

Electronic supplementary material (ESM) accompanying the manuscript:

Back-to-back bleaching in Peninsular Malaysia (2019-2020) selectively affect hard coral taxa across- and within-reef scales

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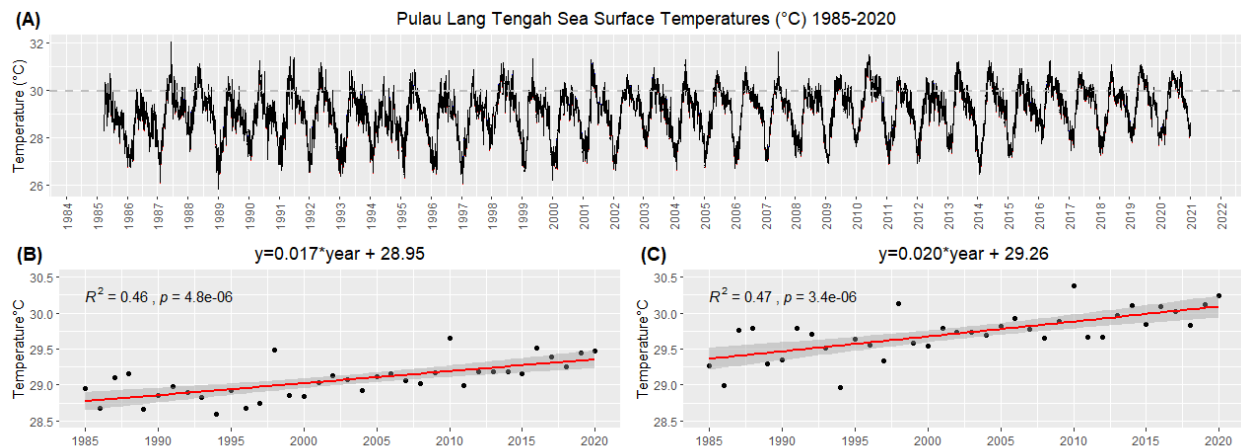
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ESM 1 | Nightly satellite measurements of sea surface temperatures (SST°C) around Pulau Lang Tengah between April 1985 and December 2020. The grey dotted line shows the maximum monthly mean (MMM=29.94°C) based on historical satellite measurements (A) by the National Oceanic and Atmospheric Association (NOAA), Coral Reef Watch (CRW) product, version 3.1. Linear regressions of mean annual sea surface temperatures (B) and mean bleaching season (April to September) sea surface temperatures (C) around Pulau Lang Tengah are shown. The regression line illustrates the warming trend since 1985, and the regression equation establishes average warming rates per year.

ESM 2 | Date of *in situ* benthic surveys and peak heat stress (i.e., max Degree Heating Week). Survey sites included BB-Batu Bulan; HR- House Reef; SR-Secret Reef; TT-Tanjung Telunjuk. nDHW-Degree Heating Weeks (°C-weeks). Note, site-specific nDHW in 2019 was not measured *in situ* (all values shown for 2019 are based on remotely sensed data on 5km² reef-scale), and *in situ* temperature data is not available for BB (values shown are based on remotely sensed satellite data on 5km² reef-scale).

Year	Site	Date of survey	nDHW on date of survey	Date of max nDHW	max nDHW (method - scale)
2019	BB	24.06.2019	6.47°C-weeks	19.06.2019	6.68°C-weeks (satellite - island)
	HR	13.06.2019	6.56°C-weeks	19.06.2019	6.68°C-weeks (satellite - island)
	SR	18.06.2019	6.64°C-weeks	19.06.2019	6.68°C-weeks (satellite - island)
	TT	23.06.2019	6.51°C-weeks	19.06.2019	6.68°C-weeks (satellite - island)
2019	BB	17.10.2023	0°C-weeks	-	0°C-weeks (satellite - island)
	HR	10.10.2023	0°C-weeks	-	0°C-weeks (satellite - island)
	SR	19.10.2023	0°C-weeks	-	0°C-weeks (satellite - island)
	TT	15.10.2019	0°C-weeks	-	0°C-weeks (satellite - island)
2020	BB	30.04.2020	0°C-weeks	-	0°C-weeks (satellite - island)
	HR	10.04.2020	0°C-weeks	-	0°C-weeks (satellite - island)
	SR	13.04.2020	0°C-weeks	-	0°C-weeks (satellite - island)
	TT	29.04.2020	0°C-weeks	-	0°C-weeks (satellite - island)
2020	BB	29.06.2020	4.48°C-weeks	07.07.2020	4.88°C-weeks (in situ - island)
	HR	02.07.2020	5.09°C-weeks	17.07.2020	5.44°C-weeks (in situ - reef)
	SR	01.07.2020	5.03°C-weeks	17.07.2020	5.44°C-weeks (in situ - reef)
	TT	30.06.2020	4.20°C-weeks	07.07.2020	4.47°C-weeks (in situ – reef)

ESM 3 | Pearson correlation of *in situ* temperature data (recorded at 8 meters water depth) and satellite sea surface temperature data by the National Oceanic and Atmospheric Association (NOAA), Coral Reef Watch (CRW) product, version 3.1. Temperature data sets were averaged and compared based on seasons where the ‘bleaching season’ is between April and September 2020, the ‘summer season’ is between May and July 2020, the ‘monsoon season’ is between October 2019 and March 2020, and the full time series is based on data between the September 2019 and September 2020.

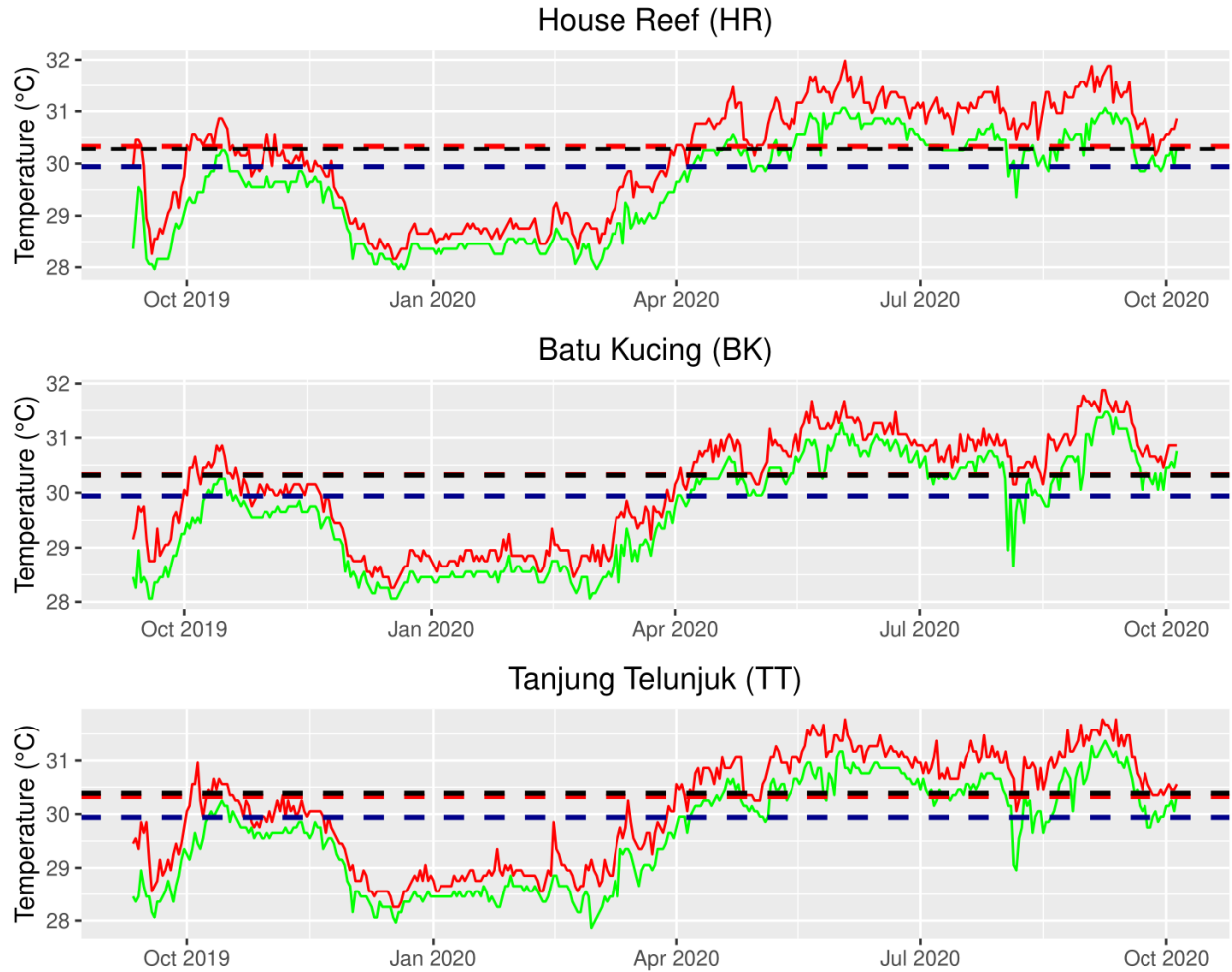
Time series	Pearson (r)	df	p	Mean NOAA	Mean <i>in situ</i>
Full time series	0.97	383	1.64E-230	29.45	29.98
Monsoon season	0.95	181	2.29E-97	28.71	29.19
Bleaching season	0.76	181	9.15E-36	30.24	30.86
Summer season	0.78	90	5.02E-20	30.39	31.00

ESM 4 | *In situ* adjusted Degree Heating Weeks values for 2020, specific to each site: HR – House Reef (leeward); BK – Batu Kucing (windward); TT – Tanjung Telunjuk (windward). avgDHW – average Degree Heating Weeks; maxDHW – maximum Degree Heating Weeks; BS – bleaching season (April to September); SS – Summer Season (May to July); max DHW date – date when the maximum DHW value was recorded for each year, respectively.

	All	HR	BK	TT
avg DHW BS	2.89	2.00	2.91	1.31
avg DHW SS	3.30	3.42	3.40	3.11
max DHW	5.08	5.27	5.20	4.79
max DHW date	07.07.20	08.07.20	07.07.20	07.07.20

ESM 5 | High-frequency diel temperature variations are presented as average daily (24h) temperature ranges (DTR) recorded at Pulau Lang Tengah at three logging stations at 8 meters of water depth. Here, House Reef (HR) is leeward, Batu Kucing (BK) and Tanjung Telunjuk (TT) are windward. All loggers recorded at an interval of 90 minutes. DTR time series include: (DTR_{Total}: September 12th, 2019, to September 30th, 2020), bleaching season (DTR_{BS}: April 1st to September 30th, 2020), peak summer season (DTR_{SS}: May 1st -July 1st, 2020), monsoon season (DTR_{MS}: October 1st -March 30th), and for the 60- and 90-day period preceding the first bleaching observation in 2020 (June 20th, 2020), respectively (DTR₆₀ and DTR₉₀). A non-parametric Kruskal-Wallis test was used to investigate seasonal differences in DTR distribution across sites. Letters indicate pairwise differences among sites after Nemenyi's post hoc test.

	Site			Kruskal-Wallis	
	HR	BK 1	TT 1	H	p
DTR _{Total}	0.55 ^a	0.44 ^b	0.48 ^c	81.32	4.38E-10
DTR _{BS}	0.65 ^a	0.45 ^b	0.53 ^c	43.10	2.19E-18
DTR _{SS}	0.61 ^a	0.39 ^b	0.49 ^c	57.62	3.07E-13
DTR _{MS}	0.43 ^a	0.39 ^a	0.41 ^a	1.18	ns
DTR ₆₀	0.59 ^a	0.41 ^{bc}	0.50 ^{bc}	19.93	4.71E-05
DTR ₉₀	0.58 ^a	0.41 ^b	0.50 ^c	7.91	0.019179



ESM 6 | Diel temperature profiles at three sites around Pulau Lang Tengah, Malaysia. The blue dotted line presents the maximum monthly mean (MMM=29.94°C) based on the National Oceanic and Atmospheric Association (NOAA), Coral Reef Watch (CRW) product, version 3.1, and the red dotted line presents the *in-situ* MMM (30.33°C) after interpolating satellite data with *in-situ* measurements. The dotted black line shows the site-specific *in-situ* MMM after interpolation (MMM HR=30.28°C, MMM BK=30.32°C, MMM TT=30.39°C). Green and red trend lines show daily minimum and maximum temperatures, respectively.

ESM 7 | ‘Best fit’ generalized linear model for the 15 morpho-taxa with significant bleaching response and a sample size $\geq$ ten observations. IE (%) – independent effect value that accounts for the explained variance by each explanatory variable. DHW – Degree Heating Weeks; WW- windward. Grey shading highlights significant results.

Morpho-taxon	Variable	Estimate	SE	z value	Pr(> z)	IE (%)
<i>Acropora hispidose</i>	(Intercept)	-46.12	7327.37	-0.006	9.95E-01	-
AICc - 26.88	Depth Shallow	24.64	6764.53	0.004	0.997	8.80
	max nDHW (6.68)	25.69	2816.29	0.009	0.993	91.20
<i>Cyphastrea</i> encrusting	(Intercept)	-1.4469	0.5557	-2.604	0.00922	-
AICc - 48.15	max nDHW (6.68)	2.2201	0.7432	2.987	0.00282	100.00
<i>Echinopora</i> branching	(Intercept)	-21.55	4432.59	-0.005	0.996	-
AICc - 26.35	max nDHW (6.68)	20.85	4432.59	0.005	0.0231	100.00
<i>Favites</i> encrusting	(Intercept)	-0.7802	0.3641	-2.143	0.03214	-
AICc - 97.59	max nDHW (6.68)	1.3192	0.4957	2.661	0.00778	100.00
<i>Fungia</i> solitary	(Intercept)	-1.0198	0.2164	-4.713	2.44E-06	-
AICc - 214.91	Wind WW	-2.8078	0.539	-5.209	1.90E-07	0.60
	max nDHW (6.68)	3.4969	0.4197	8.331	< 2e-16	99.40
<i>Goniastrea</i> encrusting	(Intercept)	-0.6592	0.318	-2.073	0.038187	-
AICc - 114.45	max nDHW (6.68)	1.7579	0.4607	3.815	0.000136	100.00
<i>Heliopora coerulea</i>	(Intercept)	-0.9204	0.287	-3.207	0.00134	-
AICc - 176.56	Depth (shallow)	3.4741	0.6358	5.464	4.65E-08	71.42
	max nDHW (6.68)	1.7649	0.3839	4.597	4.28E-06	28.58
<i>Montipora</i> encrusting	(Intercept)	0.000	1.4142	0.000	1.000	-
AICc - 33.967	Depth (shallow)	-13863	1.8028	-0.769	0.442	8.34
	max nDHW (6.68)	0.9808	1.2360	0.794	0.427	91.66
<i>Pavona</i> foliose	(Intercept)	1.6393	0.3030	5.410	6.29E-08	-
AICc - 253.74	Depth Shallow	-2.2950	0.3414	-6.722	1.798E-11	57.63
	Wind WW	-3.5291	0.8037	-4.392	1.12E-05	37.61
	max nDHW (6.68)	0.7761	0.3198	2.427	0.0152	4.76
<i>Platygyra</i> encrusting	(Intercept)	-1.0116	0.5839	-1.73	0.0832	-
AICc - 48.318	Depth Shallow	1.4171	0.7411	1.912	0.0559	100.00
<i>Platygyra</i> submassive	(Intercept)	-0.1793	0.294	-0.61	0.54196	-
AICc - 165.7	Depth Shallow	0.8861	0.3862	2.295	0.02175	37.51
	max nDHW (6.68)	1.1886	0.4135	2.875	0.00405	62.49
<i>Pocillopora</i> spp.	(Intercept)	-1.9496	0.5578	-3.495	0.000474	-
AICc - 79.00	Wind WW	1.9222	0.6122	3.14	0.00169	70.22
	max nDHW (6.68)	1.0924	0.5747	1.901	0.057298	29.78
<i>Porites</i> encrusting	(Intercept)	-0.9753	0.3799	-2.567	0.01025	-
AICc - 127.28	Depth Shallow	-1.3351	0.4775	-2.796	0.00517	80.04
	max nDHW (6.68)	2.266	0.4725	4.796	1.62E-06	19.96
<i>Porites</i> massive	(Intercept)	1.2536	0.385	3.256	0.00113	-
AICc - 418.33	Wind WW	-1.0881	0.3605	-3.018	0.00254	9.26

<i>Porites</i> spp. AICc – 1007.1	Depth Shallow	-1.6124	0.2651	-6.082	1.19E-09	57.01
	max nDHW (6.68)	1.157	0.2478	4.669	3.02E-06	33.73
	(Intercept)	-1.2241	0.3236	-3.783	0.000155	-
	Wind WW	0.5951	0.3394	1.753	1.49e-08	28.13
	Depth Shallow	0.391	0.3188	1.227	5.49e-08	24.45
	max nDHW (6.68)	1.1162	0.1596	6.995	4.53e-10	47.42

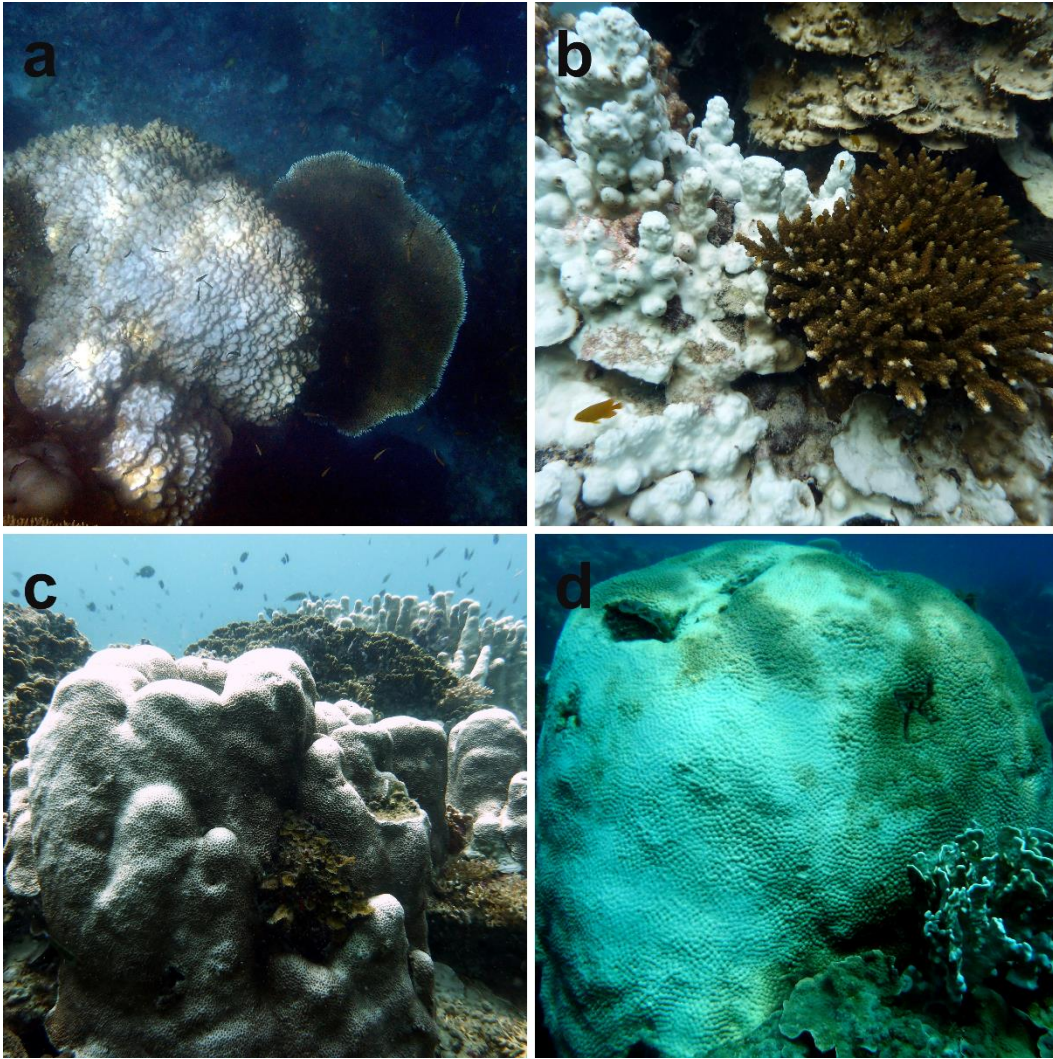
ESM 8 | Generalized linear model results and comparison of bleaching response of selected hard coral taxa (n≥10) at leeward (LW) sites compared to windward (WW) sites during successive bleaching events in 2019 and 2020. The scale specific bleaching response (BRI) index is shown together with sample size (n). Grey shading highlights significant results.

Taxon	2019						2020				
	Wind	BRI (n)	Estimate	SE	z	Pr (> z)	BRI (n)	Estimate	SE	z	Pr (> z)
All taxa	LW	43 (747)	0.89	0.08	11.02	<2e-16	13 (690)	-1.00	0.09	-11.6	<2e-16
	WW	32 (1135)	-1.09	0.10	-10.88	<2e-16	13 (1183)	-0.06	0.11	-0.60	0.55
<i>Acropora</i>	LW	9 (11)	-2.30	1.05	-2.20	0.0281	0 (9) *	-25.57	72000	0.00	1.00
arborescent	WW	13 (15)	2.17	1.17	1.86	0.0636	0 (14)	0.00	92290	0.00	1.00
<i>Acropora</i>	LW	11 (15)	0.13	0.52	0.26	0.796	12 (19)	0.11	0.46	0.23	0.8186
corymbose	WW	0 (17)	-19.70	2608.23	-0.01	0.994	6 (13)	-2.59	1.14	-2.28	0.0228
<i>Dipsastraea</i>	LW	13 (11)	-1.50	0.78	-1.92	0.0544	0 (10)	-18.57	2062.64	-0.01	0.993
submassive	WW	21 (46)	0.88	0.84	1.04	0.2978	4 (66)	16.43	2062.64	0.01	0.994
<i>Fungia</i>	LW	44 (95)	2.70	0.42	6.39	1.62e-10	10 (107)	-1.09	0.22	-4.88	1.06e-06
solitary	WW	18 (20)	-3.32	0.63	-5.26	1.45e-07	4 (30)	-1.55	0.77	-2.03	0.0424
<i>Pavona</i>	LW	69 (120)	0.97	0.20	4.74	2.12e-06	32 (110)	0.44	0.20	2.27	0.0232
foliose	WW	13 (15)	-2.84	0.79	-3.61	0.000304	0 (13)	-18.01	1097.25	-0.02	0.9869
<i>Porites</i>	LW	51 (25)	0.75	0.43	1.76	0.0787	28 (25)	0.24	0.40	0.60	0.549
massive	WW	53 (130)	-0.12	0.47	-0.25	0.8008	20 (161)	-0.61	0.43	-1.40	0.163
<i>Porites</i> spp.	LW	42 (269)	0.35	0.12	2.85	0.00436	13 (231)	-1.02	0.15	-6.87	6.55e-12
	WW	22 (178)	-1.03	0.20	-5.12	3.11e-07	12 (123)	0.30	0.24	1.21	0.226

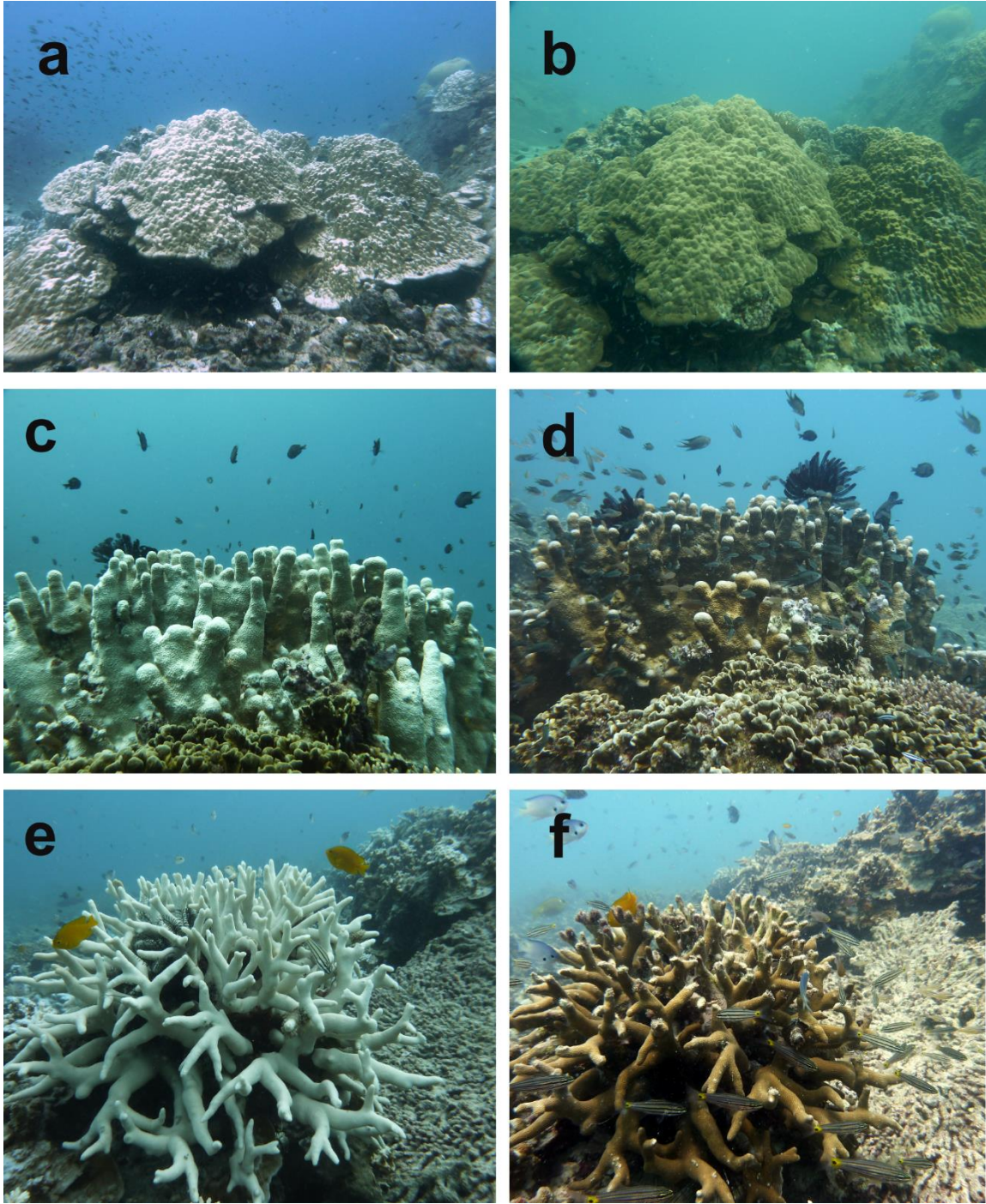
ESM 9 | Generalized linear model results and comparison of bleaching response of selected hard coral taxa (n≥10) across depth during successive bleaching events in 2019 and 2020.

The depth-specific bleaching response (BRI) index is shown together with sample size (n). Grey shading highlights significant results.

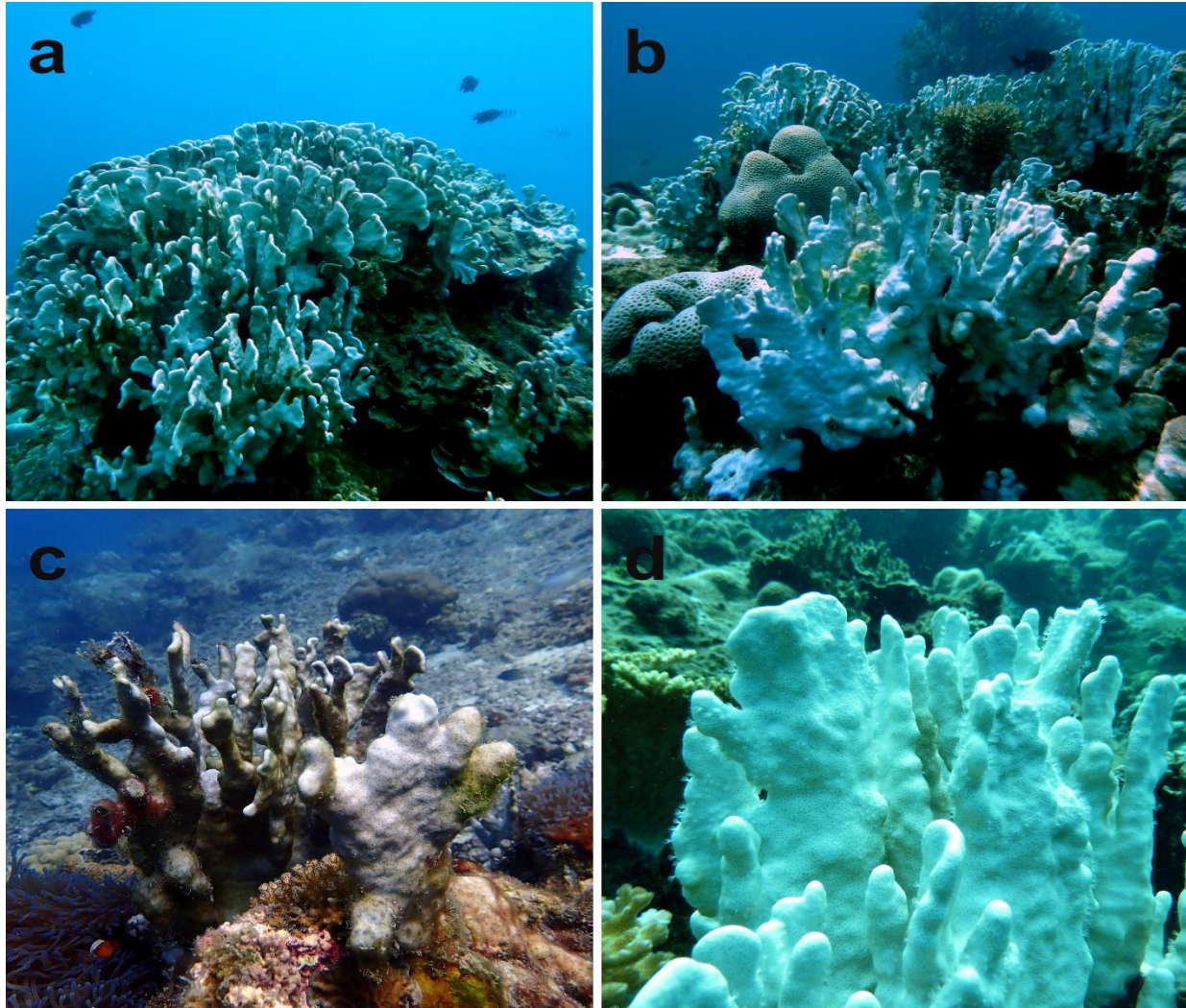
Taxon	2019						2020				
	Depth (m)	BRI (n)	Estimate	SE	z	Pr (> z)	BRI (n)	Estimate	SE	z	Pr (> z)
All taxa	6 m	34 (1203)	0.11	0.10	1.14	0.2525	11 (1138)	-0.52	0.11	-4.90	9.65E-07
	12 m	41 (679)	0.14	0.08	1.80	0.0715	16 (735)	-0.74	0.08	-9.34	< 2e-16
<i>Dipsastraea</i>	6 m	36 (24)	2.32	0.68	3.43	0.000599	5 (33)	1.30	0.87	1.49	0.137
submassive	12 m	8 (33)	-1.98	0.53	-3.71	0.000204	3 (43)	-3.02	0.72	-4.17	3.03E-05
<i>Fungia</i>	6 m	42 (81)	1.47	0.52	2.82	0.00481	8 (89)	-0.71	0.43	-1.67	0.0958
solitary	12 m	34 (34)	0.74	0.37	2.01	0.04421	10 (48)	-0.89	0.32	-2.79	0.0052
<i>Galaxea</i>	6 m	3 (61)	17.68	1817.76	0.01	0.992	6 (67)	0.36	0.85	0.42	0.675122
submassive	12 m	0 (35)	-19.57	1817.76	-0.01	0.991	3 (31)	-2.67	0.73	-3.66	0.000254
<i>Goniastrea</i>	6 m	75 (34)	0.76	0.70	1.09	0.277	19 (27)	0.80	0.69	1.16	0.246
encrusting	12 m	57 (14)	0.59	0.56	1.05	0.292	9 (17)	-1.18	0.57	-2.06	0.0393
<i>Heliopora</i>	6 m	100 (58)	18.78	1412.07	0.01	0.98939	78 (31)	3.09	0.67	4.59	4.41E-06
coerulea	12 m	66 (64)	0.79	0.27	2.92	0.00346	25 (57)	-0.86	0.29	-2.96	0.00312
<i>Leptastrea</i>	6 m	10 (35)	1.71	1.12	1.52	0.129386	12 (35)	0.75	0.69	1.09	0.276
encrusting	12 m	3 (34)	-3.50	1.02	-3.45	0.000572	6 (45)	-2.33	0.52	-4.44	8.88E-06
<i>Lobophyllia</i>	6 m	5 (12)	-0.51	0.87	-0.59	0.557	4 (20)	-0.51	0.87	-0.59	0.557
massive	12 m	7 (14)	-0.59	0.56	-1.05	0.292	6 (14)	-0.59	0.56	-1.05	0.292
<i>Pavona</i>	6 m	38 (69)	-2.39	0.47	-5.12	3.08E-07	19 (61)	-2.03	0.41	-4.93	8.18E-07
foliose	12 m	89 (66)	2.13	0.40	5.33	9.69E-08	37 (62)	1.23	0.30	4.06	4.98E-05
<i>Platygyra</i>	6 m	33 (29)	-2.39	0.47	-5.12	3.08E-07	24 (40)	-0.52	0.11	-4.90	9.65E-07
submassive	12 m	29 (27)	2.13	0.40	5.33	9.69E-08	16 (40)	-0.74	0.08	-9.34	< 2e-16
<i>Porites</i>	6 m	53 (30)	-0.74	0.65	-1.15	0.251	4 (48)	-1.96	0.72	-2.72	0.00651
encrusting	12 m	52 (17)	0.88	0.53	1.65	0.1	21 (28)	-0.75	0.40	-1.85	0.06481
<i>Porites</i>	6 m	34 (73)	-2.01	0.39	-5.14	2.78E-07	13 (75)	-0.87	0.31	-2.77	0.00565
massive	12 m	69 (82)	1.76	0.31	5.65	1.66E-08	27 (111)	0.05	0.19	0.29	0.77586
<i>Porites</i> spp.	6 m	32 (317)	-0.29	0.21	-1.37	0.17	12 (247)	-0.66	0.25	-2.66	0.00775
	12 m	39 (130)	0.15	0.18	0.88	0.381	14 (107)	-0.48	0.20	-2.39	0.01666
<i>Psammodora</i>	6 m	2 (13)	18.08	5345.91	0.00	0.997	0 (15)	0.00	85740.00	0.00	1
foliose	12 m	0 (11)	-20.57	5345.91	0.00	0.997	0 (11)	-25.57	65130.00	0.00	1



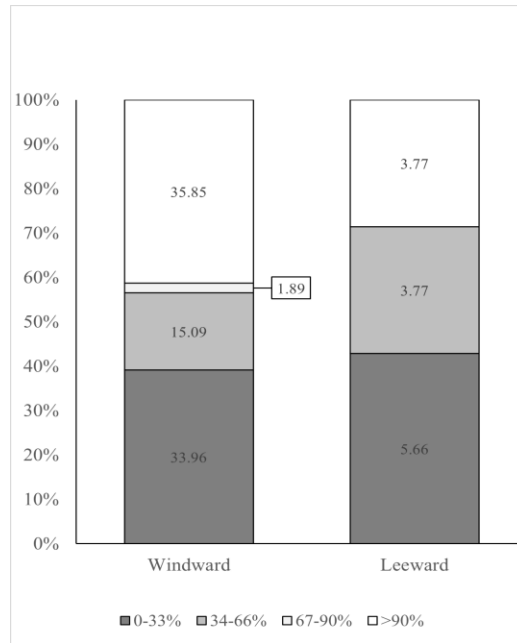
ESM 10 | Examples of coral bleaching in Pulau Lang Tengah. (a) comparison of tabular *Acropora* and massive *Porites* in 2020; (b) Severe bleaching response of *Porites* spp. compared to no bleaching of digitate *Acropora* in 2020; (c) Foreground shows severely bleached massive *Gardinoseris* colony, and in the background differential bleaching severity of *Psammocora contigua* and *Psammocora digitata* is highlighted; (d) Partial bleaching of *Diploastrea heliopora* in 2019.



ESM 11 | Example of recovery in October 2019 from coral bleaching in June 2019. (a) fully bleached massive *Porites* and subsequent recovery (b); (c-d) recovery of *Psammocora digitata* from severe bleaching; (e-f) recovery of *Porites cylindrica* from severe bleaching.



ESM 12 | High bleaching incidence and severity of *Heliopora coerulea* in June 2019 and June 2020 around Pulau Lang Tengah. (a) large *Heliopora coerulea* colony on a shallow (5-6 m) windward reef; (b) high bleaching incidence of *Heliopora coerulea* at windward sites; (c) bleaching induced partial mortality of individual colonies; (d) – fully bleached *Heliopora coerulea* colony with extended tentacles.



ESM 13 | Percent of colonies with bleaching induced mortality (October 2019) in each category and based on reef site (windward and leeward).

ESM 14 | Tukey's HSD post hoc test for taxa whose bleaching response was more severe in 2020 (group 2) compared to 2019 (group 1). LW – leeward; WW – windward; df – degrees of freedom; Shallow – 6 meters water depth; Deep – 12 meters water depth.

Taxon	group 1	group 2	df	std err	q-stat	p-value
<i>Acropora corymbose</i>	2019	2020	62	0.12	1.84	0.20
<i>Acropora corymbose</i>	WW 2019	WW 2020	28	0.19	1.63	0.26
<i>Acropora corymbose</i>	LW 2019	LW 2020	34	0.14	0.33	0.82
<i>Dipsastraea encrusting</i>	2019	2020	40	0.11	1.20	0.40
<i>Galaxea encrusting</i>	2019	2020	192	0.07	2.36	0.10
<i>Galaxea encrusting</i>	Shallow 2019	Shallow 2020	126	0.10	1.69	0.23
<i>Galaxea encrusting</i>	Deep 2019	Deep 2020	64	0.06	2.16	0.13
<i>Leptastrea encrusting</i>	2019	2020	147	0.14	0.66	0.64
<i>Leptastrea encrusting</i>	Shallow 2019	Shallow 2020	68	0.24	0.35	0.80
<i>Leptastrea encrusting</i>	Deep 2019	Deep 2020	77	0.15	0.93	0.51
<i>Platygyra encrusting</i>	2019	2020	33	0.26	1.09	0.45

ESM 15 | Tukey's HSD post hoc test results (Q test) highlighting within-reef scale differences in bleaching response of hard coral taxa across successive bleaching events in 2019 and 2020. Grey shading highlights insignificant differences in bleaching response. LS – leeward shallow; LD – leeward deep; WWS – windward shallow; WWD – windward deep.

Reef scale 1	Reef scale 2	Mean	SE	q-stat	p-value	mean-crit
LS 2019	LD 2019	0.780482	0.110012	7.094533	1.56E-05	0.47151
LS 2019	WWS 2019	0.535827	0.070316	7.620226	2.18E-06	0.301376
LS 2019	WWD 2019	0.124394	0.073133	1.700938	0.931315	0.313446
LS 2019	LS 2020	1.482557	0.072347	20.49237	6.69E-14	0.310078
LS 2019	LD 2020	0.745683	0.113293	6.581915	9.33E-05	0.485573
LS 2019	WWS 2020	1.359797	0.07087	19.18734	6.69E-14	0.303747
LS 2019	WWD 2020	1.294471	0.070899	18.25783	6.69E-14	0.303875
LD 2019	WWS 2019	1.316309	0.109656	12.00396	6.77E-14	0.469986
LD 2019	WWD 2019	0.904876	0.111483	8.116714	3E-07	0.477816
LD 2019	LS 2020	2.263039	0.110969	20.39341	6.69E-14	0.475614
LD 2019	LD 2020	1.526165	0.141122	10.81453	9.07E-13	0.604848
LD 2019	WWS 2020	2.140279	0.110012	19.45501	6.69E-14	0.47151
LD 2019	WWD 2020	2.074952	0.110031	18.85789	6.69E-14	0.471593
WWS 2019	WWD 2019	0.411433	0.072597	5.667376	0.001628	0.31115
WWS 2019	LS 2020	0.946731	0.071805	13.18473	6.71E-14	0.307756
WWS 2019	LD 2020	0.209856	0.112948	1.857998	0.893873	0.484093
WWS 2019	WWS 2020	0.82397	0.070316	11.71804	7.24E-14	0.301376
WWS 2019	WWD 2020	0.758644	0.070347	10.78437	1.05E-12	0.301506
WWD 2019	LS 2020	1.358163	0.074565	18.21448	6.69E-14	0.319586
WWD 2019	LD 2020	0.621289	0.114722	5.415608	0.003306	0.491698
WWD 2019	WWS 2020	1.235403	0.073133	16.89265	6.66E-14	0.313446
WWD 2019	WWD 2020	1.170077	0.073162	15.99304	6.68E-14	0.313571
LS 2020	LD 2020	0.736874	0.114223	6.451209	0.000144	0.489558
LS 2020	WWS 2020	0.12276	0.072347	1.696829	0.932156	0.310078
LS 2020	WWD 2020	0.188087	0.072376	2.598741	0.594282	0.310204
LD 2020	WWS 2020	0.614114	0.113293	5.420595	0.003261	0.485573
LD 2020	WWD 2020	0.548787	0.113311	4.843175	0.014482	0.485653
WWS 2020	WWD 2020	0.065327	0.070899	0.9214	0.998104	0.303875