2 adj$ = 74%, Var(ϵ) = 0.39)			

Appendix B: Tests for environmental variables as covariates

Table B1. Model selection tests of GPCP precipitation as an explanatory variable for the catch during spawning months (Jul-Sep) using 1983 to 2015 data. The data range is determined by the years for which SST was available in order to use a consistent dataset across covariate tests. S_t is the catch during Jul-Sep of season t. V_t is the covariate in the current season which spans two calendar years from July to June in the next year. V_{t-1} is the covariate in the prior Jul-Jun season.

Model	Residual df	Residual deviance	F	p value	AIC
V = Jun-Jul Precipitation					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \epsilon$	29.6	44.66			111.57
(R^2adj = 27%, Var(ϵ) = 1.49)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \beta V_t + \epsilon$	28.6	43.39	0.86	0.361	112.56
(R^2adj = 27%, Var(ϵ) = 1.49)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + \epsilon$	26.8	40.45	1.08	0.348	112.74
(R^2adj = 29%, Var(ϵ) = 1.45)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + \beta V_{t-1} + \epsilon$	25.9	39.91	0.37	0.543	114.23
(R^2adj = 27%, Var(ϵ) = 1.49)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + s(V_{t-1}) + \epsilon$	24.2	39.13	0.3	0.707	115.94
(R^2adj = 25%, Var(ϵ) = 1.52)					
V = Apr-May Precipitation					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \epsilon$	29.6	44.66			111.57
(R^2adj = 27%, Var(ϵ) = 1.49)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \beta V_t + \epsilon$	28.6	43.46	0.78	0.386	112.65
(R^2adj = 26%, Var(ϵ) = 1.5)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + \epsilon$	26.8	42.17	0.45	0.621	114.13
(R^2adj = 25%, Var(ϵ) = 1.52)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + \beta V_{t-1} + \epsilon$	25.8	42.18	NA	NA	116.09
(R^2adj = 23%, Var(ϵ) = 1.57)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + s(V_{t-1}) + \epsilon$	24.1	40.14	0.76	0.459	116.79
(R^2adj = 23%, Var(ϵ) = 1.56)					

Table B2. Model selection tests of sea surface temperature off Cochi as the explanatory variable (V) for the catch during spawning months (Jul-Sep) using 1983 to 2015 data. See Table B1 for an explanation of the models.

Model	Residual df	Residual deviance	F	p value	AIC
V = Jul-Sep SST					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \epsilon$	29.6	44.66			111.57
($R^2 adj$ = 27%, Var(ϵ) = 1.49)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \beta V_t + \epsilon$	28.6	42.38	1.86	0.184	111.77
($R^2 adj$ = 28%, Var(ϵ) = 1.46)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + \epsilon$	27	35.62	3.35	0.061	108.26
($R^2 adj$ = 37%, Var(ϵ) = 1.27)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + \beta V_{t-1} + \epsilon$	26	34.03	1.34	0.256	108.68
($R^2 adj$ = 38%, Var(ϵ) = 1.26)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + s(V_{t-1}) + \epsilon$	24.7	32.65	0.79	0.422	109.19
($R^2 adj$ = 38%, Var(ϵ) = 1.25)					
V = Jan-Dec SST					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \epsilon$	29.6	44.66			111.57
($R^2 adj$ = 27%, Var(ϵ) = 1.49)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \beta V_t + \epsilon$	28.6	41.84	1.98	0.172	111.38
($R^2 adj$ = 29%, Var(ϵ) = 1.44)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + \epsilon$	26.7	41.56	0.1	0.9	113.89
($R^2 adj$ = 26%, Var(ϵ) = 1.5)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + \beta V_{t-1} + \epsilon$	25.7	39.4	1.58	0.22	114.02
($R^2 adj$ = 28%, Var(ϵ) = 1.47)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + s(V_{t-1}) + \epsilon$	23.9	37.02	0.91	0.406	114.58
($R^2 adj$ = 28%, Var(ϵ) = 1.46)					

Table B3. Model selection tests of upwelling intensity off Cochi as the explanatory variable. See Table B1 for an explanation of the models.

Model	Residual df	Residual deviance	F	p value	AIC
V = Jul-Sep Upwelling current and prior seasons					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \epsilon$	29.6	44.66			111.57
($R^2 adj$ = 27%, Var(ϵ) = 1.49)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \beta V_t + \epsilon$	28.6	40.75	2.63	0.119	110.5
($R^2 adj$ = 31%, Var(ϵ) = 1.4)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + \epsilon$	26.6	39.74	0.34	0.712	112.5
($R^2 adj$ = 29%, Var(ϵ) = 1.44)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + \beta V_{t-1} + \epsilon$	25.7	39.71	0.02	0.886	114.38
($R^2 adj$ = 27%, Var(ϵ) = 1.49)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_t) + s(V_{t-1}) + \epsilon$	24	38.65	0.4	0.649	116.08
($R^2 adj$ = 25%, Var(ϵ) = 1.52)					
V = Oct-Dec Upwelling prior season					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \epsilon$	29.6	44.66			111.57
($R^2 adj$ = 27%, Var(ϵ) = 1.49)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \beta V_{t-1} + \epsilon$	28.6	44.25	0.27	0.604	113.24
($R^2 adj$ = 25%, Var(ϵ) = 1.52)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_{t-1}) + \epsilon$	27.2	43.85	0.18	0.756	114.8
($R^2 adj$ = 23%, Var(ϵ) = 1.56)					
V = Jan-Mar Upwelling prior season					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \epsilon$	29.6	44.66			111.57
($R^2 adj$ = 27%, Var(ϵ) = 1.49)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + \beta V_{t-1} + \epsilon$	28.6	44.08	0.38	0.54	113.13
($R^2 adj$ = 25%, Var(ϵ) = 1.52)					
$ln(S_t) = \alpha + s(ln(N_{t-1})) + s(V_{t-1}) + \epsilon$	26.9	42.45	0.62	0.525	114.3
($R^2 adj$ = 25%, Var(ϵ) = 1.53)					

Table B4. Model selection tests of GPCP precipitation as an explanatory variable for the catch during the non-spawning months (Oct-Jun) using 1983 to 2014 data. The data range is determined by the years for which SST was available in order to use a consistent dataset across covariate tests. N_t is the catch during Oct-Jun of season t. V_t is the covariate in the current season which spans two calendar years from July to June in the next year. V_{t-1} is the covariate in the prior Jul-Jun season.

Model	Residual df	Residual deviance	F	p value	AIC
V = Jun-Jul Precipitation					
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \epsilon$ ($R^2 adj$ = 61%, Var(ϵ) = 0.59)	25.6	15.58			80.66
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_t + \epsilon$ ($R^2 adj$ = 63%, Var(ϵ) = 0.55)	24.6	14.11	2.69	0.115	79.44
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_t) + \epsilon$ ($R^2 adj$ = 62%, Var(ϵ) = 0.56)	22.9	13.77	0.36	0.66	80.94
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_{t-1} + \epsilon$ ($R^2 adj$ = 59%, Var(ϵ) = 0.61)	24.6	15.54	0.07	0.783	82.49
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_{t-1}) + \epsilon$ ($R^2 adj$ = 61%, Var(ϵ) = 0.58)	22.7	14.09	1.31	0.288	82.1
V = Apr-May Precipitation					
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \epsilon$ ($R^2 adj$ = 61%, Var(ϵ) = 0.59)	25.6	15.58			80.66
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_t + \epsilon$ ($R^2 adj$ = 60%, Var(ϵ) = 0.6)	24.6	15.42	0.27	0.601	82.28
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_t) + \epsilon$ ($R^2 adj$ = 59%, Var(ϵ) = 0.61)	22.9	14.99	0.41	0.641	83.74
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_{t-1} + \epsilon$ ($R^2 adj$ = 59%, Var(ϵ) = 0.61)	24.6	15.55	0.05	0.83	82.58
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_{t-1}) + \epsilon$ ($R^2 adj$ = 59%, Var(ϵ) = 0.62)	22.9	15.04	0.5	0.58	83.78

Table B5. Model selection tests of sea surface temperature off Cochi as the explanatory variable (V) for the catch during the non-spawning months (Oct-Jun) using 1983 to 2014 data. See Table B4 for an explanation of the models.

Model	Residual df	Residual deviance	F	p value	AIC
V = Jan-Dec SST					
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \epsilon$ ($R^2 adj = 61\%$, Var(ϵ) = 0.59)	25.6	15.58			80.66
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_t + \epsilon$ ($R^2 adj = 68\%$, Var(ϵ) = 0.48)	24.6	12.34	6.8	0.016	75.14
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_t) + \epsilon$ ($R^2 adj = 67\%$, Var(ϵ) = 0.49)	22.8	11.96	0.44	0.626	76.63
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_{t-1} + \epsilon$ ($R^2 adj = 61\%$, Var(ϵ) = 0.58)	24.6	14.91	1.31	0.263	81.2
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_{t-1}) + \epsilon$ ($R^2 adj = 64\%$, Var(ϵ) = 0.53)	22.8	12.92	2.12	0.147	79.13
V = Jul-Sep SST					
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \epsilon$ ($R^2 adj = 61\%$, Var(ϵ) = 0.59)	25.6	15.58			80.66
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_t + \epsilon$ ($R^2 adj = 66\%$, Var(ϵ) = 0.5)	24.6	12.89	7.19	0.015	76.47
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_t) + \epsilon$ ($R^2 adj = 73\%$, Var(ϵ) = 0.4)	23.1	9.78	5.15	0.021	69.77
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_{t-1} + \epsilon$ ($R^2 adj = 59\%$, Var(ϵ) = 0.61)	24.6	15.54	0.07	0.78	82.47
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_{t-1}) + \epsilon$ ($R^2 adj = 60\%$, Var(ϵ) = 0.59)	23.3	14.67	1.07	0.334	82.5

Table B6. Model selection tests of upwelling intensity off Cochi as the explanatory variable. See Table B4 for an explanation of the models.

Model	Residual df	Residual deviance	F	p value	AIC
V = Jul-Sep Upwelling					
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \epsilon$ ($R^2 adj$ = 61%, Var(ϵ) = 0.59)	25.6	15.58			80.66
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_t + \epsilon$ ($R^2 adj$ = 65%, Var(ϵ) = 0.53)	24.6	13.47	4.15	0.054	77.96
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_t) + \epsilon$ ($R^2 adj$ = 65%, Var(ϵ) = 0.52)	22.8	12.75	0.78	0.453	78.75
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_{t-1} + \epsilon$ ($R^2 adj$ = 61%, Var(ϵ) = 0.58)	24.6	14.86	1.23	0.276	81.09
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_{t-1}) + \epsilon$ ($R^2 adj$ = 59%, Var(ϵ) = 0.61)	22.8	14.71	0.14	0.844	83.4
V = Oct-Dec Upwelling					
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \epsilon$ ($R^2 adj$ = 61%, Var(ϵ) = 0.59)	25.6	15.58			80.66
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_t + \epsilon$ ($R^2 adj$ = 60%, Var(ϵ) = 0.6)	24.6	15.36	0.37	0.538	82.15
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_t) + \epsilon$ ($R^2 adj$ = 59%, Var(ϵ) = 0.61)	23.2	14.95	0.5	0.54	83.1
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_{t-1} + \epsilon$ ($R^2 adj$ = 61%, Var(ϵ) = 0.59)	24.6	15.03	0.94	0.339	81.47
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_{t-1}) + \epsilon$ ($R^2 adj$ = 59%, Var(ϵ) = 0.6)	23.3	14.94	0.12	0.794	82.97
V = Jan-Mar Upwelling					
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \epsilon$ ($R^2 adj$ = 61%, Var(ϵ) = 0.59)	25.6	15.58			80.66
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_t + \epsilon$ ($R^2 adj$ = 60%, Var(ϵ) = 0.6)	24.6	15.42	0.28	0.588	82.24
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_t) + \epsilon$ ($R^2 adj$ = 60%, Var(ϵ) = 0.6)	23	14.59	0.87	0.412	82.72
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + \beta V_{t-1} + \epsilon$ ($R^2 adj$ = 59%, Var(ϵ) = 0.61)	24.6	15.57	0.02	0.887	82.61
$ln(N_t) = \alpha + s(ln(N_{t-1})) + s(ln(S_{t-2})) + s(V_{t-1}) + \epsilon$ ($R^2 adj$ = 58%, Var(ϵ) = 0.63)	22.9	15.3	0.27	0.725	84.35

Appendix C: Tests for Chlorophyll-a as a covariate

Table C1. Model selection tests of Chlorophyll-a as an explanatory variable for the catch during spawning months (Jul-Sep) using 1998 to 2014 data. The data range is determined by the years for which CHL was available. S_t is the catch during Jul-Sep of season t. V_t is the covariate in the current season which spans two calendar years from July to June in the next year. V_{t-1} is the covariate in the prior Jul-Jun season. For Oct-Dec and Jan-Mar only Chlorophyll-a in the prior season is used since these months are after spawning in the current season. Non-linearity is modeled as a 2nd-order polynomial due to data constraints and appears as $p()$ in the model equations. The non-spawner catch is modeled as a function of non-spawner catch in the prior year only, without spawner catch 2-years prior as in the other covariate analyses (Appendix B). This is done due to data constraints. The models are nested; the roman numeral indicates the level of nestedness. Models at levels II and higher are shown with the component that is added to the base level model (M1) at top.

Model	Residual df	Residual deviance	F	p value	AIC
I-M1: $ln(S_t) = \alpha + p(ln(N_{t-1})) + \epsilon$	14	1.97			19.6
($R^2 adj$ = 14%, Var(ϵ) = 0.14)					
V = Jul-Sep Chlorophyll					
II: $ln(S_t) = M1 + \beta V_t$	13	1.68	0.74	0.41	18.93
($R^2 adj$ = 26%, Var(ϵ) = 0.13)					
III: $ln(S_t) = M1 + p(V_t)$	12	1.68	0.02	0.878	20.89
($R^2 adj$ = 20%, Var(ϵ) = 0.14)					
IV: $ln(S_t) = M1 + p(V_t) + \beta V_{t-1}$	11	1.67	0.08	0.781	22.76
($R^2 adj$ = 13%, Var(ϵ) = 0.15)					
V: $ln(S_t) = M1 + p(V_t) + p(V_{t-1})$	10	1.64	0.16	0.694	24.48
($R^2 adj$ = 6%, Var(ϵ) = 0.16)					
V = Oct-Dec Chlorophyll					
II: $ln(S_t) = M1 + \beta V_{t-1}$	13	1.79	0.12	0.733	19.95
($R^2 adj$ = 21%, Var(ϵ) = 0.14)					
III: $ln(S_t) = M1 + p(V_{t-1})$	12	1.68	0.73	0.408	20.94
($R^2 adj$ = 20%, Var(ϵ) = 0.14)					
V = Jan-Mar Chlorophyll					
II: $ln(S_t) = M1 + \beta V_{t-1}$	13	1.79	0.07	0.798	20.02
($R^2 adj$ = 21%, Var(ϵ) = 0.14)					
III: $ln(S_t) = M1 + p(V_{t-1})$	12	1.77	0.13	0.721	21.83
($R^2 adj$ = 15%, Var(ϵ) = 0.15)					

Table C2. Model selection tests of Chlorophyll-a as an explanatory variable for the catch during the non-spawning months (Oct-Jun) using 1998 to 2014 data. The data range is determined by the years for which CHL was available. N_t is the catch during Oct-Jun of season t. V_t is the covariate in the current season which spans two calendar years from July to June in the next year. V_{t-1} is the covariate in the prior Jul-Jun season. Non-linearity is modeled as a 2nd-order polynomial due to data constraints and appears as $p()$ in the model equations. The non-spawner catch is modeled as a function of non-spawner catch in the prior year only, without spawner catch 2-years prior as in the other covariate analyses (Appendix B). This is done due to data constraints. The models are nested; the roman numeral indicates the level of nestedness. Models at levels II and higher are shown with the component that is added to the base level model (M1) at top.

Model	Residual df	Residual deviance	F	p value	AIC
I-M1: $ln(N_t) = \alpha + p(ln(N_{t-1})) + \epsilon$	14	1.97			19.6
(R^2adj = 14%, Var(ϵ) = 0.14)					
V = Jul-Sep Chlorophyll					
II: $ln(N_t) = M1 + \beta V_t$	13	1.96	0.06	0.815	21.52
(R^2adj = 8%, Var(ϵ) = 0.15)					
III: $ln(N_t) = M1 + p(V_t)$	12	1.87	0.54	0.478	22.69
(R^2adj = 5%, Var(ϵ) = 0.16)					
II: $ln(N_t) = M1 + \beta V_{t-1}$	13	1.92	0.32	0.582	21.17
(R^2adj = 10%, Var(ϵ) = 0.15)					
III: $ln(N_t) = M1 + p(V_{t-1})$	11.6	1.87	0.22	0.731	22.75
(R^2adj = 4%, Var(ϵ) = 0.16)					
V = Oct-Dec Chlorophyll					
II: $ln(N_t) = M1 + \beta V_t$	13	1.88	0.77	0.402	20.84
(R^2adj = 11%, Var(ϵ) = 0.14)					
III: $ln(N_t) = M1 + p(V_t)$	12	1.71	1.55	0.241	21.17
(R^2adj = 13%, Var(ϵ) = 0.14)					
IV: $ln(N_t) = M1 + p(V_t) + \beta V_{t-1}$	11	1.14	4.99	0.05	16.37
(R^2adj = 36%, Var(ϵ) = 0.1)					
V: $ln(N_t) = M1 + p(V_t) + p(V_{t-1})$	10	1.13	0.12	0.733	18.16
(R^2adj = 31%, Var(ϵ) = 0.11)					
II: $ln(N_t) = M1 + \beta V_{t-1}$	13	1.5	4.32	0.063	16.96
(R^2adj = 29%, Var(ϵ) = 0.12)					
III: $ln(N_t) = M1 + p(V_{t-1})$	10.3	1.2	1.03	0.409	17.14
(R^2adj = 33%, Var(ϵ) = 0.11)					
V = Jan-Mar Chlorophyll					
II: $ln(N_t) = M1 + \beta V_t$	13	1.97	0	0.972	21.6
(R^2adj = 7%, Var(ϵ) = 0.15)					
III: $ln(N_t) = M1 + p(V_t)$	12	1.82	0.93	0.358	22.23
(R^2adj = 7%, Var(ϵ) = 0.15)					
II: $ln(N_t) = M1 + \beta V_{t-1}$	13	1.67	2.14	0.171	18.78
(R^2adj = 21%, Var(ϵ) = 0.13)					
III: $ln(N_t) = M1 + p(V_{t-1})$	11	1.63	0.12	0.884	21.25
(R^2adj = 14%, Var(ϵ) = 0.14)					

Table C3. Model selection tests of Chlorophyll-a as an explanatory variable for the catch during the non-spawning months (Oct-Jun) using box 5.

Model	Residual df	Residual deviance	F	p value	AIC
I-M1: $ln(N_t) = \alpha + p(ln(N_{t-1})) + \epsilon$ (R^2adj = 14%, Var(ϵ) = 0.14)	14	1.97			19.6
V = Jul-Sep Chlorophyll					
II: $ln(N_t) = M1 + \beta V_t$ (R^2adj = 21%, Var(ϵ) = 0.13)	13	1.67	2.01	0.187	18.76
III: $ln(N_t) = M1 + p(V_t)$ (R^2adj = 15%, Var(ϵ) = 0.14)	12	1.66	0.05	0.836	20.69
II: $ln(N_t) = M1 + \beta V_{t-1}$ (R^2adj = 10%, Var(ϵ) = 0.15)	13	1.91	0.46	0.512	21.04
III: $ln(N_t) = M1 + p(V_{t-1})$ (R^2adj = 15%, Var(ϵ) = 0.14)	10.5	1.53	1.09	0.383	21.19
V = Oct-Dec Chlorophyll					
II: $ln(N_t) = M1 + \beta V_t$ (R^2adj = 27%, Var(ϵ) = 0.12)	13	1.55	4.22	0.067	17.57
III: $ln(N_t) = M1 + p(V_t)$ (R^2adj = 31%, Var(ϵ) = 0.11)	12	1.35	2.11	0.177	17.13
IV: $ln(N_t) = M1 + p(V_t) + \beta V_{t-1}$ (R^2adj = 44%, Var(ϵ) = 0.09)	11	1	3.51	0.091	14.1
V: $ln(N_t) = M1 + p(V_t) + p(V_{t-1})$ (R^2adj = 40%, Var(ϵ) = 0.1)	10	0.98	0.18	0.684	15.8
II: $ln(N_t) = M1 + \beta V_{t-1}$ (R^2adj = 35%, Var(ϵ) = 0.11)	13	1.37	5.15	0.044	15.47
III: $ln(N_t) = M1 + p(V_{t-1})$ (R^2adj = 29%, Var(ϵ) = 0.12)	11	1.35	0.11	0.895	17.89
V = Jan-Mar Chlorophyll					
II: $ln(N_t) = M1 + \beta V_t$ (R^2adj = 25%, Var(ϵ) = 0.12)	13	1.59	3.35	0.097	17.92
III: $ln(N_t) = M1 + p(V_t)$ (R^2adj = 20%, Var(ϵ) = 0.13)	12	1.57	0.17	0.692	19.72
II: $ln(N_t) = M1 + \beta V_{t-1}$ (R^2adj = 19%, Var(ϵ) = 0.13)	13	1.72	2.78	0.125	19.33
III: $ln(N_t) = M1 + p(V_{t-1})$ (R^2adj = 46%, Var(ϵ) = 0.09)	10.4	0.98	3.25	0.071	13.58

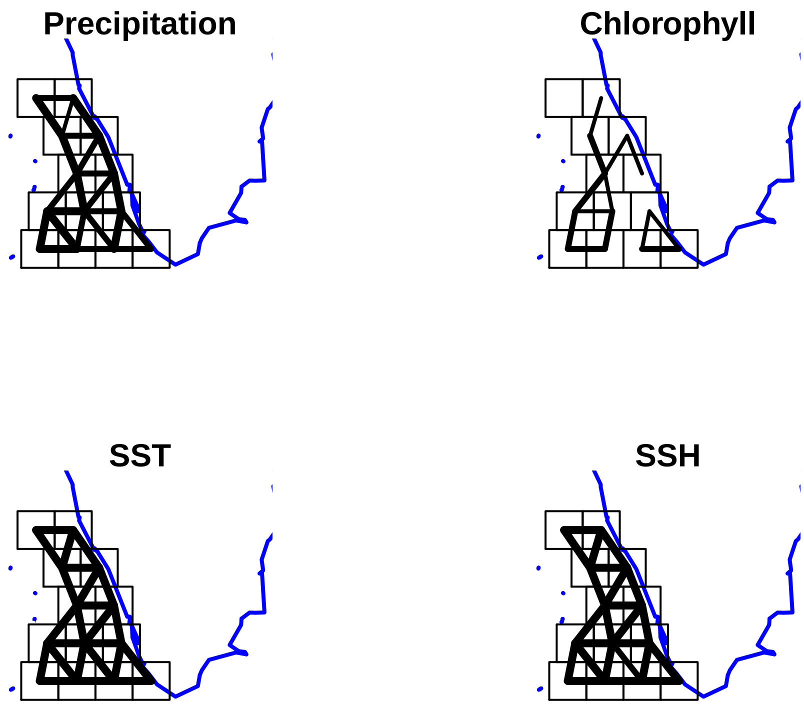

Figure C1. Correlation of the covariates across boxes. Correlation is shown by the width of the lines between neighboring boxes.

Appendix D: Correlation of covariates across the boxes

Appendix E: Covariates along the SE India coast

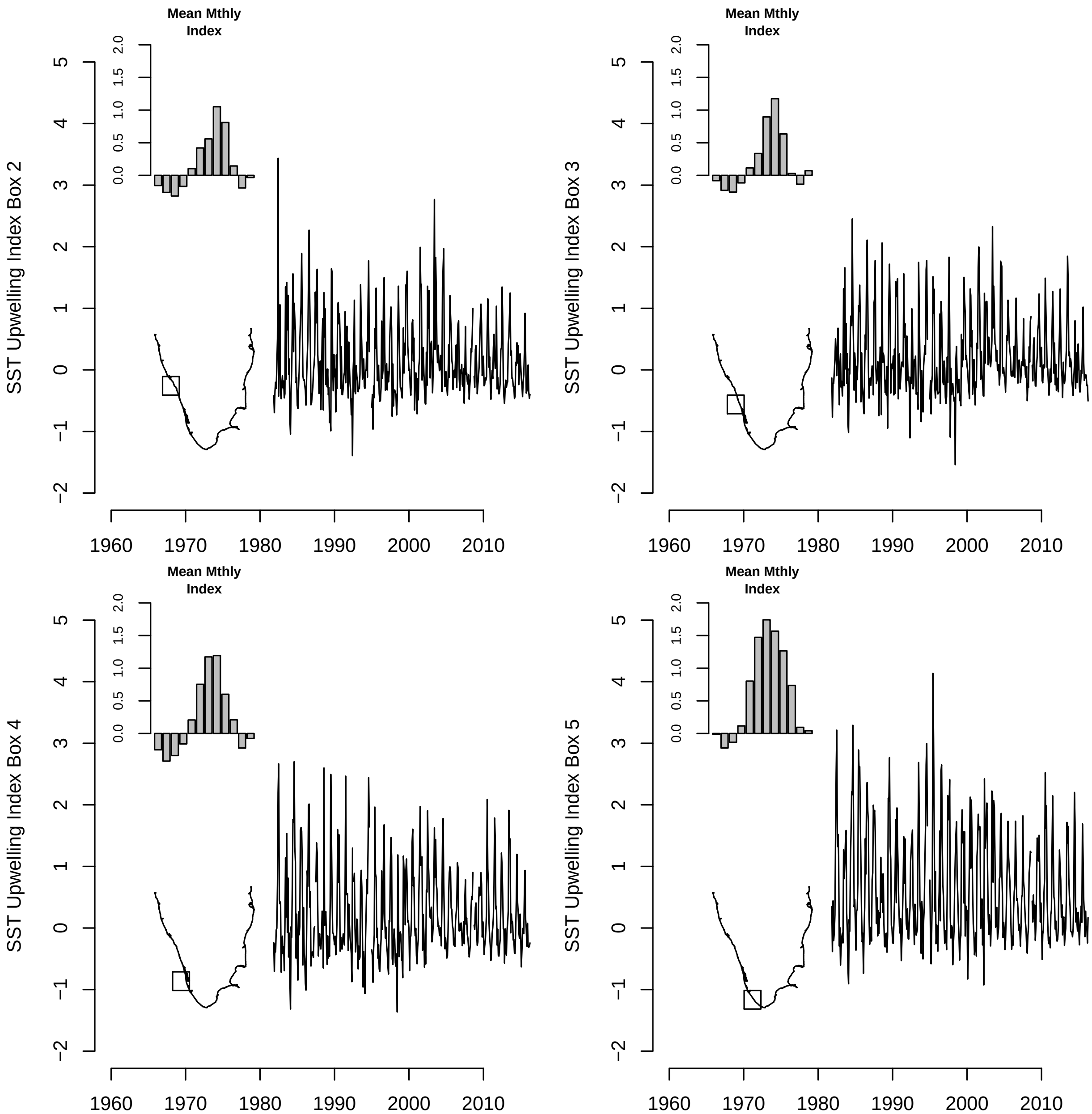

Figure E1. Upwelling index.

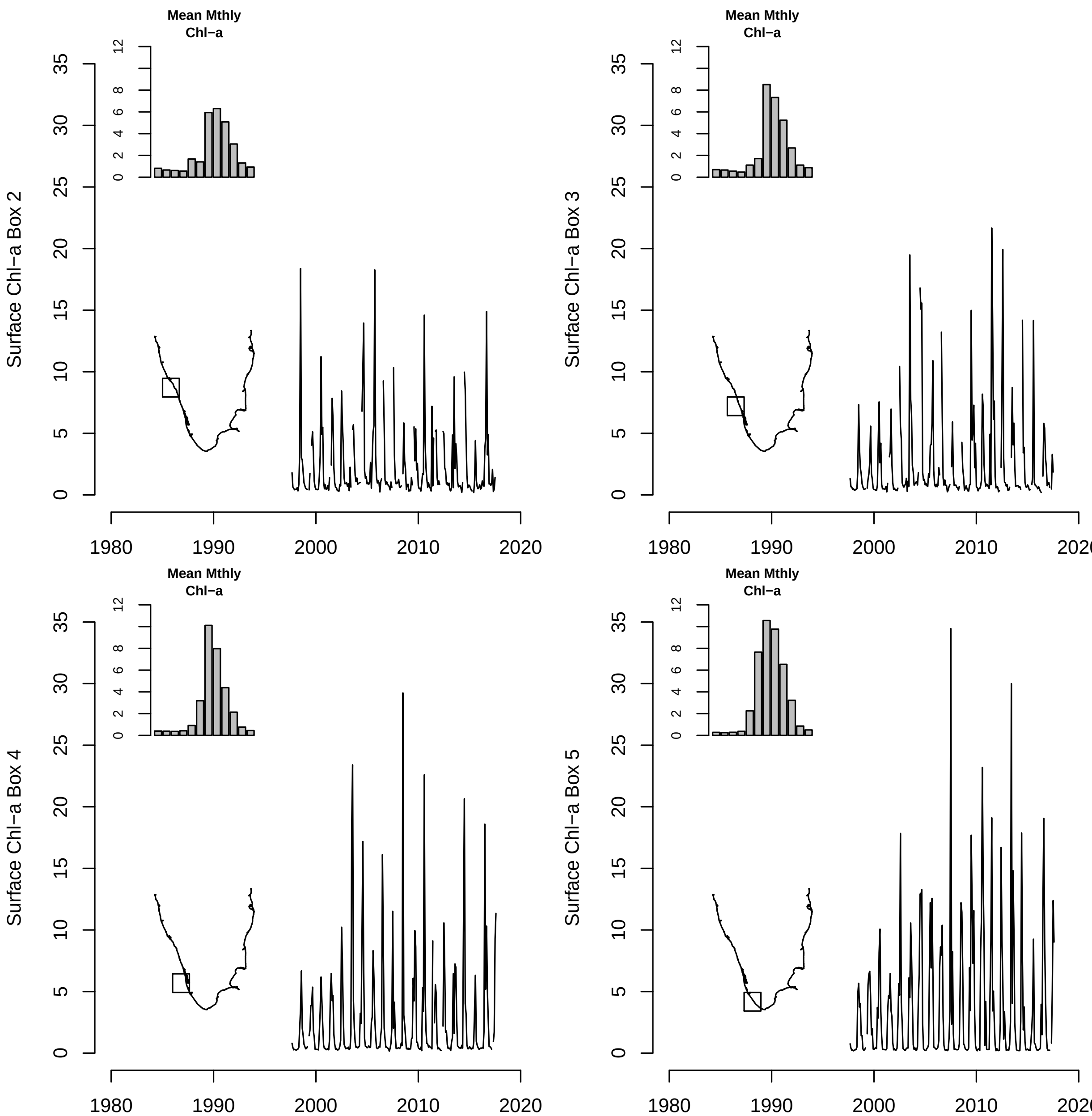

Figure E2. Chlorophyll-a.

Appendix F: Comparison of land and oceanic rainfall measurements

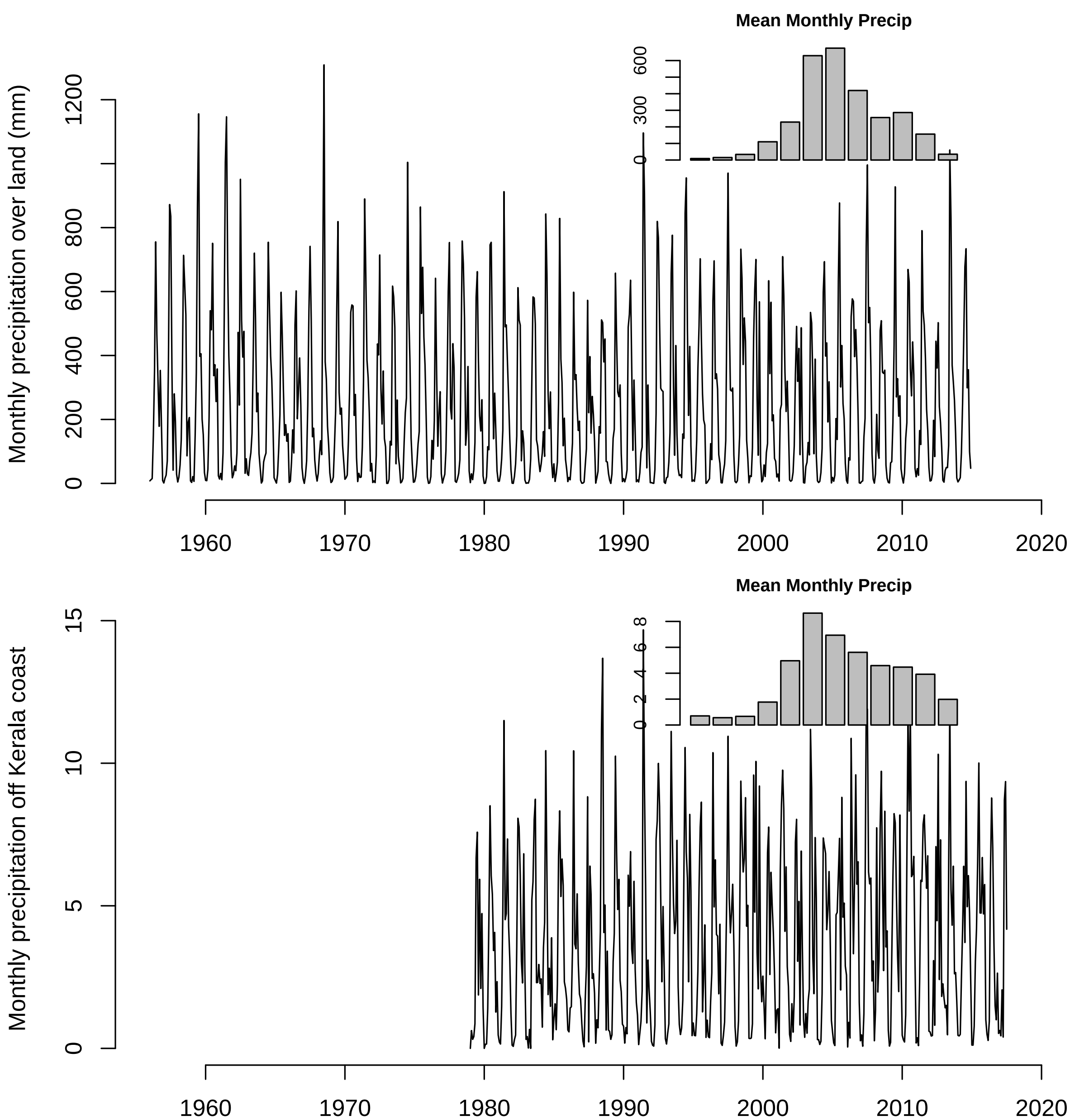
Mean Monthly Precip
0
300
600
Monthly precipitation over land (mm)
0
200
400
600
800
1200
1960
1970
1980
1990
2000
2010
2020
Mean Monthly Precip
0
2
4
6
8
Monthly precipitation off Kerala coast
0
5
10
15
1960
1970
1980
1990
2000
2010
2020

Figure F1

Appendix G: Chlorophyll-a images in 2016

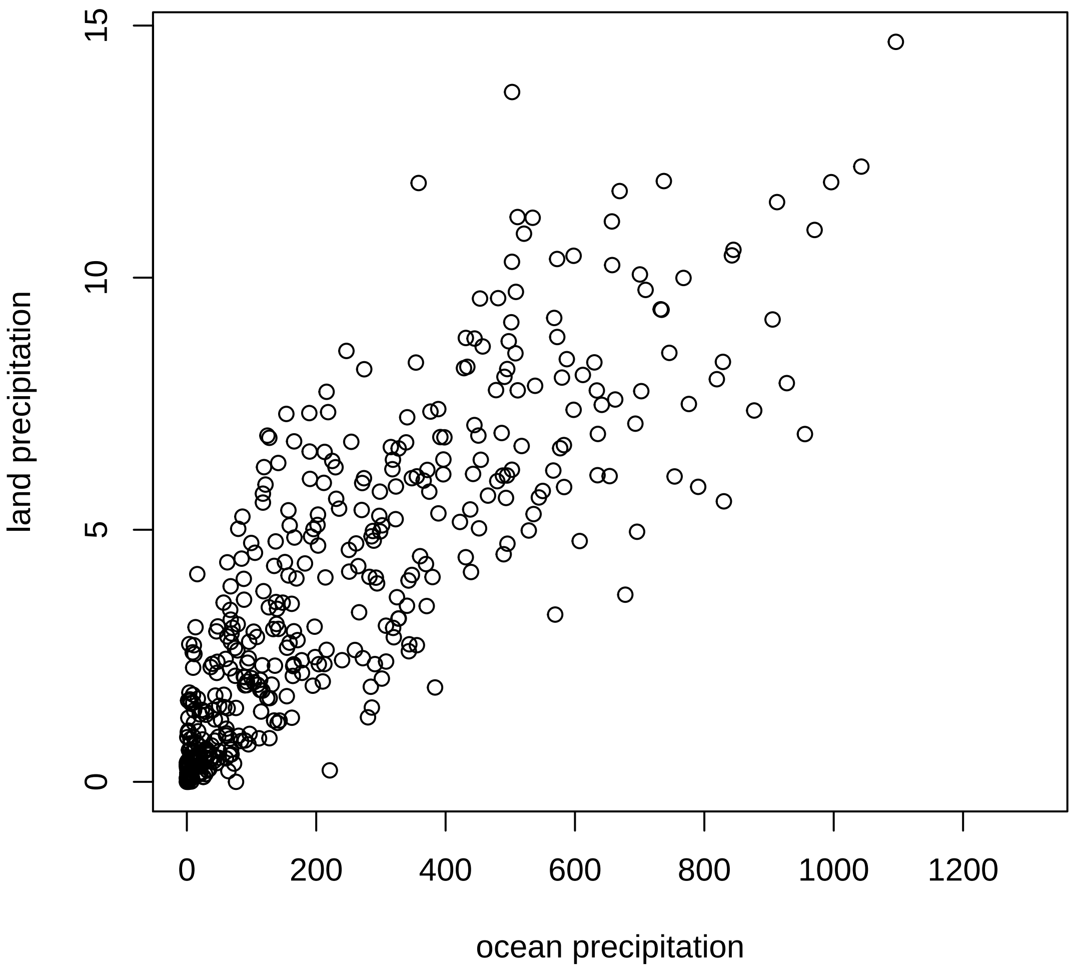

Figure F2. Monthly precipitation measured over land via land gauges versus the precipitation measured via remote sensing over the ocean.

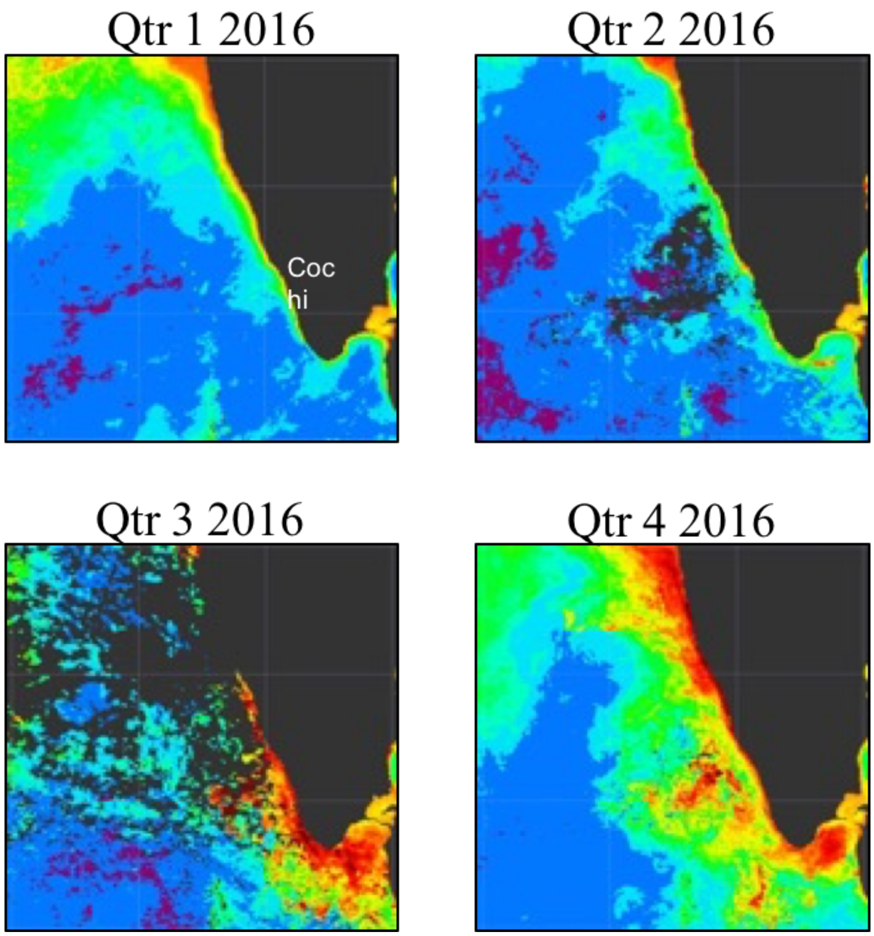

Figure 1