



# Status of Coral Reefs of the World: 2020

## Chapter 14. Statistical Methods

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## Chapter 14.

# Statistical Methods

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To explore the status and trends of global live hard coral and algae, a hierarchical modelling approach was used in which the trends of individual statistical models (fitted to biographical subsets of the full data) were combined into progressively larger spatial aggregates. This hierarchical approach served multiple purposes. First, it allowed us to validate trends at smaller spatial scales against the knowledge of experts at those scales and thus have confidence that if the trends at smaller spatial scales were reasonable, then the resulting larger scale aggregations were also likely to be reasonable. Second, it permitted us to report trends at multiple spatial scales and compare and contrast status and trends between different spatial units. Finally, from an analytical perspective, it permitted us to approximate a much larger, more complex spatio-temporal model without prohibitive computational loads.

Marine Ecosystems of the World (MEOW) were selected as the basic spatial units for statistical modelling as they are a well recognised classification system with a strong biogeographic focus that capture important community, evolutionary, dispersal and isolation processes<sup>1</sup>. Individual statistical (Bayesian hierarchical) models were used to reconstruct the likely trends in the covers of live hard coral and algae from the multiple sources taking into account broad differences between individual sampling locations, the inherent differences in various data sources (e.g. methodologies and sampling designs) as well as the expected location of reefs within the MEOW.

MEOW trends (along with their associated uncertainties) were aggregated together into larger subregions that were then further aggregated into regions and finally a global synthesis. To ensure that the contribution of each MEOW to the relevant subregional aggregation was proportional to the amount of coral reef they contained rather than the degree of sampling effort that had occurred within the MEOW, MEOWs were weighted according to their relative reef area (based on Tropical Coral Reefs of the World [500 m resolution grid])<sup>2</sup>. Similarly, subregions were proportionally weighted when aggregating to regions and regions weighted when aggregating to the global scale. The MEOWs that comprised each GCRMN subregion and region are defined in tab 14.1 and the hierarchical aggregation is illustrated in fig 14.1.

The modelled and aggregated outputs (posteriors) were further aggregated into 5-year units (2004-2009, 2010-2014, 2015-2019) that were compared pairwise in order to explore medium-term changes in the covers of hard coral and algae at global, regional and subregional scales.

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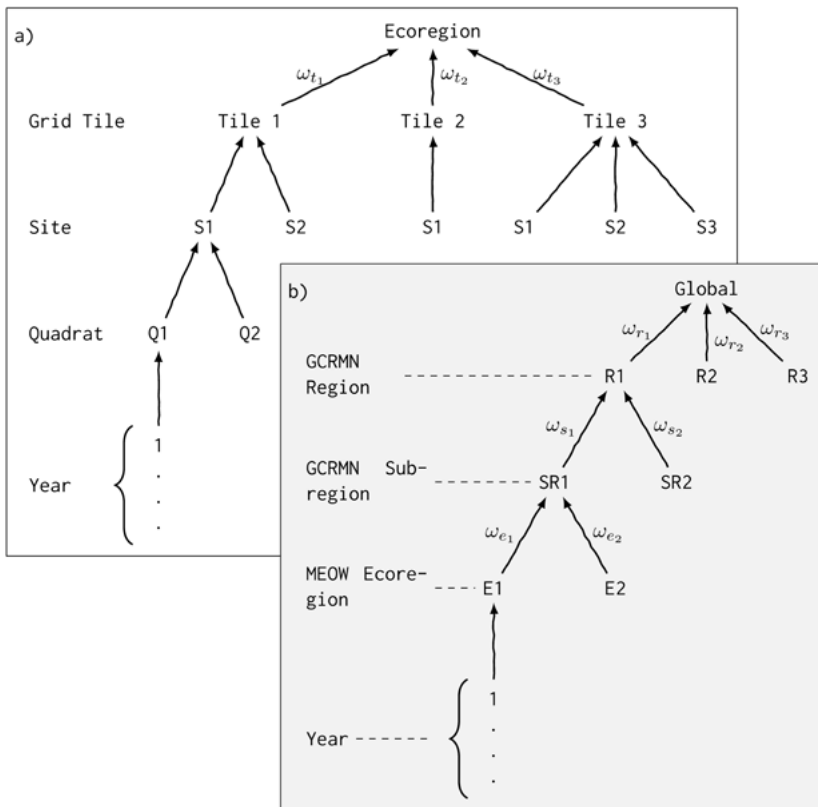
<sup>1</sup> Spalding, M. D., E. H. F., Allen, G. R., Davidson, N., Ferdaña, Z. A., Finlayson, M., Halpern, B. S., Jorge, M. A., Lombana, A., Lourie, S. A., Martin, K. D., McManus, E., Molnar, J., Recchia, C. A., & Robertson, J. (2007). Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas, *BioScience*, Volume 57, Issue 7, Pages 573–583. <https://doi.org/10.1641/B570707>

<sup>2</sup> Institute for Marine Remote Sensing, University of South Florida (IMaRS/USF), Institut de Recherche pour le Développement (IRD), UNEP-WCMC, The WorldFish Center, and WRI, 2011. Global Coral Reefs composite dataset compiled from multiple sources for use in the Reefs at Risk Revisited project incorporating products from the Millennium Coral Reef Mapping Project prepared by IMaRS/USF and IRD. <http://datasets.wri.org/dataset/tropical-coral-reefs-of-the-world-500-m-resolution-grid>

The trends in global hard coral cover were also overlaid with rolling mean smoothed sea surface temperature anomaly<sup>3</sup> to visually explore the association between large scale trends in the cover of hard coral and global climatic metrics.

To explore regional resilience, we calculated the percentage of disturbed long-term monitoring sampling units that had subsequently recovered to within 90 percent of the pre-disturbance hard coral cover. Disturbed long-term monitoring sampling units were defined as those for which data spanning more than 15 years were available and had experienced a relative decline in live hard coral cover of at least 20 percent. A sampling unit was defined as the specific area that was surveyed repeatedly. Depending on the survey method used and how the data were provided, a sampling unit could be a transect, a quadrat or even a site. For greater insights, we also calculated the associated mean absolute and relative declines. Similarly, incidences of increases and subsequent algal cover returns were enumerated to provide insights into potential phase shifts.

More detailed descriptions of all the statistical methodologies can be found at <https://gcrmn.net/2020-report/>.



**Figure 14.1.** Schematic representation of the a) individual MEOW Ecoregion Bayesian modelling hierarchies and b) spatial aggregation hierarchy. Note the quadrat-level is de-emphasized to highlight that the quadrat to site level aggregation has occurred outside of the statistical model. The  $\omega$  symbolises the use of spatial weights.

<sup>3</sup> Kennedy, J. J., N. A. Rayner, C. P. Atkinson, and R. E. Killick. 2019. "An Ensemble Data Set of SeaSurface Temperature Change from 1850: The Met Office Hadley Centre HadSST.4.0.0.0 Data Set." *Journal of Geophysical Research: Atmospheres* 124: 7719–63. <https://doi.org/10.1029/2018JD029867>.

**Table 14.1.** Spatial hierarchy relating Marine Ecosystems of the World Ecoregions<sup>1</sup> to GCRMN Regions and Subregions. PERSGA is the area included within the Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden. ROPME is the sea area surrounded by the eight Member States of the Regional Organisation for the Protection of the Marine Environment. WIO is the Western Indian Ocean.

GCRMN Region	GRCRMN Subregion	MEOW Ecoregion
Australia	Australia.1	142: Torres Strait Northern Great Barrier Reef
		143: Central and Southern Great Barrier Reef
		202: Tweed-Moreton
	Australia.2	140: Arnhem Coast to Gulf of Carpentaria
		141: Bonaparte Coast
		144: Exmouth to Broome
		145: Ningaloo
		210: Shark Bay
		211: Houtman
	Australia.3	120: Cocos-Keeling/Christmas Island
Australia.4	151: Lord Howe and Norfolk Islands	
Brazil	Brazil.1	074: Fernando de Naronha and Atoll das Rocas
	Brazil.2	075: Northeastern Brazil
	Brazil.3	076: Eastern Brazil
		077: Trindade and Martin Vaz Islands
	Brazil.4	071: Guianan
		072: Amazonia
Caribbean	Caribbean.1	062: Bermuda
		063: Bahamian
	Caribbean.2	064: Eastern Caribbean
		066: Southern Caribbean
	Caribbean.3	065: Greater Antilles
	Caribbean.4	067: Southwestern Caribbean
		068: Western Caribbean
	Caribbean.5	043: Northern Gulf of Mexico
		069: Southern Gulf of Mexico
		070: Floridian

GCRMN Region	GRCRMN Subregion	MEOW Ecoregion
East Asian Seas	East Asia.1	126: Palawan/North Borneo
		127: Eastern Philippines
		128: Sulawesi Sea/Makassar Strait
	East Asia.2	129: Halmahera
		130: Papua
		131: Banda Sea
		133: Northeast Sulawesi
		138: Gulf of Papua
		139: Arafura Sea
	East Asia.3	115: Gulf of Thailand
		116: Southern Vietnam
		117: Sunda Shelf/Java Sea
		118: Malacca Strait
	East Asia.4	119: Southern Java
		132: Lesser Sunda
	East Asia.5	109: Andaman and Nicobar Islands
		110: Andaman Sea Coral Coast
		111: Western Sumatra
	East Asia.6	112: Gulf of Tonkin
		113: Southern China
		114: South China Sea Oceanic Islands
East Asia.7	051: Central Kuroshio Current	
	052: East China Sea	
	121: South Kuroshio	
Eastern Tropical Pacific	ETP.1	060: Cortezian
		061: Magdalena Transition
	ETP.2	166: Mexican Tropical Pacific
		167: Chiapas-Nicaragua
		168: Nicoya
	ETP.3	170: Panama Bight
		171: Guayaquil
	ETP.4	169: Cocos Islands
		172: Northern Galapagos Islands
		173: Eastern Galapagos Islands
		174: Western Galapagos Islands
	ETP.5	164: Revillagigedos
		165: Clipperton

GCRMN Region	GRCRMN Subregion	MEOW Ecoregion
Pacific	Pacific.1	122: Ogasawara Islands
		123: Mariana Islands
		124: East Caroline Islands
		125: West Caroline Islands
	Pacific.2	134: Bismarck Sea
		135: Solomon Archipelago
		136: Solomon Sea
		137: Southeast Papua New Guinea
	Pacific.3	146: Tonga Islands
		147: Fiji Islands
		148: Vanuatu
		149: New Caledonia
		150: Coral Sea
	Pacific.4	152: Hawaii
	Pacific.5	153: Marshall Islands
		154: Gilbert/Ellis Islands
	Pacific.6	155: Line Islands
		156: Phoenix/Tokelau/Northern Cook Islands
		157: Samoa Islands
	Pacific.7	158: Tuamotus
		159: Rapa-Pitcairn
160: Southern Cook/Austral Islands		
161: Society Islands		
162: Marquesas		
PERSGA	PERSGA.1	087: Northern and Central Red Sea
	PERSGA.2	088: Southern Red Sea
	PERSGA.3	089: Gulf of Aden
ROPME	ROPME.1	090: Arabian (Persian) Gulf
	ROPME.2	091: Gulf of Oman
	ROPME.3	092: Western Arabian Sea
South Asia	South Asia.1	106: Chagos
	South Asia.2	105: Maldives
	South Asia.3	103: Western India
		104: South India and Sri Lanka
	South Asia.4	107: Eastern India
108: Northern Bay of Bengal		

GCRMN Region	GRCRMN Subregion	MEOW Ecoregion
Western Indian Ocean	WIO.1	093: Central Somali Coast
		094: Northern Monsoon Current Coast
		095: East African Coral Coast
	WIO.2	096: Seychelles
	WIO.3	097: Cargados Carajos/Tromelin Island
		098: Mascarene Islands
	WIO.4	099: Southeast Madagascar
		100: Western and Northern Madagascar
	WIO.5	101: Bight of Sofala/Swamp Coast
		102: Delagoa

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