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Supplementary Material

Reproductive phenology of the kelp *Ecklonia radiata* at its Australian warm-range edge and the influence of environmental factors

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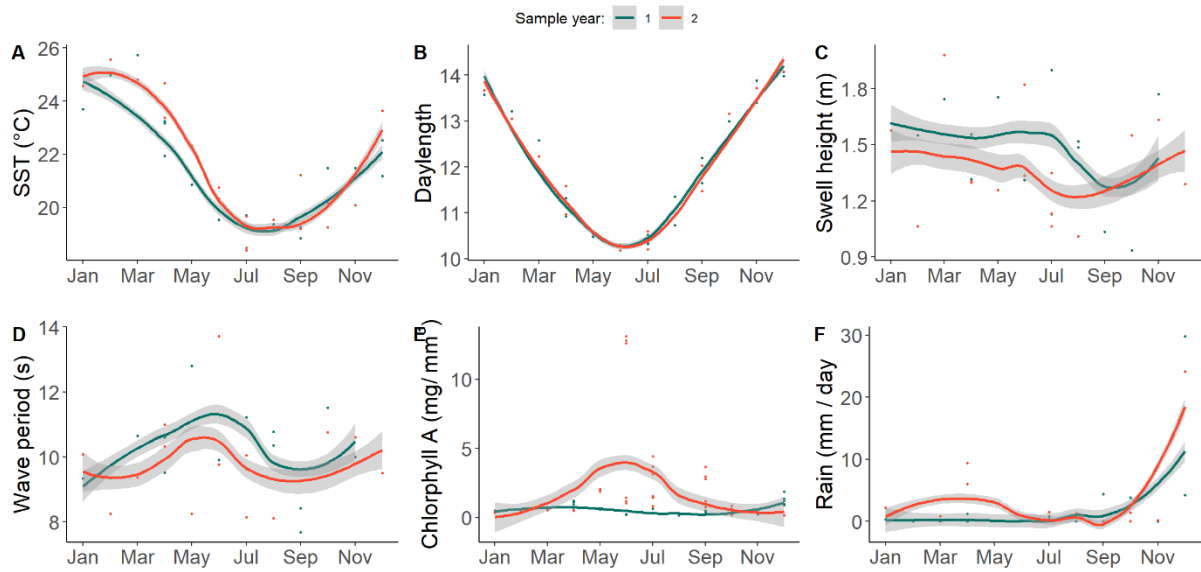


Figure S1. Environmental parameters used in analysis plotted over the sample period. Dots represent individual data points and the lines represent a smoothing function using localised regression. Grey areas denote the 95% confidence interval.

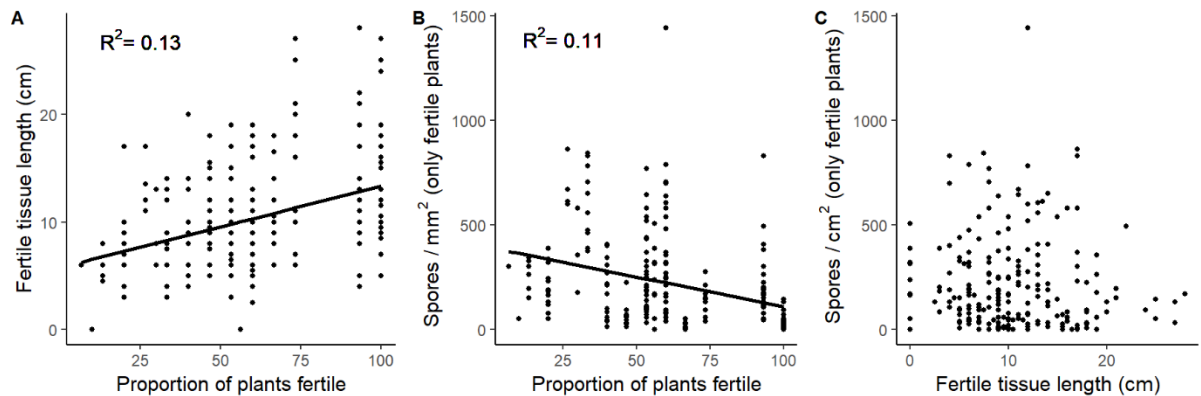


Figure S2. Significant linear regression line between (A) proportion of plants fertile and the fertile tissue length; (B) proportion of plants fertile and the spores released from fertile plants per square millimetre, and (C) length of fertile tissue and the spores released from fertile plants per square millimetre. The r^2 of each regression line is depicted in the left top corner for the two significant relationships (A and B). Dots represent individual data points.

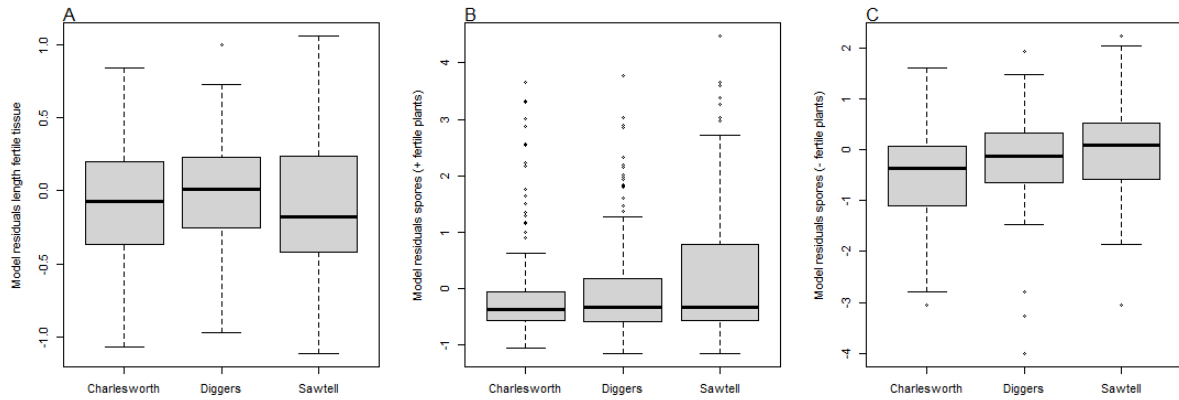


Figure S3. Box and whisker plot of model residuals of GLMs relating ‘Month’ and ‘Year’ to fertility response variables (A) fertile tissue length (cm), (B) number of spores released per square millimetre of fertile tissue with infertile plants included, (C) number of spores released per square millimetre of fertile tissue without infertile plants included to their sample location. The line in the boxes represents the median, the boxes extend to the 25 and 75% quartiles of the data and the whiskers extend to the 95% quartiles. No patterns were found in these residuals, therefore ‘sample location’ was not included in the final GLMs.

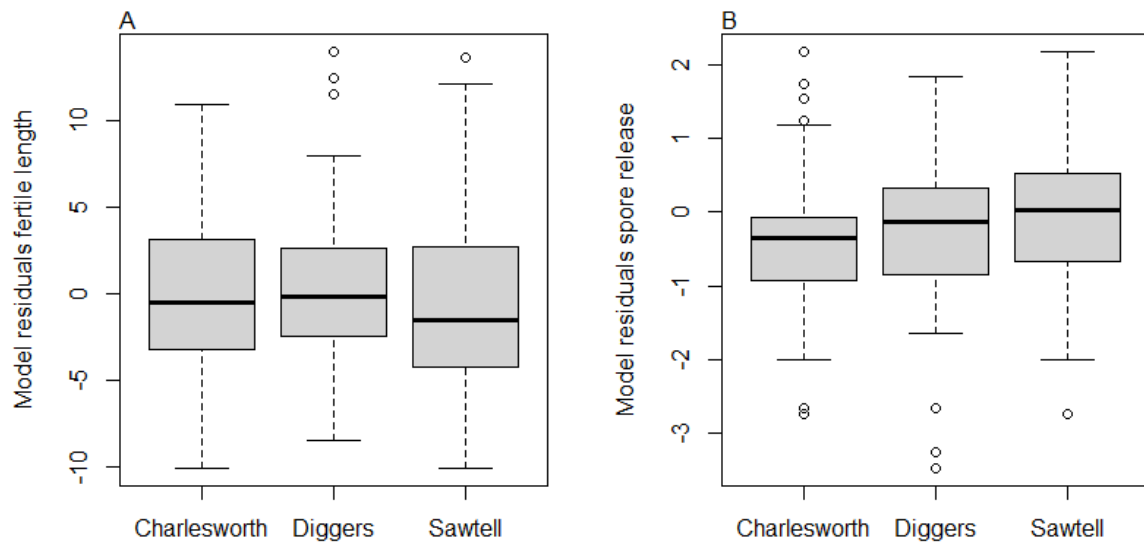


Figure S4. Box and whisker plot of model residuals of GAMs relating environmental parameters to fertility response variables (A) fertile tissue length (cm) and (B) number of spores released per square millimetre of fertile tissue, to their sample location. The line in the boxes represents the median, the boxes extend to the 25 and 75% quartiles of the data and the whiskers extend to the 95% quartiles. No patterns were found in these residuals, therefore ‘sample location’ was not included in the final GAMs.

Table S1. Summary of linear models used to test for a relationship between the fertility metrics spore release (spores per square millimetre of fertile tissue), fertile length (cm) and percentage of total plants fertile, and morphological predictors total plant length, stipe length and thallus length (cm)

Response variable & predictors	r^2	d.f.	F	P
Spores (number per square millimetre of fertile tissue)				
Total plant length (cm)	0.024	48	1.182	0.283
Thallus length (cm)	0.007	48	0.330	0.568
Stipe length (cm)	0.046	48	2.340	0.133
Fertile tissue length (cm)				
Total plant length (cm)	0.050	48	2.529	0.118
Thallus length (cm)	0.027	48	1.318	0.257
Stipe length (cm)	0.052	48	2.607	0.113
Percentage fertile				
Total plant length (cm)	0.043	48	2.148	0.149
Thallus length (cm)	0.025	48	1.231	0.273
Stipe length (cm)	0.039	48	1.936	0.171

Table S2. Summary of environmental predictors used in the data analysis, as well as environmental predictors not included in data analysis due to covariance.

Predictor	Description	Range	Source
SST	<i>In situ</i> daily sea surface temperature derived from three daily readings. Averaged over the 2 days prior to each sample date.	18.37–25.75°C	NSW DPI Fisheries shark listening station, Park Beach, Coffs Harbour
Swell height	Swell height from Coffs Harbour Wave Rider buoy. Average for 3 days previous sample date.	1.98–0.93 m	Manly Hydraulics Lab, located at 30°22'S, 153°16'E
Wave period	Coffs Harbour Wave Rider buoy. Average for 3 days previous sample date.	13.71–7.68 s	Manly Hydraulics Lab, located at 30°22'S, 153°16'E
Daylength	Hours of sunlight daily.	14.08–10.18 h	Bureau of Meteorology Coffs Harbour station located at 30°32'S, 153°12'E
Chlorophyll- <i>a</i>	8-day composite mass concentration of chlorophyll- <i>a</i> in seawater (level 4).	0.16–13.11 mg m ⁻³	Globcolour downloaded from CMEMS (product #009_082). Spatial resolution 4 km.
Temperature anomaly	Sea level anomaly, maximum intensity of marine heatwave.	2.31–1.63°C	Marineheatwaves.org, pixel used located at 30°38'S, 153°13'E
Storms	Number of days with +3 m waves within 10 days preceding sampling from Coffs Harbour Wave Rider buoy.	0–2 days	Manly Hydraulics Lab, buoy located at 30°22'S, 153°16'E
Rainfall	Rainfall	0–29.8 mm ² day ⁻¹	Bureau of Meteorology Coffs Harbour station located at 30°32'S, 153°12'E
Environmental predictors not included in data analysis due to covariance			
Swell direction	Swell direction from Coffs Harbour Wave Rider buoy. Average for 3 days previous sample date.	89.49–169.99°	Manly Hydraulics Lab, located at 30°22'S, 153°16'E
Temperature anomaly (days)	Number of days where SST was considered anomalous	0–2 days	marineheatwaves.org pixel used located at 30°38'S, 153°13'E
Temperature anomaly (maximum)	Mean intensity of SST anomalies	-1.52–1.75°C	marineheatwaves.org pixel used located at 30°38'S, 153°13'E
Temperature anomaly (cumulative)	Cumulative intensity of SST anomalies	-9.11–34.91°C	marineheatwaves.org pixel used located at 30°38'S, 153°13'E
PAR	Average daily measures of photosynthetically active radiation	2.43–13.77 μmol m ⁻² s ⁻¹	Bureau of Meteorology Coffs Harbour station located at 30°32'S, 153°12'E

For every predictor, distinct spatial coordinates were used to extract data for each monitoring site (i.e. Sawtell, 30°37'S, 153°08'E; Charlesworth, 30°27'S, 153°14'E; Diggers, 30°28'S, 153°15'E) over the sampling period unless otherwise indicated.

Table S3. Summary of model selection and the statistics of the retained model predictors.

Response variable & predictors	AIC	d.f.	<i>F</i>	χ^2	<i>P</i>
Spores (+ infertile plants)	3081.098				
Year \times Month (Negative binomial)		11		82.094	<0.001
Month (binomial)		11		110.42	<0.001
Spores (– infertile plants)	2598.2				
Month		444.9		86.912	<0.001
Year		334.31		110.585	<0.001
Month \times Year		257.66		76.652	<0.001
Percentage of plants fertile	53.296				
Month		24		9.4136	0.584
Length of fertile tissue	3159.8				
Month		192	2.3292		0.010
Year		191	9.3817		0.003

For each metric, it shows the AIC and d.f. of the final model, and the test statistic of each model parameter (approximately χ^2 -distributed for binomial and negative binomial data structure, and *F*-distributed for a gamma data structure).

Table S4. Summary of model selection of environmental correlation analysis.

Iteration	Model	Variable dropped	Δ AIC
Spores			
0	nutr + s(swh) + s(wvp) + s(rain)	-	0
1	nutr + s(swh) + s(rain)	wvp	22.37
2	s(swh) + s(rain)	nutr	30.49
3	s(swh)	rain	70.35
Percentage of fertile plants			
0	dayl + SST	-	0
1	dayl	SST	2.51
Fertile tissue length			
0	SST + s(swh) + nutr + storms	-	0
1	SST + s(swh) + storms	nutr	13.17
2	storms + SST	s(swh)	26.58
3	storms	SST	43.71

It shows the difference in Akaike information criterion (AIC) that resulted from dropping each predictor that was retained in the final models. Predictors were chlorophyll-a (nutr), swell height (swh), wave period (wvp), rainfall (rain), daylength (dayl), sea surface temperature (SST), and storm days (storms). Note the slight increase in AIC when leaving SST out of the model for percentage of fertile plants. As daylength and temperature can correlate, the authors decided to retain only daylength in the final model.

Table S5. Summary of results for the optimal model of fertile tissue length.

Variable	Effective degrees of freedom	Coefficient estimate	<i>P</i>
s(Swell height)	6	-	<0.001
Storm days	-	3.063	<0.001
Chlorophyll- <i>a</i>	-	0.542	<0.001
SST	-	0.851	<0.001

Smoothing factors are denoted by 's'. Units of variables: swell height (m), storm days

(number of days out of 10 days preceding sample date), chlorophyll-*a* (mg / m³), SST (°C).

Table S6. Summary of results for the optimal spore release model.

Variable	Effective degrees of freedom	Coefficient estimate	<i>P</i>
s(Swell height)	5	-	<0.001
s(Wave period)	4	-	<0.001
Chlorophyll- <i>a</i>	-	-0.15894	<0.001
s(Rain)	2	-	<0.001

Smoothing factors are denoted by 's'. Units of variables: swell height (m), wave period (s),

chlorophyll-*a* (mg m⁻³), rain (mm² day⁻¹).