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18C Spatially-explicit and multi-disciplinary approaches for coral reef conservation

Towards marine spatial planning for Hervey Bay's coral reefs

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Abstract. Values and connections of coral reefs within subtropical Hervey Bay, south of the Great Barrier Reef (GBR), were characterized with a view to their inclusion as inputs to local and regional planning. The approach included: (1) mapping of reefs; (2) assignment of biodiversity and geomorphic values; and (3) a descriptive assessment of risks. In-situ substrate and species datasets for both dominant communities (matching Quickbird satellite image resolution) and for low density species were used to define a reef typology for mapping and connectivity analyses. User's and producer's accuracies for identifying homogeneous (dominant) geomorphic substrates on images were generally high (coral 60-65%; sand 85%). Field investigations at high taxonomic resolution revealed that a number of regionally rare and high latitude species are present in Harvey Bay. Its dominant communities resemble GBR nearshore reefs (i.e. reef-forming *Turbinaria, Goniopora* and *Acropora)* more closely than they do subtropical (faviid-dominated) coral communities, reflecting historical and/or present larval connectivity with the GBR. Hervey Bay's reefs are part of a reef-seagrass-mangrove complex that is one of three such complexes in the region. Flood plumes from the region's Mary and Burnett Rivers extend northward across the GBR lagoon to the Capricorn-Bunker reef group, episodically linking these reefs functionally to the GBR via biota and nutrient fluxes. Overall, our results provide the types of information needed to support marine spatial planning for coral reefs in the context of the catchments and oceanographic processes that influence them.

Key words: Values, coral, high latitude, mapping, planning.

Introduction

Coral reefs are threatened at local, regional and global scales (Hoegh-Guldberg 1999), requiring ecosystem-based planning at corresponding scales to address risks (Fernandes *et al.* 2005; Foley *et al.* 2010). Nearshore coral reef habitats experience multiple stressors capable of interaction. A spatially-explicit approach can identify areas with intrinsic biodiversity values and high human use value; locate risks and identify their spheres of influence. High value habitats with high potential risks may then become priorities for management intervention.

Many spatial factors determine risks for coral reefs and their potential for survival. An inshore or offshore position indicates proximity to human influence. Sheltered waters experience greater eutrophication than wave-washed waters. Vulnerability to climate change induced effects and human stressors are exacerbated in the subtropics, where coral communities exist closer to their environmental thresholds. Impacts of urban and rural pollutant sources vary according to proximity from the reef concerned (e.g. in Kanoehe Bay, Hawaii, reefs closest to rivers experienced greater impacts from catchment pollution than distant reefs, Stimson and Conklin 2008). Spatial factors may also enhance reef survival, e.g. proximity to mangroves and to seagrass beds (Olds *et al.* 2012); potential for dispersal and recolonisation of recruits.

This study involved a spatially-explicit investigation of values and risks for reefs of subtropical Hervey Bay, Queensland, Australia. These turbid-water reefs are within the Great Barrier Reef (GBR) lagoon but lie beyond the main reef tract. Adjacent to an urban centre of some 50,000 people, these reefs are already valued highly recreationally, providing easy access for diving, fishing, boating and indigenous use. Potentially Hervey Bay's reefs are reef-forming, of high biodiversity value and exist close to environmental thresholds of reef formation and ecological limits of turbidity, temperature and human stressors (DeVantier 2010, Zann 2012). The reefs' close proximity to the urban environment and the influence of a large agricultural catchment potentially threaten their existence. Episodic Mary River floods deposit sediment, nutrients and chemicals into the bay, resulting in the loss of seagrass beds and death of dugong (1992 - Preen *et al*. 1995); the loss of corals (2011-Butler 2012 in prep.); and herbicide pollution of bay sediments (McMahon *et al.* 2006). Spatially identifying threats may provide opportunities for management initiatives promoting reef recovery, as occurred in Kanoehe Bay reefs (Stimson and Conklin 2008).

Material and Methods

The study area, Hervey Bay and the Great Sandy Strait are outside the GBR but within the GBR lagoon. Regional reef outlines were interpreted from Landsat (2004) imagery and aerial photography (Fig.1, top right). Three data types were used to determine values and risks of reefs in the local study area, Hervey Bay City and Great Sandy Strait:

(1) Spatial data: Quickbird imagery (2004, 2007) was acquired over the local mapping area. Field-derived dominant benthic substrate (living and non-living) provided a dataset to train supervised classification of Quickbird imagery (after Roelfsema and Phinn 2009). This enabled live coral cover and geomorphic units to be discerned (Zann 2012). A connectivity dataset was produced by analysis of Euclidean distance between reef, seagrass and mangrove spatial datasets (Zann 2012; Campbell & McKenzie 2004; Qld Wetland Program 2009)

(2) Biodiversity values: Field snorkel, scuba and drop camera surveys provided quantitative transect data for dominance analysis and categorical abundance data for diversity analysis (for localities see Fig.1). Patterns of dominance taxa were extracted by CPCE analysis of point transect photos (Kohler 2006) and cluster, NMDS and SIMPER analyses in PRIMER (Clarke & Gorley 2006). Rapid Ecological Assessment (REA) species surveys (DeVantier 2010; Zann 2012) constituted the diversity dataset. PRIMER diversity indices were calculated for the survey localities (Clark & Gorley 2006) which were ranked by mean scores. When interpreted with the spatial dataset, the biodiversity dataset provided information about the geomorphic and biodiversity values i.e. context, biodiversity 'hotspots', rarity, evidence of reef-building and turbid water species.

(3) Risks: Pre-2011 flood coral health observations were proxies for cumulative stressor effects (i.e. disease, bleaching, *Cliona* sponge overgrowth - DeVantier (2010), Zann 2012). Development indicators potentially contributing to cumulative effects (structures, hardened surfaces- EPA 2006) were mapped. Post-2011 flood surveys were conducted at various reefs in Hervey Bay including Point Vernon East (Butler *et al.* 2012 in. prep). High flood risk reefs were identified based on flood plumes (MODIS 2008, 2011) and flood models (Grawe *et al.* 2010). Potential sources of sediment, nutrients and chemicals were mapped in the catchment (DERM 2009).

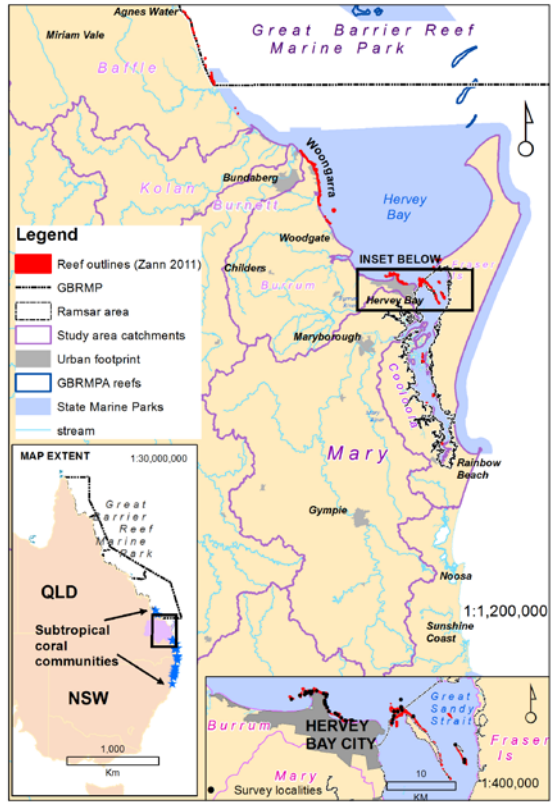

Figure 1: The study area, Hervey Bay, lies south of the Great Barrier Reef at the northern extent of subtropical coral communities (left). The Mary River discharges south of the reefs into the Great Sandy Strait and Hervey Bay (top right). Survey localities were adjacent to Hervey Bay City and the Great Sandy Strait, within the Quickbird image footprint (bottom right).

Results

15km of coral communities were identified from imagery along the Woongarra and Hervey Bay coastlines. Biodiversity values and risks are presented for the latter.

Spatial data results

The multivariate analysis (Cluster / SIMPER) grouped the field substrate data into homogeneous benthic substrate types (% cover): coral (85%), sand (91%), soft coral (79%), algae (83%), turf algae (79%), mud and dead coral (77%). Other substrate groups were mixtures. These groups were used to train supervised classification of Quickbird images (see Fig. 2). Despite low overall accuracy (Tau 46-49%), based on supervised classifications of the 2006 image, there is >60% probability that hard coral is >80% cover. Discrimination of coral and sediments enabled differentiation of geomorphic substrate units. Two discrete reef aggregations were evident: mainland reefs of the rocky peninsula and nearby patch reefs; and the island reefs of the Great Sandy Strait. Mainland reefs were well-connected to mangroves and seagrass beds.

LOCATION	Diversity rank	Reef Building	Dominant taxa % similarity (SIMPER)
Gataker's Bay	3	Y	*Goniopora* (70%)/ *Turbinaria* (14%)
East Point Vernon	1	N	*Turbinaria* (60%) / *Goniopora* (37%)
Pialba-Torquay	1	Y	*Turbinaria (60%) / Goniopora (37%)*
Big Woody Island	4	Y	Flats*: Turbinaria* Slope*: Goniopora*
Little Woody Is	2	N	Alcyoniidae

Table 1: Summary of values for key biodiversity hotspots.

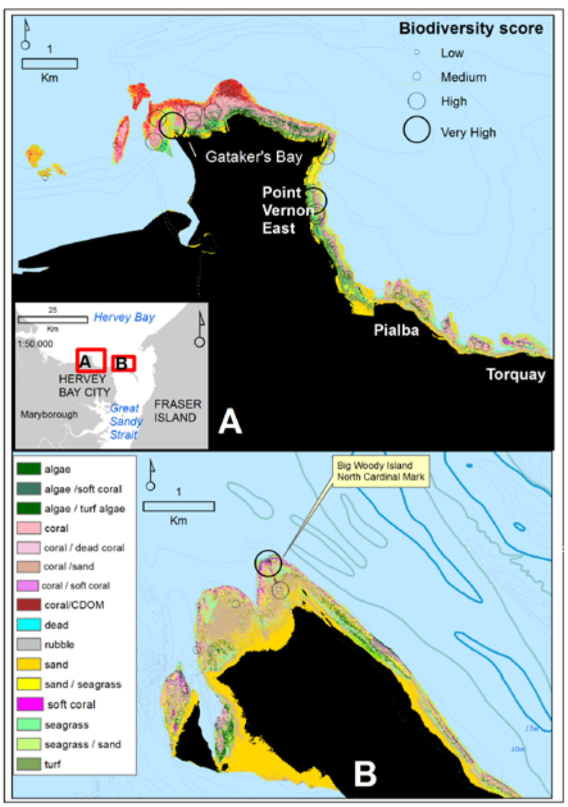

Figure 2: (A) Mainland and (B) Great Sandy Strait, showing coral reef benthic substrates and biodiversity scores. Highest scores were recorded at Gataker's Bay, Point Vernon East and Big Woody Island North Cardinal Mark. Gataker's Bay, Pialba-Torquay and Big Woody Island showed reef building structure.

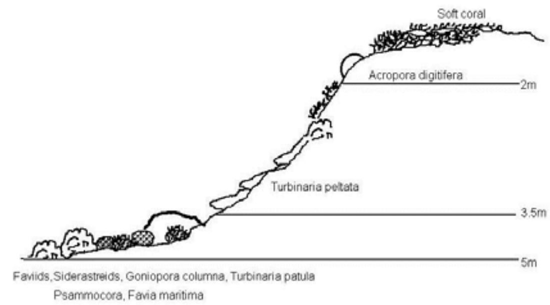

Figure 3: Depth zonation of corals at Big Woody Island North Cardinal Mark.

Biodiversity results

On the mainland the supervised classification substrate map revealed fringing coral communities of high live coral cover (>85%) surrounding the rocky peninsula, Point Vernon (Fig. 2A). Patch reefs occurred on soft sediments either side of the peninsula. Incipient reef development was evident at Gataker's Bay and at patch reefs from Pialba to Torquay, where back-reef sediment depositional features were identifiable. Well-developed reef slope/crest/flat zonation was visible on Big Woody Island in the Great Sandy Strait (Fig. 2B, Fig. 3).

The cluster analysis and SIMPER groups differentiated spatial patterns in dominant taxa. On the mainland *Goniopora* dominated the reefs from Gataker's Bay west, while *Turbinaria* dominated reefs from Point Vernon eastward. Reefs of the Great Sandy Strait were dominated by *Turbinaria* in shallow water and *Goniopora* in deep waters. Further south, Little Woody Island reefs were sparsely populated with soft corals, sponges and gorgonians.

A total of 52 hard coral species were recorded by REA surveys (46 spp - DeVantier 2010; 6 extra spp – Zann 2011). Unusually high species diversities of *Turbinaria* (8 spp) occurred at Point Vernon East and *Goniopora* (8 spp) occurred at Gataker's Bay. Uncommon high latitude species included: *Acanthastrea lordhowensis and A. hillae, Acropora bushyensis, Turbinaria radicalis, T. bifrons and T. conspicua.* Large monospecific stands of *Acropora digitifera* (300-400m^2) were present at several mainland locations and at Big Woody and Round Islands. Large massive colonies of family Faviidae and Siderastreidae at Gataker's Bay and Big Woody Island are indicative of longevity (DeVantier 2010). The diversity results revealed that points and sheltered bays were biodiversity hotspots e.g. Big Woody Island (31spp), Point Vernon East (41spp) and Little Woody Is (44 spp) (Fig. 2, Table 1). However not all reef-building reefs were highly diverse (e.g. Pialba-Torquay *Turbinaria* reefs).

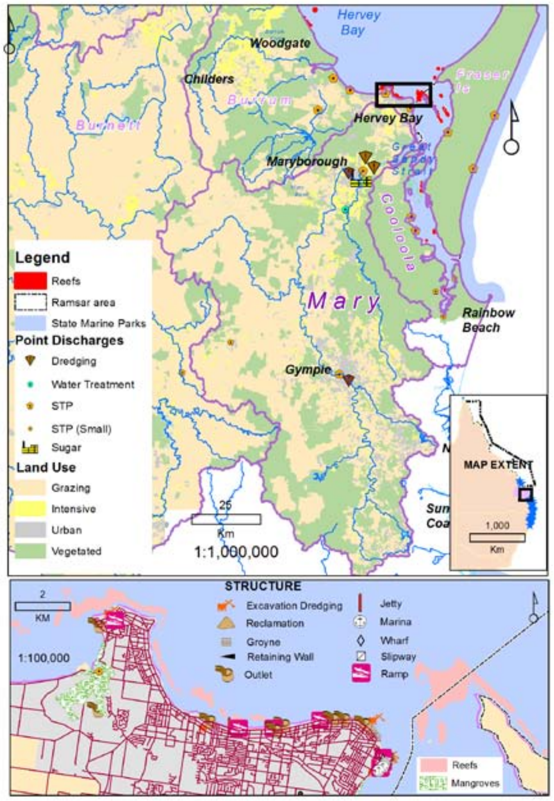

Figure 4: (top) Point sources and diffuse pollution sources from intensive agriculture (sugar), cleared riparian areas and grazing contribute sediment, nutrients and chemicals to the Mary catchment (QLUMP data). (bottom) Structures, shoreline activities and hardened surfaces may impact on coral health (DERM data).

Risk Analysis

Risk observations provided evidence of both cumulative and catastrophic effects. Cumulative effects were evident in coral health observations (2007) e.g. low levels of bleaching, disease and *Cliona* infestation (DeVantier 2010). Sedimentation was evident at Point Vernon East, where communities deteriorated in 2009 as the *Cliona* infestation killed *Goniopora* colonies (Zann 2012).

Mary River floods are a regular occurrence in Hervey Bay e.g. 1992, 1998, 2008 (Graewe *et al.* 2010). South-easterly winds concentrate the Mary River flood plume along the western coastline of Hervey Bay (MODIS imagery 2008, 2011; Graewe *et al*. 2010). January 2011 flooding in resulted in catastrophic loss of corals at Point Vernon East (Butler *et al.* 2012 in. prep.). Suspended sediments settled over the reefs along the east coast of Point Vernon for several weeks afterwards, resulting in bleaching and coral death (author's observation). Post flood substrate surveys revealed loss of 80% of hard corals and 90% of soft corals at Point Vernon East, but other reefs only experienced slight soft coral loss (Butler *et al.* 2012 in. prep).

Potential sources of sediment, nutrients and chemicals from the Mary catchment's runoff are include intensive agriculture (yellow i.e. sugar cane) and sewage treatment plants in the lower catchment as significant risks contributing nutrients and chemicals (Fig 4 top). Land clearing has contributed to streambank erosion due to a lack of riparian vegetation; and grazing reduces ground cover, resulting in sheet and gully erosion; risks that are well-known and modeled (DeRose *et al.* 2002). Land management is being addressed through catchment management programs implemented by the Mary River Catchment Coordinating Committee.

Many potential urban risks to marine water quality occur in the urban area of Hervey Bay, as shown in Fig. 4. The street network illustrates the confines of current urban areas, but urban expansion is flagged within the projected urban footprint (grey). Increased stormwater (freshwater) runoff is provided by a network of hardened surfaces and expansion of stormwater drainage to the beach. Four boat ramps, a marina and several jetties and wharves indicate substantial recreational and commercial fishing effort. A dredged channel provides access to the boat ramp at Point Vernon. Beaches east of the peninsula are heavily used and measures to address beach erosion include retaining walls, groynes and beach nourishment.

Discussion

The reefs of Hervey Bay and the Great Sandy Strait are unique both in terms of their biodiversity values and their human uses. Only rarely in Queensland do coral reefs coincide with urban centres – the nearest example being Woongarra coast, another subtropical coral community 100km further north growing along a basalt boulder coastline.

Reefs of Hervey Bay are the southernmost known reef-building coral reefs on the east coast mainland of Australia. Mature features of reefs included: reef crests characterised by high percentage cover (e.g. at Big Woody Island); reef flats exhibiting typical back-reef sequences of substrates; and large, presumably old massive colonies. Laterally accreting *Turbinaria* reefs from Pialba to Torquay were particularly rugose and their substrate base was not evident.

Although their species composition was intermediate between that of the GBR and high latitude Moreton Bay, dominance of reef-building *Turbinaria* and *Goniopora* and patchy *Acropora* demonstrate the reefs' affiliations with GBR tropical turbid water nearshore reefs (e.g. Middle Reef off Townsville - Browne *et al.* 2010). Unlike GBR turbid water reefs *Montipora* species are rare in Hervey Bay, but are regularly encountered on the Woongarra coast. Diverse *Turbinaria* and *Goniopora* communities may indicate long-term adaptation to turbid waters in Hervey Bay.

Presence of high latitude species and massive faviids demonstrates similarities between reefs of Hervey Bay and Moreton Bay, also strongly influenced by river discharge. Half of Hervey Bay's hard corals were also recorded from Moreton Bay (based on Fellegara and Harrison 2008). Notable differences are the abundance of large *Acropora* colonies in Hervey Bay, largely absent from Moreton Bay apart from a colony at Myora (Lybolt *et al.* 2010).

Despite the impacts of regular flooding, the reefs are relatively healthy and appear to have persisted over a long time. High percentages of live coral along most of the mainland reefs in 2006 indicated a relatively healthy coral community. *Acropora* colonies, capable of rapid growth (12-19 years old based on their sizes - Done *et al*. 2010) have recruited since the last severe flood in 1992. To address the question of reef recovery post-disturbance more work is required on reproductive characteristics of hard corals, their dispersal modes, duration of planktonic larvae and recruitment patterns.

Little is known about fishing effort, reef fish populations or their role in maintaining reef health. Based on limited surveys Hervey Bay appears to be the southern range limits of tropical species e.g. the Scribbled Angelfish (Maria Berger pers. comm). Maintaining fish habitat in adjacent mangrove estuaries (e.g. Eli Creek, Pulgul Creek and the Mary delta) may be important to promote health of reefs and reef fish post-flood (see Olds *et al.* 2012).

By understanding the specific nature of the reefs and the sources of the pressures on them it is possible to include them in regional and local planning processes. Eliminating pollution facilitates reef recovery post-disturbance. For example macroalgal overgrowth of coral reefs in Kanoehe Bay was reversed by reducing nutrients from sewage treatment plants in a nearby river catchment (Stimson and Conklin 2008). Catchment rehabilitation activities are gradually addressing impacts of sediment and nutrient runoff in the Mary. Better planning is required to address urban development and its future impacts (e.g. from maritime structures, acid sulfate soil disturbance etc.) on the reefs of Hervey Bay. An integrated strategy to monitor the reefs, manage urban stressors and reduce pollutants would help ensure that these unique reefs are available for the enjoyment of future generations of holidaymakers and residents of Hervey Bay.

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