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17A Science to support the coral triangle initiative

Applying habitat maps and biodiversity assessments to coral reef management

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Abstract. The Khaled bin Sultan Living Oceans Foundation is conducting a five year Global Reef Expedition (GRE) to map, characterize and assess coral reefs and develop tools and information to assist local managers in their conservation and management activities. Measurements of coral demographics, mortality and recruitment are combined with assessments of benthic cover types, biomass of algal functional groups, population structure of commercially-valuable and ecologically-relevant reef fishes, and environmental resilience indicators using a standardized, rapid, quantitative survey protocol. Concurrent groundtruthing is used to define the bathymetry, identify habitat classes and their spatial distribution and extent, characterize dominant species assemblages, substrate types, and underlying geomorphology, and create high resolution habitat maps. The assessments provide information on 1) the status of coral reefs and species that create and help maintain the health of the reefs and associated habitats; 2) local and regional threats, causes, impacts, and potential mitigation strategies; and 3) patterns of recovery from past disturbances. Coral reef data are compiled into a Geographic Information System (GIS) database with satellite imagery, habitat maps, and other physical and oceanographic GIS data layers, resulting in a landscape-scale tool useful for marine spatial planning. Following completion of the Red Sea, Caribbean and Eastern Pacific (June 2012), the GRE will focus on the Indo-Pacific, with research in the coral triangle beginning in 2013. The potential use of this information to identify sites of high resilience for inclusion into MPA networks is presented using an example from Al Wajh Bank, Saudi Arabia.

Key words: Geographic Information System Database, GIS, marine habitat mapping, resilience assessments, coral and fish demographics, algal functional groups.

Introduction

A recent focus of applied coral reef research involves an examination of coral reef health and resilience, in attempt to identify strategies that could be incorporated into management to enhance the ecological resilience of these ecosystems (Hughes et al. 2005). *Ecological Resilience* describes the capacity of a system to respond to disturbance while still retaining essentially the same function, structure, identity and feedbacks. After a mass mortality of corals, a resilient coral reef should exhibit the ability to maintain or restore its pre-disturbance structure and function without undergoing a permanent shift to a less preferred (e.g. algal dominated) state (Obura and Grimsdith (2009). Since 1998, many Indo-Pacific reefs have sustained high levels of damage from bleaching events and other acute disturbances, many of which appear to be increasing in frequency and severity. Unfortunately, coral reef managers have little control over these and other stressors associated with climate change. Furthermore, sites with chronic human impacts are less likely to resist mortality during acute disturbances, and subsequently recover from these large-scale events may be delayed or prevented. By addressing localized human impacts, coral reefs may be better able to cope with stressors associated with climate change, and recover quickly from both natural and anthropogenic impacts (Jennings and Kaiser 1998; Worm et al. 2006; Knowlton and Jackson 2008).

A detailed characterization of resilience involves an examination of the entire scope of positive and negative factors affecting the ecosystem. This includes ecological, environmental and physical parameters, as well as social factors, such as patterns of resource uses and extraction, type and extent of pollution, presence of invasive species, and effectiveness of existing conservation and management efforts. Quantitative indicators or measurable aspects of the level of resilience include: 1) functional group abundance, species diversity and community redundancy, with emphasis on corals, algae, large motile invertebrates and fishes; 2) the ecological interactions that drive dynamics within and among these groups; 3) habitat and environmental influences that directly affect reef associated organisms and interactions between them; and 4) external drivers of change, including anthropogenic and climate factors and the level of connectivity with other reefs, which allow influx of new colonizing species through dispersal of larvae to the disturbed reef area and subsequent recruitment (Roberts 1997; Nystrom et al. 2008; Green and Bellwood 2009).

Because of the complexity of coral reefs and numerous parameters that affect resilience, it is challenging to assess resilience through a single assessment. Benthic assessments often rely on different metrics to assess "health" and the level of detail and methodology may vary significantly among methods. For instance, the most common metric for corals is live cover, but this measure alone may be inadequate as it provides no information on colony abundance or size structure, two key indicators of the impact of disturbance and state of recovery (Bruckner 2011). Both the Atlantic and Gulf Rapid Reef Assessment (AGRRA) and the IUCN Resilience Assessment protocols incorporate coral population dynamics, but each emphasizes different aspects (Obura and Grimsdith 2009; Lang et al. 2010). The AGRRA protocol collects detailed measures of colony size (length, width and height) for each coral while the IUCN protocol estimates size and places each coral into one of five size classes. The IUCN method records the numbers of dead corals, but it does not include measures of partial mortality, which may result in an underestimate of the original size of the colony as only the live portion is considered when classifying colony size. Both survey approaches include assessment of recruits, which are indicators of the potential for recovery following disturbances.

During the Global Reef Expedition (GRE) rapid assessments are conducted to identify locations that exhibit high resilience to climate change. Concurrently, high resolution habitat maps are developed to illustrate the spatial distribution and size of different habitat types, and assist managers in delineating and designating marine protected areas and marine zoning. This manuscript provides an overview of the habitat mapping program and rapid assessment protocol being implemented during the GRE. An example of an approach to identify the most and least resilient reefs is presented using coral and environmental data from two adjacent sites within the lagoon of Al Wajh Bank, Saudi Arabia.

Material and Methods

From May 10-22, 2008, coral reef assessments and groundtruthing were conducted in Al Wajh Bank (25°35'N, 36°45'E), in the Saudi Arabian Red Sea (Fig. 1). A total of 2147 sq km of shallow marine habitat was surveyed in the Al Wajh study areas. This included 417 km of bathymetric data (145,087 soundings), 410 video drops (3.4 hours of video footage) and SCUBA assessments in 20 locations.

The mapping program uses multispectral satellite imagery obtained from DigitalGlobe's WorldView 2 satellite. Ground truthing data acquisition focuses on water depth soundings, optical measurements, and accurately located habitat census, with the survey vessel's track routed to include a range of depth contours across a variety of seafloor types. Continuous bathymetry is acquired using a hydrographic survey-grade acoustic sounder. The sounder operates over the 200 kHz range, emitting an acoustic pulse ten times per second and delivering an accuracy of ± 0.1m to an operating depth of 200m. At selected points (e.g. distinct changes in bottom features), a tethered video camera is deployed and run parallel to the bottom. Both devices are linked to a high accuracy dGPS unit. Additional characterization of sediment and hard substrates and habitat features involves sub-bottom profiling equipment (Stratabox and Hydrobox), fine scale photo-transect surveys, sediment samples and light reflectance measures. Much of the field effort centered on collecting the necessary data for correcting the effects associated with the attenuation of both the incident and reflected light as it passes through the atmosphere and water column prior to satellite detection, as well as training the algorithms needed to classify the different habitats; namely bathymetric, in-situ spectral, and ground truth data (see Bruckner et al. 2011).

Figure 1: Location of Al Wajh Bank, Saudi Arabia.

The rapid assessment protocol applied during the Global Reef Expedition (GRE) combines aspects of the Atlantic and Gulf Rapid Reef Assessment (Lang et al. 2010) and the IUCN Resilience Assessment of Coral Reefs protocol (Obura and Grimsditch 2009), with additional parameters. Quantitative data are obtained on 1) coral community structure (diversity, size structure, partial mortality, and condition) using 10 m X 1 m belt transects, and coral recruitment (five 0.25 m^2 quadrats per 10 m transect); 2) diversity, size and abundance of over 100 commercially-valuable reef fishes (food and ornamental fishes) and ecologically-relevant functional groups of reef fishes (e.g. herbivores, invertebrate feeders and piscivores) using 30 m X 1 m belt transects; 3) cover and abundance of major functional groups of algae (turf algae, macroalgae, crustose coralline algae and erect coralline algae), corals, and other benthic invertebrates using a point intercept method (100 points per 10 m transect); and 4) approximately 50 other ecological and environmental resilience indicators. These are quantified (e.g. abundance of corallivores, disease prevalence), ranked on a scale of 1-5 (e.g. rugosity, slope), measured off satellite imagery (e.g. reef direction and size, distance from land, to nearest reef and associated habitat, and to deep water), or obtained from external sources (e.g. sea surface temperature). Coral reef assessment data are incorporated into a GIS database with satellite imagery forming a base layer, high resolution bathymetric and habitat maps developed through this program, and other available data layers.

Results

Habitat classification

A total of 2147 sq km of shallow marine habitat was surveyed in the Al Wajh study areas. This included 417 km of bathymetric data (145,087 soundings) and 410 video drops (3.4 hours of video footage) (Fig. 2a). These surveys characterized habitats within the large (>1400 sq km) central lagoon and along the barrier reef, located about 26 km offshore, including islands and associated reef formations, grassbeds, mangroves, and algal communities (Fig. 2). The bank and adjacent coastline to the north and south supported reefs that had developed in open and closed sharms, mainland and island fringing reefs, platform reefs, reticulate reef systems, submerged patch reefs, cay reefs, lagoon pinnacles, a well developed barrier reef, and an offshore horst. Two deeper submerged ribbon reef systems were identified outside the bank, due south. Much of the habitat in the south consisted of a reticulated reef structure formed by columnar *Porites* colonies. The barrier reef system contained an exceptionally wide reef flat, exceeding 50 m in width in many places. Extensive reef habitat was also found around the small islands within the lagoon, and dense thickets of *Acropora* spp. were identified in several shallow (1-5 m depth) nearshore locations. A total of 15 habitat types were identified in Al Wajh Bank (Fig. 2b). Bathymetry of the bank is shown in figure 2C.

Biotic community structure

Twenty locations were examined using SCUBA and additional sites were evaluated by snorkeling. Reefs contained 52 genera of scleractinian corals. The reef framework was constructed by columnar *Porites*, and this genus was the dominant live taxon. Next most common were *Acropora, Millepora, Montipora, Goniastrea, Favia, Pocillopora, Stylophora* and

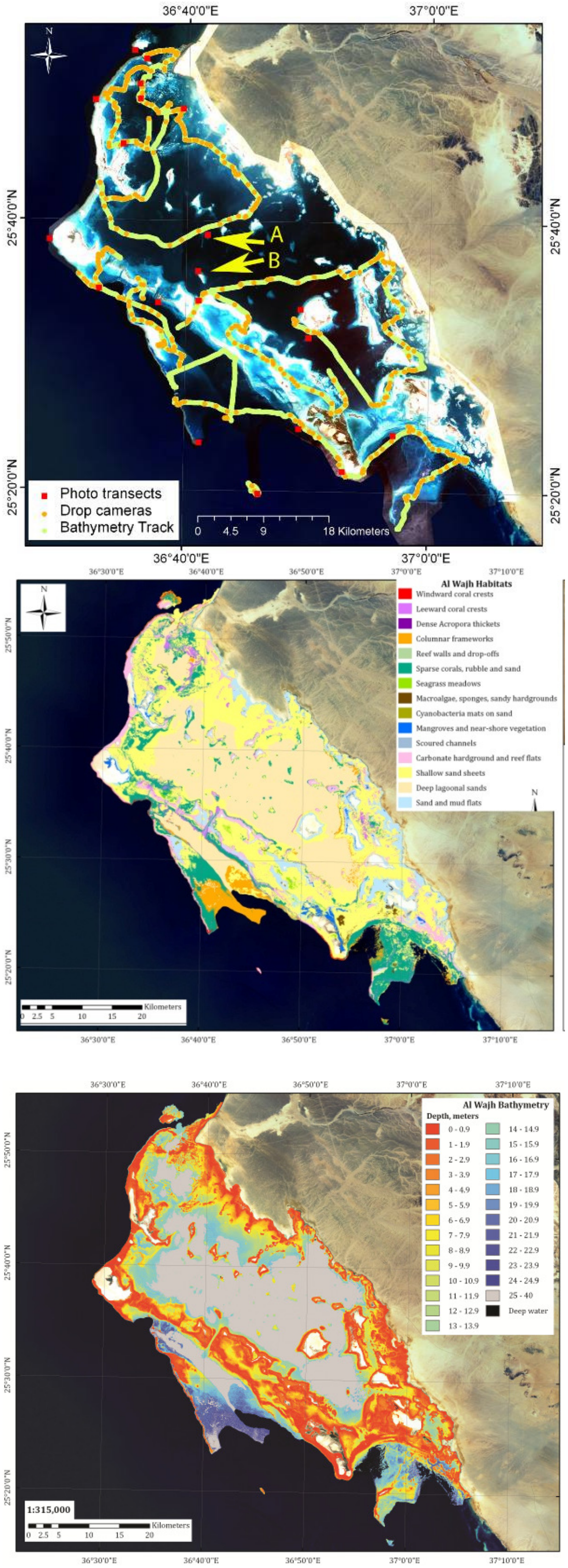

Figure 2: Al Wajh Bank, Saudi Arabia. A. QuickBird multispectral satellite imagery with the acoustic bathymetric track, drop camera locations, and SCUBA assessments; site A and B are highlighted. B. Habitat map. C. Bathymetric map. Scale= 1: 315,000.

Echinopora, respectively. Living coral cover was highest in the shallow reef crest and fore reef on the outer barrier reef (1-5 m depth; 30-70%). Dense *Acropora* thickets on shallow inner patch reefs in the northern sector, in turbid water, also had high cover (50-80% cover). Moderate cover was observed at mid depths (7-12 m depth; 20-30%) and low cover at the base of the reef slope (<5-30%) on outer sites. Most reefs (pooled depths) were dominated by small colonies (1-20 cm diameter), with larger corals on the barrier reef (Fig. 3).

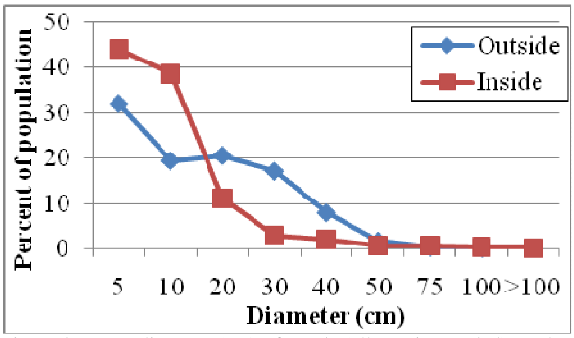

Figure 3: Mean diameter (cm) of corals (all species pooled) on the barrier reef (outside) and on lagoonal reefs (inside).

In most nearshore and lagoonal sites coral cover was lower and reef fish communities were depauperate. There was a notable absence of top predators, and other species occurred in low numbers and were of a small size. Predators were richer on offshore barrier reef locations and included many commercially-important groupers, occasional sharks, snappers, wrasse and other species, although most were juveniles and subadults (< 30 cm total length). Herbivorous fishes were more abundant than predators, although most were also small (< 30 cm total length) and dominated by juveniles.

Benthic substrates supported settlement of coral recruits. Cover of macroalgae (<5%) and turf algae (5-10%) was low in all locations. Cover of crustose coralline algae was higher (3-10%) on outer sites than lagoonal reefs (1-5%). At the base of reefs, especially where the *Porites* framework was dead, much of the substrate was colonized by soft corals (e.g. *Xenia*).

Identification of a resilient lagoonal reef

A comparison of two lagoonal reefs (Site A and B, Fig. 2a) illustrates the large variation in resilience between neighboring sites. Both reefs were similar in structure. Coral communities begin approximately 50 m from the shoreline (2-3m depth), gradually slope to about 12 m, and terminate in sand. Both reefs were is constructed of columnar and massive *Porites* colonies with sand patches (0.5-1 m diameter) between coral heads. In Site A, coral cover was <5%. The framework consisted of dead columnar and massive *Porites* colonies colonized by massive, plating and branching corals that had also subsequently died. Colonies of *Porites lobata* that were still living (n=145) had a mean diameter of 44 cm, but live tissue remnants on these skeletons were only 9 cm in diameter (Fig. 4). Most other surviving corals were also missing 60-90% of their tissue. Massive *Echinopora* colonies (the dominant remaining taxon) exhibited a high amount of recent mortality from disease and predation (n=12, 6%). At Site B the columnar and massive *Porites* framework was mostly live, with cover ranging from 20-50%. The population was dominated by medium to large (mean = 43 cm) *P. lobata* colonies with low levels of partial mortality (mean tissue mortality = 8%). Other dominant corals in Site B included *Acropora, Pocillopora, Goniastrea, Echinopora, Lobophyllia* and *Favites* and 18 other genera, all of which were mostly dead in Site A. Moderate levels of recruitment were apparent in both areas, although higher numbers of recruits were recorded at Site B. Most recruits and juveniles consisted of species other than *Porites,* especially branching corals in the genus *Acropora* and *Pocillopora.* Site A had high cover of *Xenia*, and sediment patches and dead corals were often colonized by cyanobacteria; these were rare in Site B.

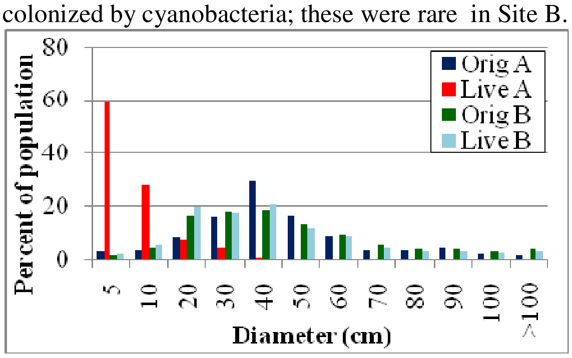

Figure 4: Population structure of *Porites lobata*. Bars represent the original size of colonies (dark blue) and size of live tissue remnants (red) at Site A (n=145), and the original size of colonies (green) and size of tissue remnants (light blue) at Site B (n=259).

Resilience indicators

The primary human impact to Al Wajh is fishing pressure (hand lines and fish pots), particularly in the lagoon. In addition to a large number of artisanal fishing boats, fish traps were widespread within lagoonal sites, and fishing line was frequently found.

Sea surface temperature data obtained for the period from 1997-2008 suggest that acute temperature stressors were minimal over this period, while chronic high temperatures occur in summer, in lagoonal sites, but not on the outer sites. Seawater temperatures on the barrier reef appear to be moderated by adjacent deep water, waves, winds and strong currents. Winter winds come from both southwest and northeast, converging in the central Red Sea. Summer winds flow from north to south. Lagoonal reefs, especially those adjacent to wide, shallow sand flats (Site A and Site B) exhibited the potential for considerable heating, due to pooling of water. The barrier reef was perforated by several narrow channels, which enhanced flushing of the lagoon. Site B was adjacent to one of the largest channels, which may have helped maintain cooler temperatures, reducing the potential for bleaching during periods of temperature stress; site A was distant from the channel.

Discussion

Al Wajh Bank contains the most extensive continuous coral reef system found off the Saudi Arabian Red Sea coastline. The bank and adjacent coastline support the greatest range of reef types in the northern Red Sea, many which contain high cover and diversity of living corals. Evidence of several large scale mortality events associated with past bleaching events and outbreaks of coral-eating predators (COTs seastars) was apparent (DeVantier, 2000). Most reefs examined in this study show signs of regeneration, including moderate recruitment and survival of tissue remnants that are continuing to grow, and substrates were in relatively good condition (e.g. little macroalgae and turf algae, moderate cover of crustose coralline algae). Nevertheless, reefs within the lagoon are at a critical threshold and could fail to recover from future disturbances. Firstly, the region is under increasing pressure from artisanal fisheries (Bruckner et al. 2011). Most of the fishing occurs within the lagoon, where temperature perturbations are greatest. In disturbed locations (Site A), few large corals survived; high numbers of dead corals in growth position were noted and remaining live colonies were greatly reduced in size due to partial mortality. The presence of cyanobacterial mats, few detritivores (e.g. sea cucumbers), a scarcity of large herbivores, and high cover of *Xenia* carpeting much of the *Porites* framework all indicate that substrate quality may be declining. An adjacent site (Site B) with a similar structure and reef framework did not experience extensive coral losses possibly due tidal flushing and strong currents that mitigate temperature stresses. Site B is more resilient to climate stressors, but remains vulnerable due to the low fish biomass.

As climate related stressors continue to increase, it is critical that human impacts are reduced. Because of the unique coral reef ecosystems found in Al Wajh, and the extensive associated nursery habitats (e.g. mangroves and seagrass beds), this area has been recommended for inclusion in a network of marine protected area. Yet, it is unlikely that the entire region would be afforded protection. Thus, those reefs under highest human stress that illustrate high resilience (Site B) should be of a high priority for protection. The high resolution habitat maps completed by the Living Oceans Foundation provide a landscape scale tool to identify the distribution, locations and size of coral reefs and associated habitats within an area. The rapid assessments identify the condition of representative reefs in the region, threats, presence (or absence) of key resilience indicators, and can be used to identify specific reefs that exhibit high resilience to climate stressors. Together, these data and tools can assist in marine spatial planning on a landscape scale.

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References

Bruckner AW, Alnazary H, Faisal M (2011) Paradigm shift for fisheries management to enhance recovery, resilience, and sustainability of coral reef ecosystems in the Red Sea. In Sustainable Fisheries: Multi-Level Approaches to a Global Problem. American Fisheries Society. pp 85-111

Bruckner A, Rowlands G, Riegl B, Purkis S, Williams A, Renaud P (2011) Khaled bin Sultan Living Oceans Foundation Atlas of Saudi Arabian Red Sea Marine Habitats. Panoramic Press, p 262

Bruckner AW (2012) Static measures of resilience of Caribbean coral populations. Rev Biol Trop 60:39-57

DeVantier L, Tourak E, Al-Shaikh K, De'ath G (2000) Coral communities of the central-northern Saudi Arabian Red Sea.. Fauna of Arabia 18:23-66

Green AL, Bellwood DR (2009) Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience – A practical guide for coral reef managers in the Asia Pacific region. IUCN working group on Climate Change and Coral Reefs. IUCN, Gland, Switzerland. p 70

Hughes TP, Bellwood DR, Folke C, Steneck RS, Wilson J (2005) New paradigms for supporting the resilience of marine ecosystems. Trends Ecol Evol 20:380–386

Jennings S, Kaiser MJ (1998) The effects of fishing on marine ecosystems. Adv Mar Biol 34:201-352

Knowlton N, Jackson JBC (2008) Shifting baselines, local impacts, and global change on coral reefs. PLoS Biol 6: e54

Lang JC (2003) Status of coral reefs in the Western Atlantic: results of initial surveys, Atlantic and Gulf Rapid Reef Assessment (AGGRA) Program. Atoll Research Bulletin 496:1-630

Nyström M, Graham NAJ, Lokrantz J, Norström A (2008) Capturing the cornerstones of coral reef resilience: linking theory to practice. Coral Reefs 27:795–809

Obura DO, Grimsdith G (2009) Resilience assessment of coral reefs – manual. IUCN working group on Climate Change and Coral Reefs. IUCN, Gland, Switzerland.

Roberts CM (1997) Connectivity and management of Caribbean coral reefs. Science 278:1454-1457

Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA., Stachowicz JJ, Watson R (2006) Impacts of biodiversity loss on ocean ecosystem services. Science 314:787-790