Ecography

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Supplementary material

APPENDIX1: Sommer et al. Differential response to abiotic stress controls range limits at biogeographic transition zones

Environmental predictors

Table A1. Environmental variables and information relating to data manipulation, spatial resolution and data sources.

Variable	Manipulation	Spatial resolution	Source
SST_Mean	Temporal mean from daily climatologies	10 km	Bluelink Reanalysis, Oke *et al.* 2008
SST_Min	Mean annual minimum from daily climatologies	10 km	Bluelink Reanalysis, Oke *et al.* 2008
VAR_Short	Standard deviation of daily climatologies over weekly periods	10 km	Bluelink Reanalysis, Oke *et al.* 2008
VAR_Long	Standard deviation of daily climatologies over entire period	10 km	Bluelink Reanalysis, Oke *et al.* 2008
PAR_Mean	Temporal mean from monthly climatologies	5 km	MODIS Aqua, Parkinson 2003
PAR_Min	Mean annual minimum from monthly climatologies	5 km	MODIS Aqua, Parkinson 2003
KD490	Temporal mean from monthly climatologies	5 km	MODIS Aqua, Parkinson 2003
pH	Temporal mean from monthly climatologies	9.2 km	Bio-ORACLE, Tyberghein *et al.* 2012

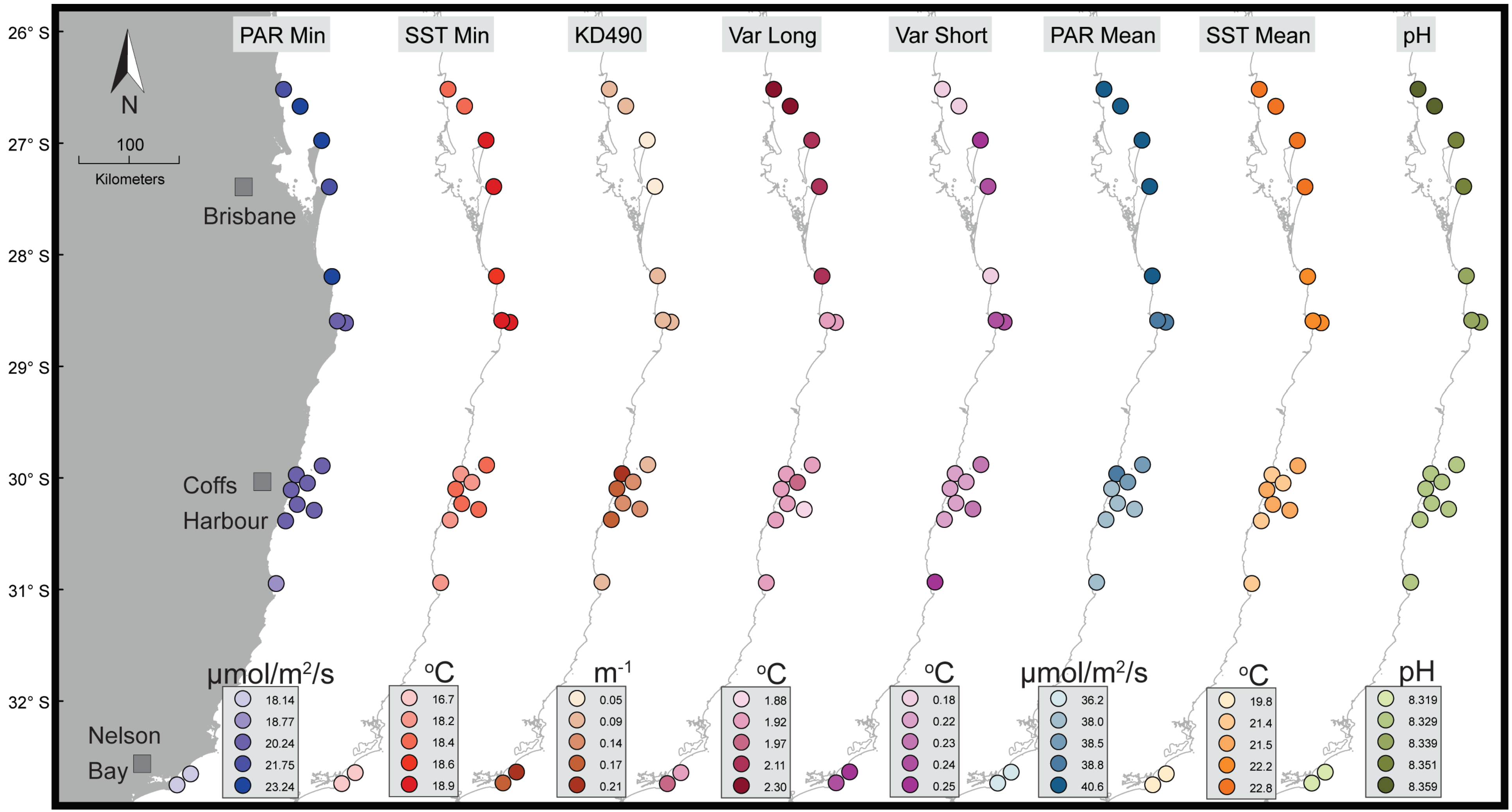

Figure A1. Map of environmental variables at the study locations.

Spearman rank correlations for environmental predictors

Table A2. Spearman rank correlation coefficients for environmental variables. We used a multicollinearity cut-off of r > 0.7 and only included one variable of correlated pairs in multiple regression models. Coefficients that exceeded r > 0.7 are highlighted in bold.

	PAR_Mean	PAR_Min	KD490	SST_Mean	SST_Min	VAR_Long	VAR_Short	pH
PAR_Min	**0.77**							
KD490	-0.65	-0.35						
SST_Mean	**0.88**	0.63	**-0.77**					
SST_Min	0.66	0.39	-0.64	**0.82**				
VAR_Long	0.67	0.57	-0.50	0.55	0.15			
VAR_Short	-0.29	-0.50	-0.20	-0.10	0.08	-0.21		
pH	**0.95**	**0.81**	-0.53	**0.86**	0.60	0.68	-0.43	
Latitude	**-0.97**	**-0.75**	0.60	**-0.87**	-0.61	-0.67	0.43	**-0.97**

Supplementary analyses: Model selection with nested pre-selection of SST and PAR parameters

Methods:

Step 1: Nested model selection of annual means versus minima for SST and PAR

In order to determine whether to include the annual means or minima for SST and PAR in multiple regression models, we initially performed nested model selection of SST and PAR parameters to identify the SST and PAR parameters with the highest explanatory power. To identify the SST parameter with the highest explanatory power (lowest AICc value) we started with both SST_Min and SST_Mean in the model and performed backward model selection. We subsequently repeated this process for PAR_Mean and PAR_Min for each of the models tested (See Table A3 for the chosen predictors).

Step 2: Multiple regression models

We then included the SST and PAR parameters with the highest explanatory power (as identified in step 1 above), as well as KD490, VAR_short and VAR_long in multiple regression models. We used generalised linear models (GLMs) with normal error structure to determine the relative importance of environmental variables in the distribution of corals. The models evaluated the associations between coral community summary metrics (species richness, the number of tropical and subtropical species, Shannon diversity, the abundance of tropical and subtropical species, and functional dispersion) and the chosen environmental predictors. For each coral community summary metric, multiple regression models included SST_Min or

SST_Mean, PAR_Min or PAR_Min, KD490, VAR_Long and VAR_Short as potential predictors (See Table S4 for the combinations of predictors used in multiple regression models). We then conducted model averaging as per the methods outlined in the methods section of the manuscript.

Step 3: Sensitivity analysis

For models where pre-selection (step 1) resulted in SST and PAR parameters with spearman rank correlation > 0.7 being chosen (for tropical abundance), we performed sensitivity analysis and reran models with all four possible combinations of SST_Min, SST_Mean, PAR_Min, PAR_Mean parameters to determine robustness of statistical results.

Results:

Step 1: Nested comparison of annual means versus minima for SST and PAR

Nested pre-selection of SST and PAR parameters resulted in PAR_Min being chosen as best PAR predictor for species richness, tropical and subtropical species richness, Shannon diversity and functional dispersion. PAR_Mean had the highest explanatory power among PAR parameters for tropical abundance, and subtropical abundance (Table A2). SST_Mean had higher explanatory power than SST_Min for species richness, tropical species richness, tropical abundance, and Shannon diversity (Table A2). For subtropical species richness, subtropical abundance and functional dispersion backwards selection indentified SST_Min as the best predictor (Table A3).

Table A3. Results of nested model selection of PAR and SST parameters, identifying the PAR and SST parameters with the highest explanatory power of biodiversity patterns of scleractinian corals in the subtropical-to-temperate transition zone in eastern Australia. Model coefficients, R^2 values and AICc values are shown for the SST and PAR parameters chosen in backward model selection.

Response & Transformation			**PAR**		**SST**	
			Mean	**Min**	**Mean**	**Min**
Species Richness	4rt	Coefficients		**0.2833**	**0.4473**	
		R^2		0.76	0.68	
		AICc		4.25	9.51	
Tropical Species Richness	4rt	Coefficients		**0.4587**	**0.7391**	
		R^2		0.79	0.73	
		AICc		18.27	22.47	
Subtropical Species Richness	4rt	Coefficients		**0.1077**		**0.2122**
		R^2		0.52		0.47
		AICc		-10.02		-0.84
Tropical Abundance	4rt	Coefficients	**0.4638**		**0.6566**	
		R^2	0.74		0.68	
		AICc	18.72		22.14	
Subtropical Abundance	4rt	Coefficients	-0.106			**-0.268**
		R^2	0.18			0.35
		AICc	11.99			8.09
Shannon Diversity	-	Coefficients		**0.4737**	**0.7389**	
		R^2		0.71	0.62	
		AICc		26.05	30.94	
Functional Dispersion	-	Coefficients		**0.0506**		**0.1207**
		R^2		0.37		0.50
		AICc		-25.78		-29.52

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Response & Transformation			PAR		SST		KD490	VAR_Long	VAR_Short	AICc	R2	Weight
			Mean	Min	Mean	Min						
Species Richness	4rt	RVI		**1**	0.11		0.18	0.11	0.09			
		Model average (5)		0.27055	0.09977		-1.68643	0.32474	0.65229	4.3-7.7	0.76-0.78	
		Best model		0.2833						4.3	0.76	0.41
Tropical Species Richness	4rt	RVI		**1**	0.16		0.41	0.06	0.07			
		Model average (6)		0.42029	0.11777		-3.99893	0.23019	2.47695	18.2-22.1	0.79-0.83	
		Best model		0.3908						18.2	0.83	0.29
Subtropical Species Richness	4rt	RVI		0.21		**0.9**	0	0.19	**0.9**			
		Model average (4)		0.02705		0.19989	0	-0.33127	-5.16858	-13.5 to -10	0.52-0.71	
		Best model				0.1894			-4.768	-13.5	0.68	0.41
Tropical Abundance	4rt	RVI	**0.85**		0.25		0.11	0.16	0.09			
		Model average (7)	0.4426		0.4284		-1.843	0.808	-1.5233	18.7-22.5	0.68-0.75	
		Best model	0.4638							18.7	0.74	0.40
Subtropical Abundance	4rt	RVI	0.25			**0.83**	0.21	0.17	0.46			
		Model average (11)	-0.1223			-0.308	-2.7157	0.4172	-6.0965	8.1-12	0.18-0.62	
		Best model				-0.2676				8.1	0.35	0.21
Shannon Diversity	-	RVI		0.11	**1**		0.28	**1**	**0.87**			
		Model average (4)		-0.2143	0.7029		-4.4866	-1.9433	-24.4775	16.8-19.7	0.84-0.91	
		Best model			0.7356			-1.798	-23.55	16.8	0.89	0.43
Functional Dispersion	-	Best model				**0.1197**		**-0.53195**	**-3.92699**	-52.4	0.92	0.80

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Step 3: Sensitivity analysis

Nested selection of SST and PAR parameters resulted in SST_Mean and PAR_Mean being chosen as best predictors of patterns in tropical abundance. Due to high collinearity (spearman rank correlation of 0.88; Table A1) of SST_Mean and PAR_Mean we ran the multiple regression GLMs with all four possible combinations of SST and PAR parameters: PAR_Mean and SST_Mean, PAR_Mean and SST_Min, PAR_Min and SST_Min, and PAR_Min and SST_Mean (Table A5). For all models tested PAR predictors had the highest explanatory power for patterns in tropical abundance (Table A4).

Table A5. Sensitivity analyses for tropical abundance, using all possible combinations of PAR_Mean, PAR_Min, SST_Mean and SST_Mean parameters in conjunction with KD490, SST_Long and SST_Short in multiple regression models, explaining the role of environmental stress in shaping patterns in coral community structure at species southern range margins. See caption of Table A4 for fu rther details.

Response & Transformation			**PAR**		**SST**		**KD490**	**VAR_Long**	**VAR_Short**	**AICc**	**R2**	**Weight**
			Mean	**Min**	**Mean**	**Min**						
Tropical	4rt	RVI	**0.85**		0.25		0.11	0.16	0.09			
Abundance		Model average (7)	0.4426		0.4284		-1.843	0.808	-1.5233	18.7-22.5	0.68-0.75	
		Best model	0.4638							18.7	0.74	0.40
Tropical	4rt	RVI	**1**			0.1	0.13	0.11	0.1			
Abundance		Model average (5)	0.4532			0.0198	-1.84301	0.34273	-1.52331	18.7-22.2	0.74-0.75	
		Best model	0.4638							18.7	0.74	0.46
Tropical	4rt	RVI		**0.94**		1.24	1.36	0.43	0.14			
Abundance		Model average (10)		0.3702		-0.6627	-4.36248	1.58723	6.45346	20.3-24.2	0.71-0.81	
		Best model		0.4011						20.3	0.71	0.17
Tropical	4rt	RVI		**0.86**	0.24		0.25	0.44	0.14			
Abundance		Model average (10)		0.3437	0.4532		-3.7167	1.371	6.4535	20.3-23.7	0.68-0.80	
		Best model		0.4011						20.3	0.71	0.17

Discussion:

The supplementary analyses using nested pre-selection of SST and PAR parameters with highest explanatory power corroborated the results of our analyses using SST_Min and PAR_Min as outlined in the main manuscript. The relative importance of environmental parameters differed for the biodiversity measures tested and for groups of species that varied in their zoogeographic distribution. Gradients in species richness were most closely related to light availability, whereas gradients in Shannon diversity and functional dispersion were mostly related to cold stress and temperature variability.

The analyses presented here also confirm our findings that species differ in their relationship with environmental gradients. Gradients in subtropical species were best explained by minimum temperature and short-term temperature variability, whereas the distribution and abundance of tropical species was most closely linked with light availability. While PAR_Min best explained gradients in tropical species richness, PAR_Mean had highest explanatory power for tropical abundance, highlighting the complexity of species-energy relationships at biogeographic transition zones.

Of all models tested, Shannon diversity was the only biodiversity metric for which SST_Mean had significant explanatory power in this nested approach, along with VAR_Long and VAR_Short (Table A4). This differs slightly from the results in the main manuscript, where SST_Min and VAR_Short best explained gradients in Shannon Diversity (see Table 1 in the main manuscript). Nevertheless, both approaches demonstrate the role of temperature and temperature variability in driving Shannon diversity of corals in this zone of biogeographical overlap.

Individually and in combination, the two modelling approaches demonstrate the role of abiotic stress in structuring coral communities in this biogeographic transition zone and cast doubt on the dominant role of mean temperature in driving biodiversity patterns. Our results therefore highlight the possibility that abiotic stress (i.e. environmental extremes, variability) may be more critical as range-limiting factors for some species in biogeographic transition zones than long-term trends in mean climatic conditions. Due to the principal role of mean temperature in predicting climate change scenarios, this has important implications for the accuracy of the assessment of species vulnerabilities to climate change in predictive modelling and conservation decision-making for biogeographic transition zones.