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Rowell, D.A., Hammerman, N.M., Golding, K.M. et al. (2025) Multi-scale observations during the 2024 mass coral bleaching event on Heron Reef, Australia. Marine Biology, 173. 17. ISSN: 0025-3162

https://doi.org/10.1007/s00227-025-04759-5

Supplementary Material

Title: Multi-scale observations during the 2024 mass coral bleaching event on Heron Reef, Australia; Journal: Marine Biology

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Supplemental Table 1 The location of temperature and light loggers deployed across Heron Reef between August 2023 - June 2024. Note that ElectricBlue EnvLoggers and HOBO® loggers record temperature only, while Odyssey loggers record temperature as well as PAR.

Reef zone	Site name	Latitude and Longitude	Depth (m)	Equipment deployed	Dates deployed	Sampling interval (minutes)
Leeward north	Libby's Lair	23.43453 S, 151.93353 E	10–15	HOBO® TidbiT MX (MX2203)	1/8/2023 to 14/5/2024	15 min
Windward east	Eco 1	23.47193 S, 151.97746 E	4–8	H1, O2	10/12/2023 to 8/6/2024	H1 10 min; O1 15 min
	Eco 1	23.472 S, 151.979317 E	10–14	H1	10/12/2023 to 8/6/2024	10 min
	Eco 2	23.47086 S ,151.95296 E	4–7	O1	13/10/2023 to 8/6/2024	15 min
	Eco 2	23.47083 S, 151.9526 E	9–13	H1	13/10/2023 to 8/6/2024	10 min
Windward west	Coral Gardens	23.44666 S, 151.91176 E	4–8	H1, O1	14/10/2023 to 11/6/2024	H1 10 min; O1 15 min
	Coral Gardens	23.44664 S, 151.91139 E	9–13	H1 (x2)	14/10/2023 to 11/6/2024	10 min

Reef zone	Site name	Latitude and Longitude	Depth (m)	Equipment deployed	Dates deployed	Sampling interval (minutes)
	Halfway Site 1	23.45042 S, 151.91724 E	4–8	O1 (x2)	16/10/2023 to 14/6/2024	15 min
	Halfway Site 1	23.45023 S, 151.91698 E	9–13	H1, O1	16/10/2023 to 14/6/2024	H1 10 min; O1 15 min
Reef Flat	Coral Gardens reef flat	23.4452 S, 151.91268 E	1–2	H1, O1	15/10/2023 to 14/6/2024	H1 10 min; O1 15 min
	Halfway reef flat	23.44841 S, 151.91821 E	1–2	H1	14/10/2023 to 14/6/2024	10 min
	Reef crest	23.4589 S, 151.9296 E	0.8	HOBO® 64K Pendant (UA-001-64)	1/8/2023 to 7/5/2024	60 min
	Research Beach - nearshore (#2)	23.44447 S, 151.91341 E	1–2	ElectricBlue EnvLogger (version T7.3)	13/12 2023 to 31/7/2024	60 min
	Research Beach - offshore (#3)	23.44552 S, 151.91311 E	1–2	ElectricBlue EnvLogger (version T7.3)	13/12 2023 to 31/7/2024	60 min
	North Beach - nearshore (#4)	23.43958 S, 151.91722 E	1–2	ElectricBlue EnvLogger (version T7.3)	13/12 2023 to 31/7/2024	60 min
	North Beach - offshore (#5)	23.43811 S, 151.91744 E	1–2	ElectricBlue EnvLogger (version T7.3)	13/12 2023 to 29/6/2024	60 min
	Shark Bay (#6)	23.44305 S, 151.92055 E	1–2	ElectricBlue EnvLogger (version T7.3)	13/12 2023 to 31/7/2024	60 min

H1 = HOBO® Pendant Mx Temperature/light Data Logger - IC-MX2202 (Bluetooth model)

O1 = Odyssey® Submersible Photosynthetic Active Radiation (PAR) Logger

Supplemental Table 2 The location of ecological data collection sites across Heron Reef between September 2022 - September 2024. Note that coordinates for photo quadrat transects are at the start of each transect.

Ecological Scale	Analysis	Geomorphic Zone	Site Name	Latitude	Longitude	Depth (m)	Time Period
Community	Photo quadrat transects	Leeward North Slope	Junction	-23.43534	151.90776	5	23/03/2024 - 27/03/2024
Community	Photo quadrat transects	Leeward North Slope	Plate Ledge	-23.43448	151.91478	5	23/03/2024 - 27/03/2025
Community	Photo quadrat transects	Leeward North Slope	Coral Grotto	-23.43392	151.92148	5	23/03/2024 - 27/03/2026
Community	Photo quadrat transects	Leeward North Slope	Cascades	-23.43335	151.93030	5	23/03/2024 - 27/03/2027
Community	Photo quadrat transects	Leeward North Slope	Libby's Lair	-23.43531	151.94222	5	23/03/2024 - 27/03/2028
Community	Photo quadrat transects	Leeward North Slope	NWTR7	-23.42922	151.95096	5	23/03/2024 - 27/03/2029
Community	Photo quadrat transects	Leeward North Slope	NWTR6	-23.43338	151.96100	5	23/03/2024 - 27/03/2030
Community	Photo quadrat transects	Leeward North Slope	NETR5	-23.43189	151.98615	5	23/03/2024 - 27/03/2031
Community	Photo quadrat transects	Windward West Slope	NETR4	-23.42959	151.99692	5	23/03/2024 - 27/03/2032
Community	Photo quadrat transects	Windward West Slope	SETR3	-23.45677	151.99469	5	23/03/2024 - 27/03/2033
Community	Photo quadrat transects	Windward West Slope	SETR2	-23.46758	151.98650	5	23/03/2024 - 27/03/2034
Community	Photo quadrat transects	Windward West Slope	SETR1	-23.47281	151.97134	5	23/03/2024 - 27/03/2035
Community	Photo quadrat transects	Windward West Slope	SETR0	-23.47034	151.94987	5	23/03/2024 - 27/03/2036
Community	Photo quadrat transects	Windward East Slope	Harry's Bommie	-23.46044	151.92997	5	23/03/2024 - 27/03/2037
Community	Photo quadrat transects	Windward East Slope	Coral Canyons	-23.45369	151.92227	5	23/03/2024 - 27/03/2038
Community	Photo quadrat transects	Windward East Slope	Halfway	-23.44928	151.91516	5	23/03/2024 - 27/03/2039
Community	Photo quadrat transects	Windward East Slope	Coral Gardens	-23.44621	151.91085	5	23/03/2024 - 27/03/2040
Community	Photo quadrat transects	Windward East Slope	Heron Bommie	-23.44208	151.90537	5	23/03/2024 - 27/03/2041

Community	Photo quadrat transects	Reef Flat	RF Blue Pools	-23.44271	151.91950	1-2	23/03/2024 - 27/03/2042
Community	Photo quadrat transects	Reef Flat	RF Research Beach	-23.44253	151.91100	1-2	23/03/2024 - 27/03/2043
Community	Photo quadrat transects	Reef Flat	RF West	-23.44141	151.91125	1-2	23/03/2024 - 27/03/2044
Colony	Coral demography plots	Leeward North Slope	Libby's Lair	-23.43458	151.93364	6-8	13/09/2022; 14/09/2023; 10/09/2024
Colony	Coral demography plots	Windward West Slope	Coral Gardens	-23.44729	151.91197	6-8	14/09/2022; 13/09/2023; 08/09/2024
Colony	Different substrate types	Windward West Slope	Halfway Interlocked	-23.44985	151.91723	8-10	18/02/2024 - 5/3/2024
Colony	Different substrate types	Windward West Slope	Halfway Loose	-23.45025	151.91725	8-10	18/02/2024 - 5/3/2024
Colony	Different substrate types	Windward West Slope	Halfway Hard Carbonate	-23.45043	151.91783	8-10	18/02/2024 - 5/3/2024
Colony	Juvenile coral quadrats	Windward West Slope	Site 1: Halfway	-23.4511	151.91818	8-10	14/02/2024 - 15/2/2024
Colony	Juvenile coral quadrats	Windward West Slope	Site 2: Halfway	-23.45239	151.9201	8-10	14/02/2024 - 15/2/2024
Colony	Coral fragments collection	Leeward North Slope	Libby’s Lair	151.93645	-23.43528	5-12	7/02/2024
Colony	Coral fragments collection	Leeward North Slope	BA1	151.95106	-23.42804	5-12	5/02/2024
Colony	Coral fragments collection	Leeward North Slope	BA2	151.92026	-23.43407	5-12	5/02/2024
Colony	Coral fragments collection	Windward East Slope	H5B	151.99738	-23.43217	5-12	3/02/2024
Colony	Coral fragments collection	Windward East Slope	H5A	151.99555	-23.4526	5-12	3/02/2024
Colony	Coral fragments collection	Windward East Slope	FR1	151.97793	-23.47209	5-12	4/02/2024
Colony	Coral fragments collection	Windward East Slope	FR2	151.95106	-23.47082	5-12	4/02/2024
Colony	Coral fragments collection	Windward West Slope	FL1	151.92568	-23.45617	5-12	6/02/2024
Colony	Coral fragments collection	Windward West Slope	Coral Gardens	151.9106	-23.44570	5-12	6/02/2024
Colony	Coral fragments collection	Windward West Slope	Heron Bommie	151.90358	-23.44094	5-12	7/02/2024

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Supplemental Table 3 ReefCloud label set used to classify benthic cover within photo quadrats, including the hard coral bleaching status and morphotype used for the analyses in this paper. Within ReefCloud, 50 random points were overlaid onto each photo quadrat and assigned a benthic classification by the machine (F1 > 0.8), typically down to morphotype or family level (Roelfsema et al. 2021; Supplementary Table 2). Training points were only annotated as bleached if the coral was distinctly white or fluorescent, to avoid model confusion between bleaching and healthy pale morphs.

Broad Category	ReefCloud Label	Hard Coral Bleaching Status	Hard Coral Morphotype
Hard coral	*Acropora* Branching	Not Bleached	Branching
	Acropora Branching Bleached	Bleached	Branching
	Acropora Digitate	Not Bleached	Branching
	Acropora Digitate Bleached	Bleached	Branching
	Acropora Hispidose	Not Bleached	Branching
	Acropora Hispidose Bleached	Bleached	Branching
	Acropora Other (*Isopora*)	Not Bleached	Branching
	Acropora Other Bleached	Bleached	Branching
	Pocillopora	Not Bleached	Branching
	Pocillopora Bleached	Bleached	Branching
	Porites Branching	Not Bleached	Branching
	Porites Branching Bleached	Bleached	Branching
	Branching Other	Not Bleached	Branching
	Branching Other Bleached	Bleached	Branching
	Favid Mussid	Not Bleached	Massive
	Favid Mussid Bleached	Bleached	Massive
	Porites Massive	Not Bleached	Massive
	Porites Massive Bleached	Bleached	Massive
	Massive Other	Not Bleached	Massive
	Massive Other Bleached	Bleached	Massive
	Acropora Tabulate and Corymbose	Not Bleached	Plate/Encrusting
	Acropora Tabulate and Corymbose Bleached	Bleached	Plate/Encrusting
	Acroporidae Plate Encrusting (*Montipora*)	Not Bleached	Plate/Encrusting
	Acroporidae Plate Encrusting Bleached	Bleached	Plate/Encrusting
	Foliose or Plate with ridges	Not Bleached	Plate/Encrusting
	Foliose or Plate with ridges Bleached	Bleached	Plate/Encrusting
	Foliose or Plate with round corallites	Not Bleached	Plate/Encrusting
	Foliose or Plate with round corallites Bleached	Bleached	Plate/Encrusting
	Porites Encrusting	Not Bleached	Plate/Encrusting
	Porites Encrusting Bleached	Bleached	Plate/Encrusting
	Solitary coral	Not Bleached	-
	Solitary coral Bleached	Bleached	-
Soft Coral	Alcyoniidae Soft Coral	-	-
	Alcyoniidae Soft Coral Bleached	-	-
	Gorgonian	-	-
	Gorgonian Bleached	-	-
	Soft Coral Other	-	-

	Soft Coral Bleached	-	-
Other Invertebrates	Sessile Invertebrate Other	-	-
	Crown of Thorns Sea Star	-	-
	Mobile Invertebrate	-	-
Algae	BMA Sand	-	-
	Caulerpa	-	-
	Chlorodesmis	-	-
	Crustose Coralline Algae on DHC	-	-
	Crustose Coralline Algae on Rubble	-	-
	Dictyota species	-	-
	Epithelial Algal Matrix on DHC	-	-
	Epithelial Algal Matrix on Rubble	-	-
	Halimeda	-	-
	Lobophora Species	-	-
	Padina	-	-
	Sargassum	-	-
	Turbinaria algae	-	-
	Algae Other	-	-
Cyanobacteria	Cyano species	-	-
Seagrass	Seagrass	-	-
Abiotic Cover	Sand	-	-
Other	Transect gear	-	-
	Unclear	-	-
	Unknown	-	-
	Water	-	-
	All Other	-	-

Supplemental Table 4 Genera that were recorded and grouped into Merulinidae and Pocilloporidae for coral demography plot analyses.

Merulinidae	**Pocilloporidae**
Astrea	*Pocillopora*
Cyphastrea	*Seriatopora*
Dipsastraea	*Stylophora*
Echinopora	
Favites	
Goniastrea	
Hydnophora	
Leptoria	
Merulina	
Mycedium	
Oulophyllia	
Platygyra	

The CoralWatch program has historically relied upon changes to average colour scores as an indicator of potential bleaching events (Figure S6 and Table S5). However, data collected during the 2024 mass bleaching event at Heron Island revealed that this metric is insufficient when used on its own to signal bleaching events to citizen scientists. A chi-squared test found statistically significant differences in the frequency distribution of colour scores before and during the bleaching event across all zones (p-value < 0.001; Table S6; Presented in Manuscript Section 3.2.2). We then tested the difference between the average colour scores across each of the four zones before and after the bleaching with a Welch's t-test. The differences between average colour scores were only significant in the Leeward North and Reef Flat zones (p-value < 0.001 and p-value = 0.004, respectively; Table S5).

Coral species exhibit varying levels of susceptibility and resilience to thermal stress, leading to significant differences in colour as they enter and recover from a bleaching event. As a result, averaging colour scores across a coral colony, and across surveys can produce a deceptively high overall score, which obscures the fine-scale differences in coral colour during the progression of bleaching. Due to variation in coral colour when entering and recovering from bleaching events, average colour scores recorded during the bleaching event remained high (Table S5). This limitation meant that bleaching events could only be identified after a substantial number of corals had already become fully bleached. As a result of these findings, the approach to recording and reporting bleaching events in the CoralWatch global coral health database has been improved and now incorporates changes to the frequency distribution of recorded colour scores to assist in the early detection and communication of bleaching events.

Supplemental Table 5 Average CoralWatch colour scores calculated across the four reef zones before and during the 2024 mass bleaching event. Due to variation in coral colour when entering and recovering from bleaching events, average colour scores recorded during the bleaching event remained high. *Indicates statistical significance at p = <0.005.

	Before				During				Welch's t-test		
Zone	**Ave. colour score**	**Min**	**Max**	**SE**	**Ave. colour score**	**Min**	**Max**	**SE**	**t**	**df**	**p**
Leeward north	3.05	1	6	0.05	2.68	1	6	0.04	5.65	668.25	2.35E-08*
Windward west	2.97	1.5	5.5	0.05	3.03	1	6	0.07	-0.73	504.26	0.468
Windward east	2.62	2	5	0.11	2.44	1	4.5	0.1	1.23	110.87	0.221
Reef flat	3.34	1	5.5	0.03	3.18	1	6	0.05	2.89	860.77	0.004*

Supplemental Table 6 Chi-squared test results comparing the frequency distribution of colour scores before and during the bleaching event for each of the four Heron Reef zones.

Zone	X-Squared	P
Leeward north	140.72	< 2.2e-16
Windward west	196.5	< 2.2e-16
Windward east	63.151	2.71E-12
Reef flat	145.11	< 2.2e-16

Supplemental Table 7 Summary statistics of log coral size ratio (log_2(new size/old size)) across two sites before (2022-23) and after (2023-24) the bleaching event (time period). n is the number of corals recorded.

Site	Time period	n	mean	sd	min	Q1	median	Q3	max
Coral Gardens	2022-23	104	-0.259	1.677	-6.567	-0.764	0.135	0.574	4.100
	2023-24	39	-0.653	1.4	-4.826	-1.249	-0.237	0.101	1.964
Libby's Lair	2022-23	233	0.084	1.164	-5.997	-0.412	0.068	0.588	3.495
	2023-24	99	-0.548	1.0	-4.739	-0.943	-0.399	0.184	0.976

Supplemental Table 8 Summary statistics of log coral size ratio (log_2(new size/old size)) across the four most abundant taxa groups before (2022-23) and after (2023-24) the bleaching event (time period). n is the number of corals recorded.

Taxa	Time period	n	mean	sd	min	Q1	median	Q3	max
Acropora	2022-23	137	0.170	1.415	-6.567	-0.437	0.088	0.698	3.495
	2023-24	53	-0.531	1.201	-4.500	-1.126	-0.375	0.323	1.954
Merulinidae	2022-23	65	-0.112	0.503	-1.619	-0.406	-0.078	0.173	0.969
	2023-24	42	-0.626	0.989	-4.739	-1.094	-0.500	-0.050	0.778
Montipora	2022-23	52	-0.249	1.147	-3.321	-0.776	0.106	0.570	1.317
	2023-24	17	-0.972	1.468	-4.826	-1.343	-0.417	0.024	0.462
Pocilloporidae	2022-23	55	0.110	1.827	-5.997	-0.394	0.515	1.060	4.100
	2023-24	7	-0.264	0.645	-1.310	-0.586	-0.057	0.156	0.381

Supplemental Table 9 Post-hoc Dunn's test statistics for pair-wise comparisons of log_2(new size/old size) across the four most abundant taxa groups before (2022-23) the bleaching event. Log size ratio differences across taxa were not significant at 95% significance level.

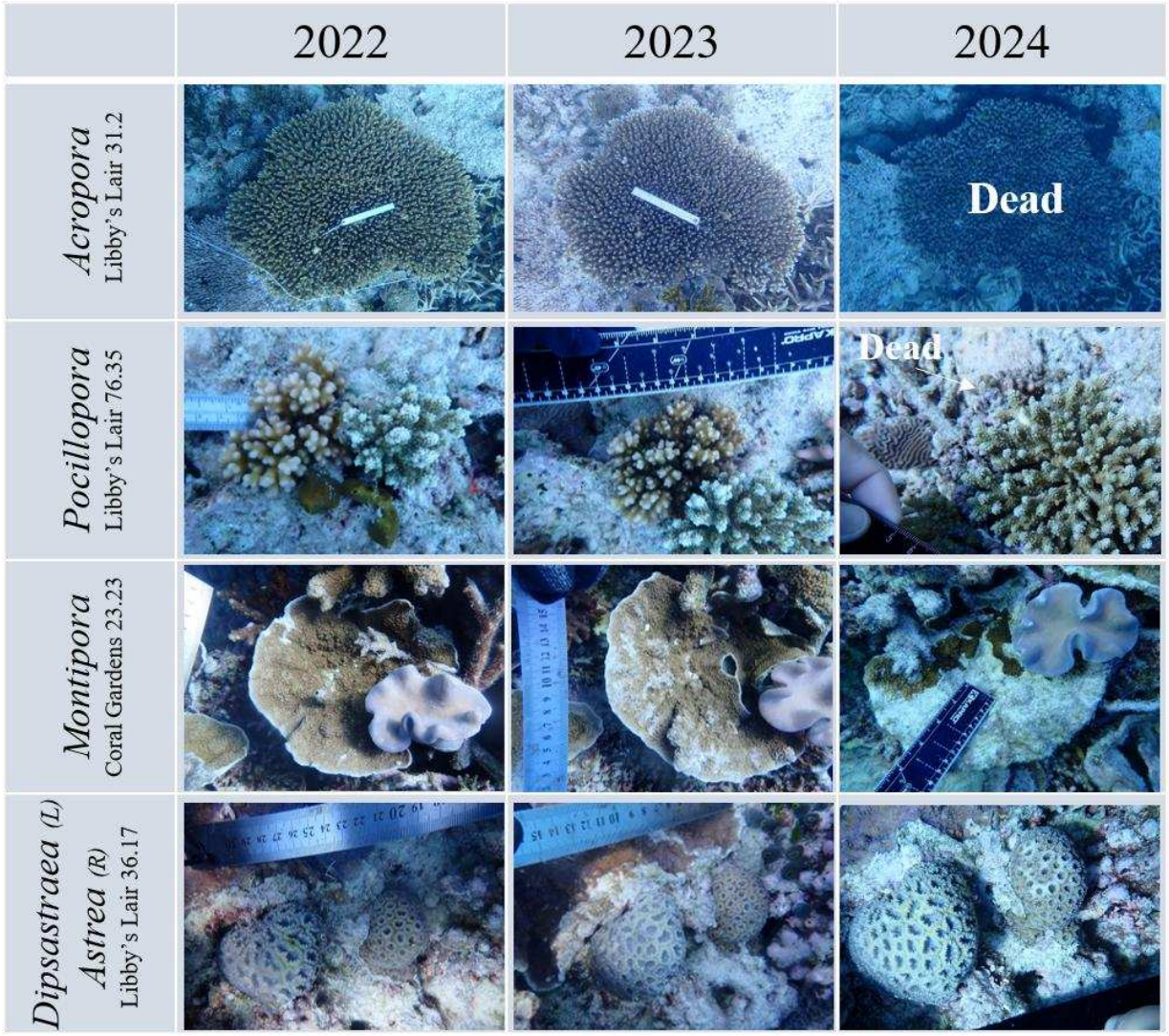
Comparison	Z	P unadjusted	P adjusted
Acropora-Merulinidae	1.90	0.057	0.342
Acropora-*Montipora*	1.04	0.297	1.00
Merulinidae-*Montipora*	-0.588	0.556	1.00
Acropora-Pocilloporidae	-0.998	0.319	1.00
Merulinidae-Pocilloporidae	-2.36	0.018	0.109
Montipora-Pocilloporidae	-1.68	0.093	0.560

Supplemental Table 10 Conditional odds ratios (using the R function 'odds.ratio()') of mortality by site (Libby's Lair and Coral Gardens) and by taxa (*Acropora*, Merulinidae, *Montipora,* and Pocilloporidae).

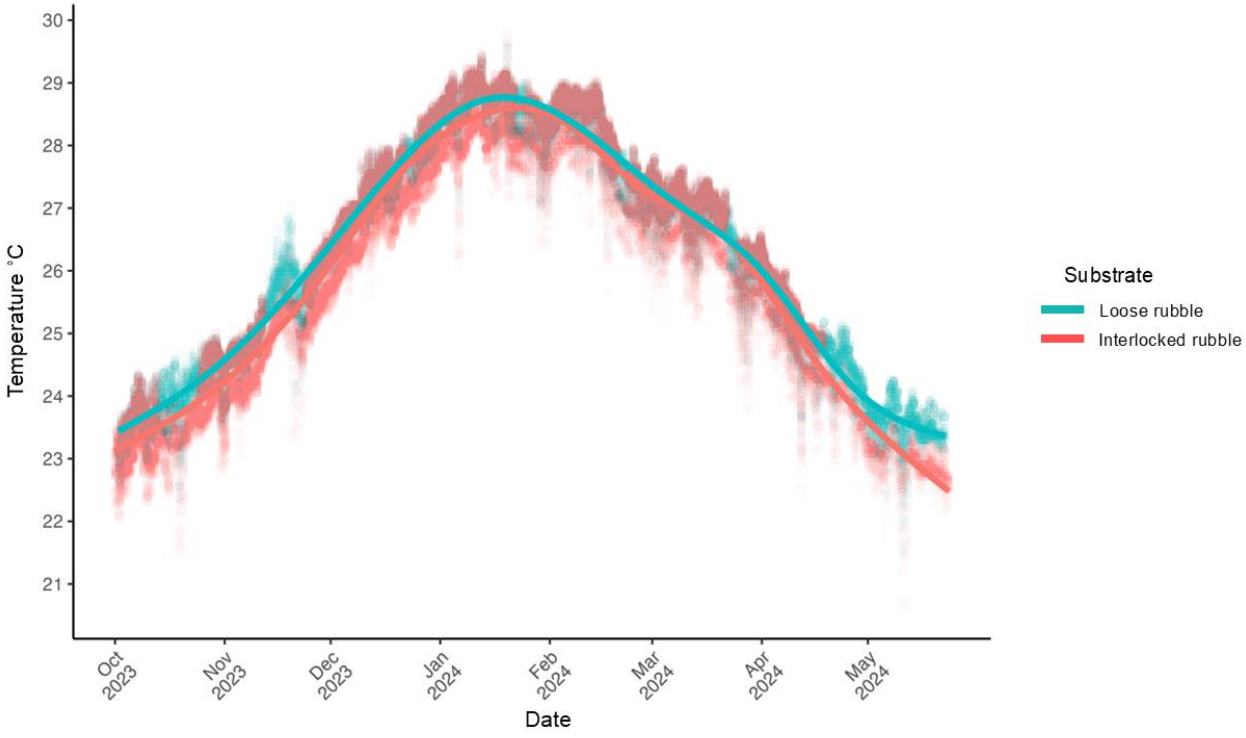
		Conditional odds ratio
Site	Libby's Lair	3.50
	Coral Gardens	5.66
Taxa	Acropora	4.38
	Merulinidae	2.54
	Montipora	7.31
	Pocilloporidae	16.1

Supplemental Table 11 PERMANOVA results from coral morphotype community composition analysis between substrates (loose rubble beds vs. interlocked rubble beds vs. hard carbonate plots).

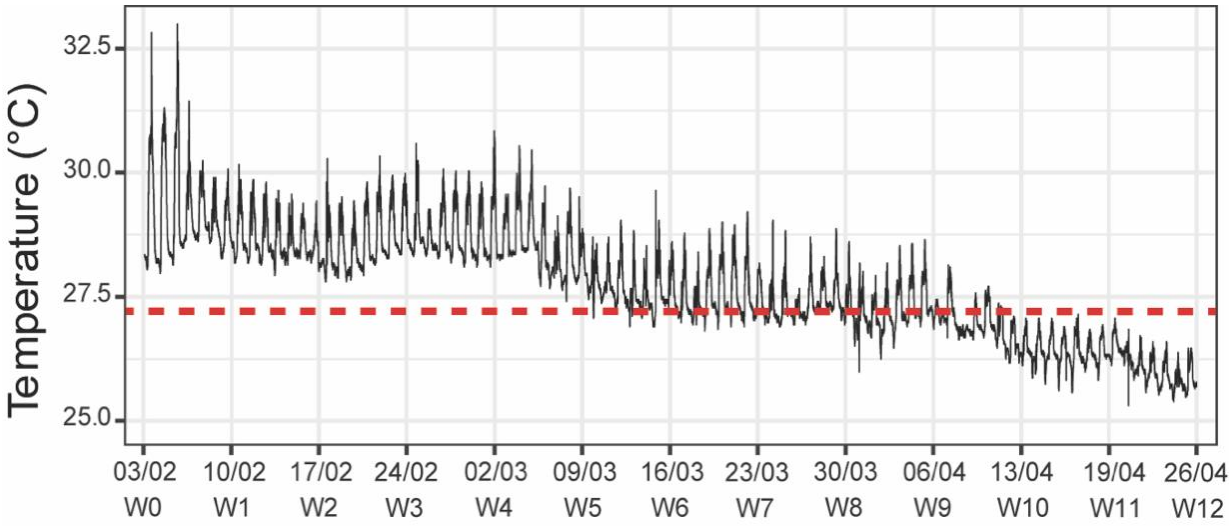
Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Substrate	2	3668.6	1834.3	3.0269	0.067	999
Site	5	2969.8	593.97	1.1304	0.326	998
Res	41	21544	525.45			
Total	48	28182				



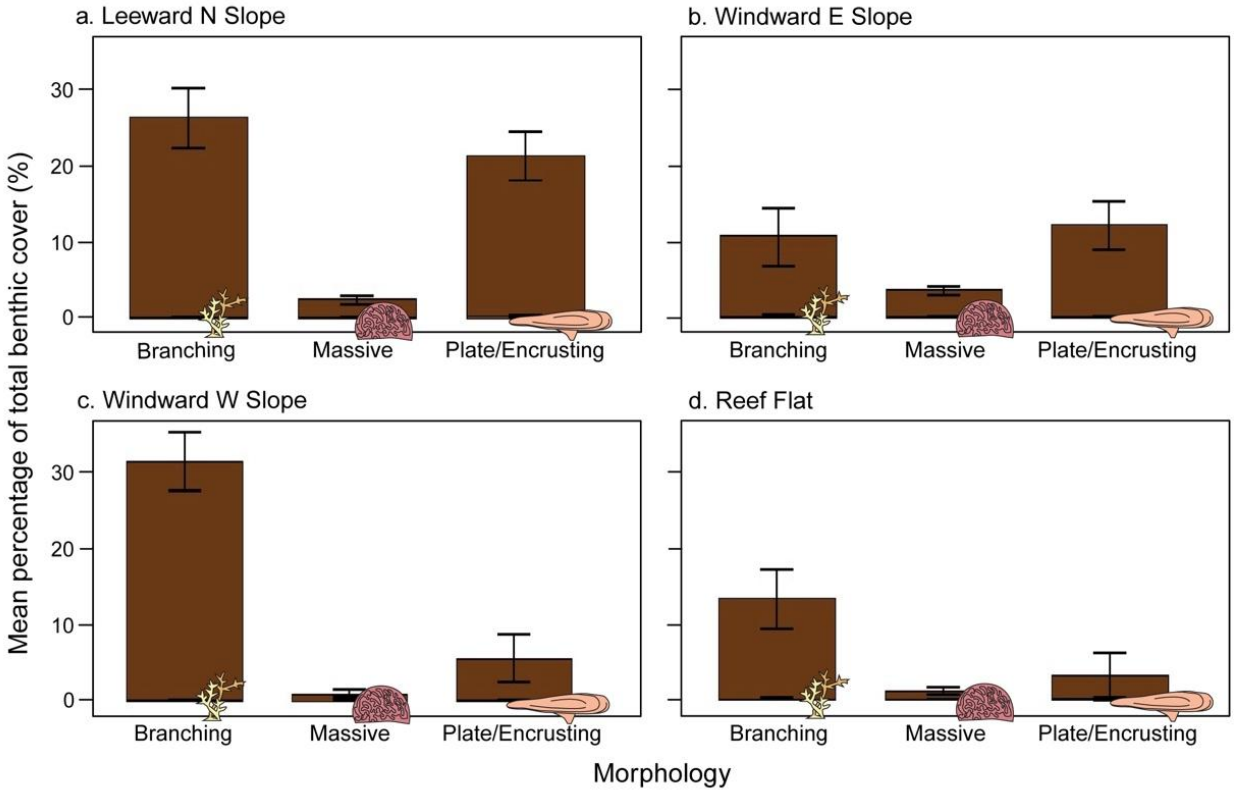
Supplemental Figure 1 Images showing the trajectories of five focal coral colonies from 2022 to 2024. The *Acropora*, *Pocillopora* and *Dipsastraea,* and *Astrea* colonies were from Libby's Lair, while the *Montipora* colony is from Coral Gardens. All photos by Fiona Chong or Victoria Hsiao.



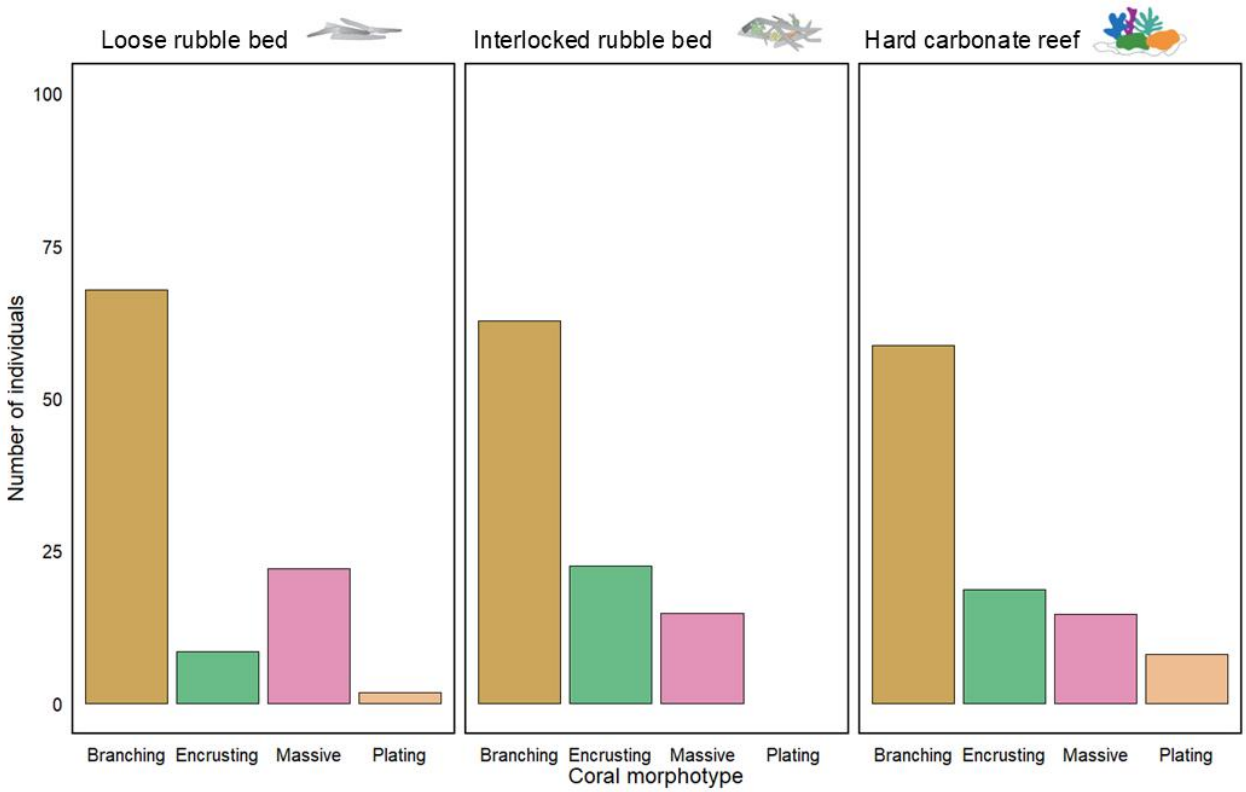
Supplemental Figure 2 Mean daily temperature (˚C) from October 2023 through May 2024 in the loose and interlocked rubble bed plots on the windward west slope.



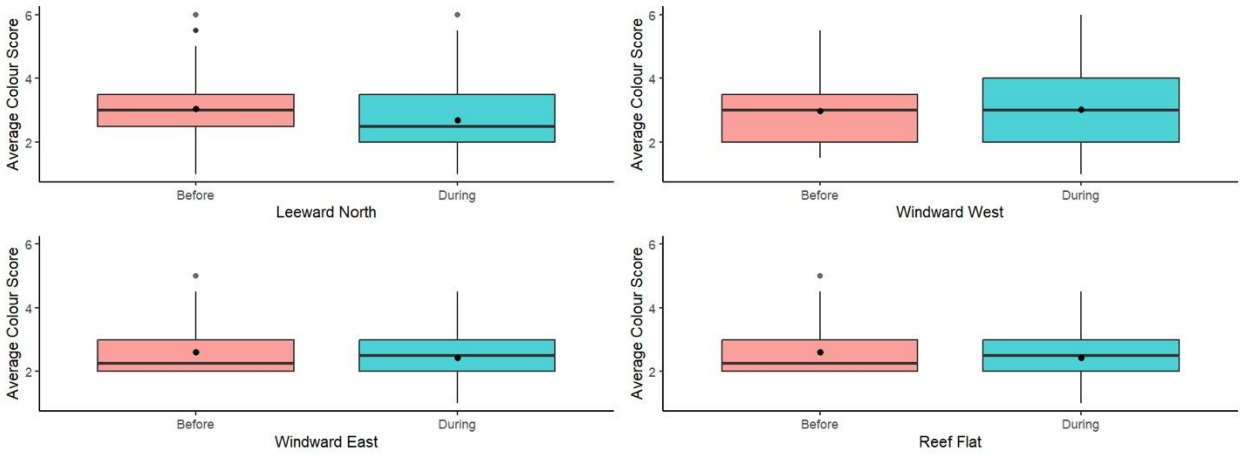
Supplemental Figure 3 Temperature profile in the common garden experiment, following the concurrent heatwave. Week 0 (W0) to Week 12 (W12) represent the time points at which phenotypic measurements were taken. Vertical grid lines are separated by one week and the red dashed line represents the climatic maximum monthly mean at Heron Reef (27.3°C).



Supplemental Figure 4 Mean percentage of total benthic cover (% ± standard error) of live hard coral prior to the bleaching event, for three hard coral morphotypes (branching, massive, plate/encrusting), within each of four geomorphic zones (panels a - d) on Heron Reef in November 2023. The slope was surveyed at ~5 m depth and the reef flat at 1-2 m depth. Refer to Figure 1b for the location of each zone. Data from Carrasco Rivera et al. (2025).



Supplemental Figure 5 Number of individual corals per coral morphotype (branching, encrusting, massive, plating) in the three substrate typologies studied (hard carbonate, loose, or interlocked rubble beds) on the windward west slope during the bleaching event (February 2024).



Supplemental Figure 6 Average colour scores (± SE) of coral colonies before and during the bleaching event across four reef zones (leeward north, windward west, windward east, and reef flat).

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