Corals at the edge of environmental limits: A new conceptual framework to re-define marginal and extreme coral communities

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Supplemental Figures

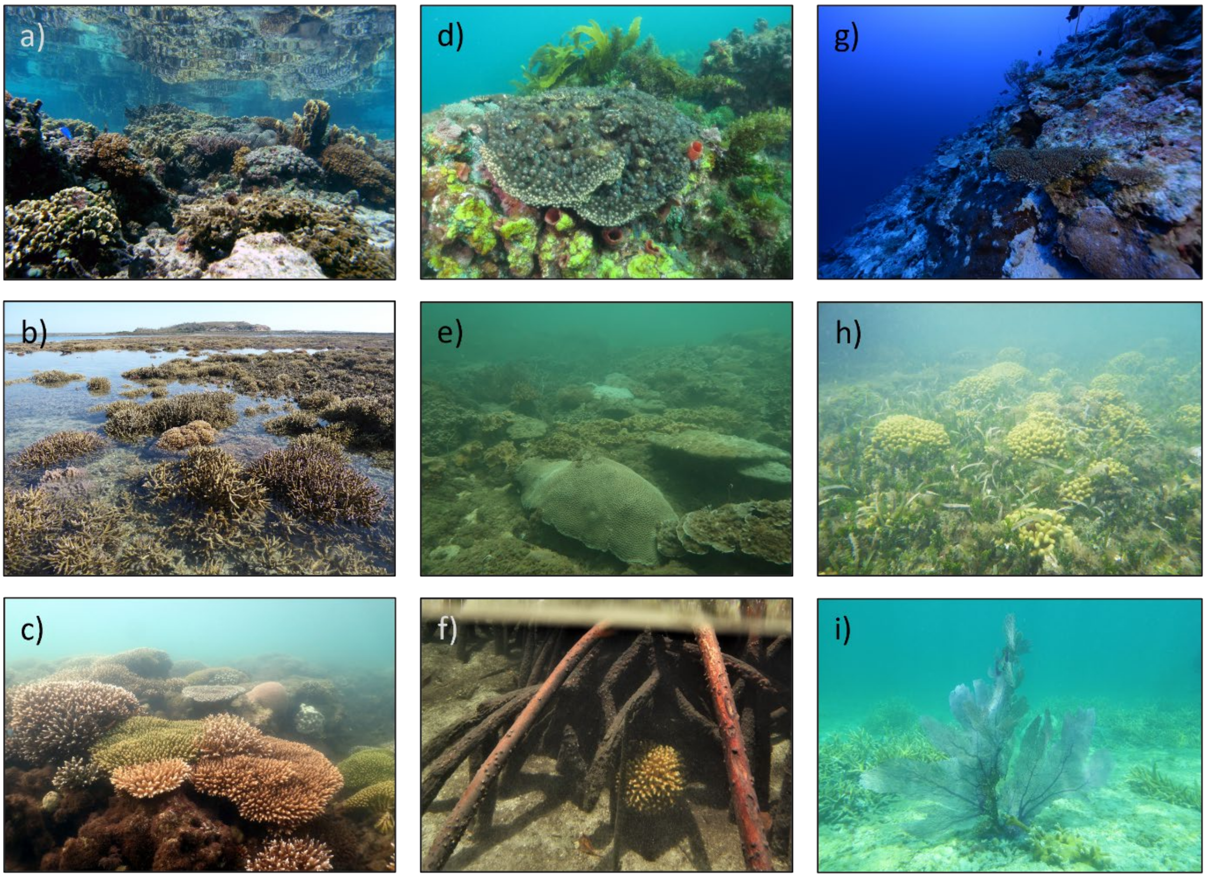

Figure S1: Examples of (a-c) extreme, (d-h) extreme and marginal, and (i) marginal coral communities. **(a)** back-reef pool in American Samoa (Credit: D. Barshis), **(b)** macrotidal coral community in the macrotidal Kimberley region, NW Australia (Credit: V. Schoepf), **(c)** semi-enclosed Bouraké Lagoon, New Caledonia (Credit: R. Rodolfo-Metalpa), **(d)** high-latitude coral community with neighbouring kelp, Solitary Islands, Australia (Credit: B. Sommer), **(e)** turbid coral community at Miri, Malaysia (Credit: N. Browne), **(f)** corals growing under mangrove roots, Great Barrier Reef (Credit: E. Camp), **(g)** Mesophotic coral community at 60 m depth at Pakin Atoll, Pohnpei, Micronesia (Credit: D. Barshis), **(h)** Branching *Porites* corals growing in a seagrass meadow in Spaanse Water, Curaçao (Credit: V. Schoepf), **(i)** Coral community in Broward County, Florida (Credit: B. Riegl).

Supplemental Tables

See next page

Supplemental Table S1. Example sites of extreme, extreme and marginal, and marginal coral communities

Type of coral community Reef site/region	Coral reef extremeness (environmental criteria)			Coral reef marginality (ecological criteria)				Classification	Key references
	High environmental variance	Shift in environmental mean conditions	Local anthropogenic stressors	Altered or low coral cover - yes or no (Y/N)	Altered or low coral diversity – yes or no (Y/N)	Altered community composition	Altered or low reef functioning - yes or no (Y/N)	extreme, marginal or both	
Macro- and mesotidal reefs									
Kimberley, NW Australia									
Shell Island	Y	Y[1]	N	N (17-30%)	N (19 genera)	N	N	extreme	Schoepf et al 2015, Dandan et al 2015, Le Nohaic et al 2017
Tallon Island	Y	Y[1]	N	Y (3%)	Y (9 species)	Y	Y	both	Richards and O'Leary 2015, Pedersen et al 2016, Gruber et al 2017, Cornwall et al 2018
Bonaparte Archipelago	Y	Y[1]	N	N	N (225 species)	N	N	extreme	Richards et al 2015
Other locations									
Andaman Sea	Y	na	*	N*	N (up to 353 species)	N	N	extreme	Brown 2007, Turak et al 2005
Turbid (inland) bays/lagoons									
Hervey Bay, Queensland, Eastern Australia (25°S)	Y	Y	Y	N (11.3-42.3%)	N (>30 species)	Y	Y	extreme, some both	Butler et al 2013, 2015; Sommer et al 2021
Moreton Bay, Queensland, Eastern Australia (27°S)	Y	Y	Y	N (up to 50%)	N (143 species)	Y	Y	extreme, some both	Wallace et al 2009; Dalton and Roff 2013; Sommer et al 2014; Hammerman et al 2022
Curaçao, Caribbean	Y	Y	*	Y (<2%)	Y* (up to 18 species)	Y	Y	both	Debrot et al 1998, Vermeij et al 2007
Cape Verde	Y	Y	N	N[2]	Y (5 species)	Y	Y	both	Moses et al 2003
Belize nearshore patch reefs	Y	Y	*	Y	Y	Y	Y	both	Baumann et al 2016
Turbid reefs									
Inshore Great Barrier Reef									
Middle Reef	Y	Y	N	N (40%)	N (>80 species)	N	N	extreme	Browne et al 2010
Paluma Shoals	Y	Y	N	N (38%)	N (23 genera)	N	N	extreme	Morgan et al 2017, Browne et al 2013, Zweifler et al 2021
Inshore central Western Australia									
Eva Reef	Y	N	N	Y (10%)	Y (<15 genera)	Y	Y	marginal	Dee et al 2020

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Fly Reef	Y	N	N	Y (8%)	Y (<15 genera)	Y	Y	marginal	Dee et al 2020
Other regions									
Eves Garden, Miri, Malaysia	Y	Y	Y	Y (22%)	Y (16 genera)	Y	Y	both	Guest et al 2016, Zweifler et al 2021
Wakatobi Marine National Park, S.E Sulawesi Indonesia	Y	Y	N	Y (5-32%)	Y (1-34 species)	Y	na	both	Hennige et al 2008, 2010
Bay of Banten, NW Sulawesi, Indonesia	na	Y	Y	N (14-27%)	N (27-48 species)	Y	na	extreme, some both	Bak and Meesters 2003
Urban reefs									
Inshore reefs Singapore	N	Y	Y	N (31%)	N (26 genera)	Y	Y	extreme, some both	Guest et al 2016, Zweifler et al 2021
Tolo Harbour, Hong Kong	Y	Y	Y	Y (<5%)	Y (<15 species)	Y	Y	both	Duprey et al 2016, Cybulski et al 2020
Pearl River Delta megacity, China	Y	Y	Y	Y	Y	Y	Y	both	Duprey et al 2020
Varadero Reef, Colombia	N	Y	Y	N (45%)	N (42 species)	N	N	extreme	Lopez-Victoria et al 2015, Pizarro et al 2017
Semi-enclosed bays									
Bouraké, New Caledonia	Y	Y	N	N (up to 80%)	N (66 species)	N	Y	extreme	Camp et al 2017, Maggioni et al 2021
Nikko Bay, Palau	N	Y	N	N (34-82%)	N (<15 genera)	Y	Y	extreme	Golbuu et al 2016, Kurihara et al 2021
Mangrove lagoons									
Great Barrier Reef	Y	Y	N	Y (<5%)	Y (34 species)	Y	Y	both	Camp et al 2019
Hurricane Hole, US Virgin Islands	Y	Y	N	N	N (33 species)	Y	Y	both	Yates et al 2014
Belize	Y	Y	N	Y	Y	Y	Y	both	Scavo Lord et al 2020
Bocas del Toro, Panama	Y	Y	N	N (43%)	N (34 species)	Y	Y	both	Stewart et al 2022
Kaledupa Island, Wakatobi, SE Sulawesi, Indonesia	Y	Y	N	na	Y (2 genera)	Y	Y	both	Polapa et al 2021
Seagrass environments									
Cayman Islands, British West Indies	Y	Y	N	Y (3.1%)	Y (8 species)	Y	Y	both	Camp et al 2016
Curieuse, Seychelles	Y	Y	N	Y (4.2%)	Y (8 species)	Y	Y	both	Camp et al 2016
Wakatobi, southeast Sulawesi	Y	Y	N	Y (5.4%)	Y (14 species)	Y	Y	both	Camp et al 2016

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CO_2 seep/vent and other low pH coral communities									
Normanby, Papua New Guinea	Y	Y	N	N (up to 33%)	N (>100 species)	Y	Y	extreme	Fabricius et al 2011
Ambitle, Papua New Guinea	Y	Y	N	N	N (>100 species)	N	N	extreme	Pichler et al 2019, Comeau et al 2022
Iwotorishima, Japan	Y	Y	N	Y (<30%)	na	Y	Y	both	Inoue et al 2013
Shikine, Japan	Y	Y	N	Y (up to 11%)	Y (9 species)	Y	Y	both	Agostini et al 2018, Harvey et al 2021
Rock Islands, Palau	N	Y	N	N (32-63%)	N (12 genera)	Y	Y	extreme	Shamberger et al 2013; Barkley et al 2015
Upwelling-influenced coral communities									
Bermuda	Y	N	N	Y	Y	Y	Y	both	Sawall et al 2020
Galapagos Islands, Eastern Tropical Pacific	Y	Y	N	Y	Y (24 species)	Y	Y	both	Riegl et al 2019
Mexican Province, Eastern Tropical Pacific	Y	Y	N	Y	Y (24 species)	Y	Y	both	Glynn and Ault 2000, Cortés et al 2017, Glynn et al 2017
Panamanian Province, Eastern Tropical Pacific	Y	Y	N	Y	Y (26 species)	Y	Y	both	Glynn and Ault 2000, Cortés et al 2017, Glynn et al 2017
Clipperton Atoll, Eastern Tropical Pacific	Y	Y	N	N (55-85%)	Y (10 species)	Y	Y	both	Pogoreutz et al 2022, Glynn and Adult 2000
Internal wave-influenced coral communities									
Scott Reef (offshore), Western Australia	Y	N	N	N (44%)	N (300 species)	N	na	extreme	Gilmour et al 2013
Andaman Sea, Thailand	Y	Y	N	N (36-49%	Y (27-38 species)	Y	Y	both	Wall et al 2012, Wall et al 2015, Buerger et al 2015, Schmidt et al 2012, 2016
Reef flats or back reef sites									
Ofu Island, American Samoa	Y	N	N	N (25-26%)	N (~80 species)	N	N	extreme	Craig et al 2001, Thomas et al 2018
Reef flat and lagoon, Heron Island, Australia	Y	N	N	Y (2-20%)	N	Y	N	extreme or both	Brown et al 2018
One Tree Island lagoon, Australia	Y	N	N	Y (10-15%)	N (20 genera)	N	Y	extreme or both	Nolan et al 2021, Davis et al 2019, Sommer unpublished
Intertidal rock pools, South Africa	Y	Y	N	Y	Y (16 species)	Y	Y	both	Smit and Glassom 2017, Onyango et al 2021
High-latitude coral communities									

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Australia									
Houtman Abrolhos, Western Australia (28.5°S)	Y	Y	N	N (29%)	N (184 species)	Y	Y	both	Veron and Marsh 1988
Hall Bank, Western Australia (32°S)	Y	Y	N	N (53%)	Y (~14 species)	Y	Y	both	Thomson and Frisch 2010
Bremer Bay, Western Australia (34.5°S)	N	Y	N	Y[2]	Y	Y	Y	both	Ross et al 2018
Solitary Islands, New South Wales, Eastern Australia (30°S)	Y	Y	Y	N (8.5-50.9%)	N (90 species)	Y	Y	both	Harriott et al 1994, Dalton and Roff 2013, Sommer et al 2014, Mizerek et al 2021
Black Rock, New South Wales, Eastern Australia (30.5°S)	Y	Y	N	N (24%)	Y (8 species)	Y	Y	both	Harriott et al. 1999
Lord Howe Island, Eastern Australia (31.5°S)	Y	Y	N	N (>30%)	N (59 species)	Y	Y	both	Harriott et al 1995; Dalton and Roff 2013
Sydney, Eastern Australia (34°S)	Y	Y	Y	N (>50%)	Y (3 species)	Y	Y	both	Booth and Sear 2018, Precoda et al 2018, Goyen et al 2019, González-Pech et al 2022
Other regions									
Kermadec Islands, New Zealand (30.3°S)	Y	Y	N	N (1.2-18%)	Y (16 species)	Y	Y	both	Brook 1999, Wicks et al 2010
Nine-Mile Reef, Sodwana Bay, South Africa (27.5°S)	Y	Y	N	Y (<10%)	N (<20 genera)	Y	Y	both	Schleyer et al 2008
Tatsukushi, Japan (32.75°N)	Y	N	N	N (60%)	N (73 species)	N	Y	both	Denis et al 2013
Tosa Bay, Kochi, Japan (34°N)	Y	Y	N	N (41.9%)	N (136 species)	Y	Y	both	Mezaki and Kubota 2012
Iki Island, Japan (34°N)	Y	Y	Y	Y	Y (<10 species)	Y	Y	both	Yamano et al 2001, 2012
Southeast Florida (26°N)	Y	N	Y	Y (<15%)	N (<20 species)	Y	Y	extreme or marginal	Moyer et al 2003, Jones et al 2022
North Carolina (34°N)	Y	Y	N	Y	Y	Y	Y	both	Macintyre et al 1969, Macintyre 2003
Mesophotic coral communities									
Red Sea, Israel	N	Y	N	na	(93 species)	Y	Y	both	Eyal et al 2019, Muir and Pichon 2019
Submerged Shoals, Northwest Australia	N	Y	N	Y (11.9-16.5%)	Y (65 species)	Y	Y	both	Hayward and Radford 2019, Muir and Pichon 2019
Northern Great Barrier Reef, Australia	N	Y	N	*[2]	(196 species)	Y	Y	both	Bridge et al 2019, Muir and Pichon 2019
Ryukyu Islands, Japan	N	Y	N	na	(88 species)	Y	Y	both	Muir and Pichon 2019, Sinniger et al 2019
Pulley Ridge, Gulf of Mexico, USA	N	Y	N	Y (1.5%)	Y (17 species)	Y	Y	both	Reed et al 2019
Discover Bay, Jamaica	N	Y	N	na	Y (<30 species)	Y	Y	both	Dustan and Lang 2019, Muir and Pichon 2019

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Bermuda	N	Y	N	na	Y (<20 species)	Y	Y	both	Goodbody-Gringley et al 2019, Muir and Pichon 2019
Corals in the world's hottest sea, the Persian/Arabian Gulf									
Qatar and United Arab Emirates	Y	Y	Y	Y (6-60%)	Y	Y	Y	both	Riegl and Purkis 2012, Burt et al 2020, Burt and Bauman 2020
Offshore islands; southeastern Arabian Gulf	Y	Y	Y	Y (1.9-17.1%)	Y (~10 genera)	Y	Y	both	Foster et al 2012
Abu Dhabi coast, southeastern Arabian Gulf	Y	Y	Y	Y (27.5-46.5)	Y (~10 genera)	Y	Y	both	Foster et al 2012
Northwestern Gulf of Oman	Y	Y	Y	Y (23-44.9%)	Y (~10 genera)	Y	Y	both	Foster et al 2012
South-western Atlantic, Brazil									
Equatorial sandstone reef, Pedra da Risca do Meio, Brazil	Y	Y	Y	Y (<5%)	Y (2 species)	Y	Y	both	Leão et al 2016, Soares et al 2017
Coral coast, Brazil	Y	Y	Y	Y (<20%)	Y (<5 species)	Y	Y	both	Aued et al 2018, Pereria et al 2018
Abrolhos, Brazil	Y	Y	Y	Y (<20%)	Y (<20 species)	Y	Y	both	Francini-Filho et al 2013, Aued et al 2018, Teixeira et al 2012
Queimada Grande, Brazil (24°S)	Y	Y	Y	N (40-60%)	Y (<5)	Y	Y	both	Grillo et al 2021

[1] *naturally high turbidity*
[2] *coral cover can be very high in some areas*
** site specific*
na ... not available

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