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Spatial and temporal recovery patterns of coral reefs within the Gulf of Oman (United Arab Emirates) following the 2007 cyclone disturbance

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Abstract. In June 2007 Cyclone Gonu, the most powerful storm in the region in 60 years, impacted reefs in the United Arab Emirates along the Gulf of Oman coastline. The extent of destruction of the reef corals varied considerably depending on site, taxa and colony morphology. This study describes the short-term recovery of corals following the cyclone disturbance. Monitoring stations have been installed near the cities of Dibba and Fujairah. Each station consists of two primary components; (i) transect markers that create a three-ray pattern for repetitive photographic surveys, and (ii) a settlement plate rack with horizontal and vertical limestone tiles. Analyses of the transect photographs provide spatial and temporal comparisons such as coral area cover, colony size frequency distributions and colony growth rates. Examination of the settlement plates indicates coral larvae recruitment into the area, which may also indicate future shifts in community structure. Site data such as hourly seawater temperatures measured approximately 0.5m above the reef, sea urchin and crown-of-thorn starfish densities, and rugosity (topographic complexity) are evaluated in relation to the spatial and temporal patterns. While this study focuses on the short-term recovery of these reefs, future studies may continue to track their long-term progression at the permanent monitoring stations.

Key words: Cyclone Gonu, hurricane disturbance, recovery, Gulf of Oman.

Introduction

Coral communities in the eastern United Arab Emirates (northwestern Gulf of Oman) exist in shore-parallel patches and around rock islands. Coral cover in this area has typically been 30-40% at depths of 4-12m. The overall condition of corals in the Gulf of Oman had been relatively stable prior to June 2007. Upwelling mitigates elevated SST anomalies that lead to bleaching elsewhere and storm damage has been uncommon. On occasion, coral communities have experienced localized temporal variability due to crown-of-thorns starfish outbreaks and periodic recruitment episodes (Rezai et al. 2004).

In June 2007, Cyclone Gonu hit the Arabian Peninsula as the strongest storm since recordkeeping began in 1945. Following such a disturbance, coral community structures are reshaped based on the recovery of the surviving colonies and the recruitment of new individuals into the community (Hughes 1989; Smith and Hughes, 1999; Riegl 2001; Loch et al. 2003; Lirman 2003; Golbuu et al. 2007; Guzman and Cortes 2007). Positive recovery outcomes include the continued growth of undamaged colonies, fragment reattachment, and remnant tissue regrowth on partial-mortality colonies. Negative recovery outcomes include subsequent mortality due to disease resulting from compromised colony health, transportation of fragments to unsuitable locations, and the collapse of reef framework resulting from bioerosion. Recruitment of new individuals may be the result of sexual reproduction of local surviving colonies or the immigration of larvae that have dispersed over long distances. Sexual reproduction of local surviving colonies may be negatively impacted by sublethal stresses that require increased energy expenditure for maintenance, repair and growth. Fecundity may be decreased and reproductive cycles may be interrupted, delayed or skipped in such colonies (Harrison and Wallace 1998).

The objective of this study was to compare the short-term recovery patterns between and among the coral communities offshore Fujairah and Dibba, UAE. Data collected from permanent monitoring stations shall be used to describe the community structures of the surviving colonies, as well as the recruitment patterns of new individuals into the population.

Methods

Monitoring stations were installed in areas representing various levels of disturbance along coastal Dibba and Fujairah, United Arab Emirates. The monitoring stations consist of three replicate 10.0m x 1.5m belt transects in a three-ray pattern (Fig. 1). A settlement plate rack serves as the center point of the station. Three transect markers are cemented into the nearby reef, approximately 12m from the center marker and at 120° angles from each other. Temporary lines are strung from the center marker to each of the end markers to create the three rays of the star pattern. These transect markers ensure the repeatability of photographs and benthic measurements (i.e. rugosity, slope, depth, sea urchin abundance) by marking the start and end points of the surveys.

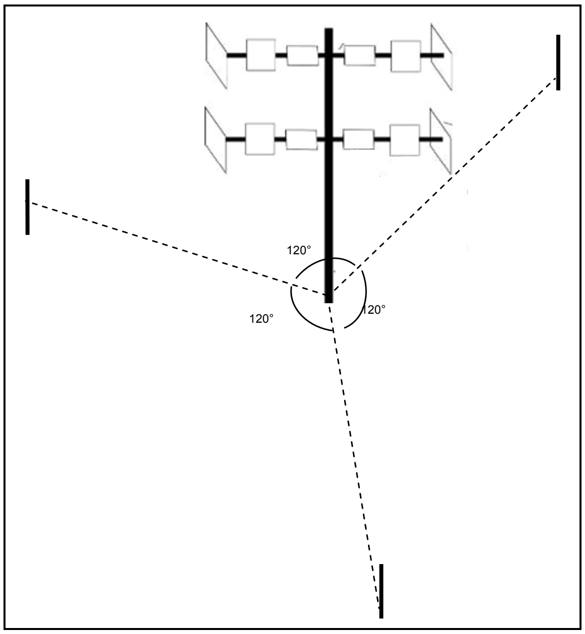

Figure 1: Three-ray monitoring station design. A settlement plate rack serves as the center point. Transect markers are permanently cemented into the reef to create the three rays of the star pattern.

Limestone or terra cotta tiles (10cm x 10cm x 1 cm thick) were attached to the settlement plate rack. The tiles were positioned (i) horizontally, (ii) vertically and parallel to the rack, and (iii) vertically and perpendicular to the rack. Tiles in positions (i) and (ii) were in pairs to create unshaded upper and shaded lower surfaces as well as cryptic space in the gap between the tiles. Tiles will be replaced annually and examined for coral spat.

Digital images were be taken along each of the transect rays using housed Olympus C-750/C-770 cameras (4 mega pixel) and 16 mm wide-angle conversion lenses set 50 cm above the reef inside rigid photo-framers. These photographs were analyzed for hard coral area cover. Image mosaics were created and individual colony surface areas were be traced and color coded by species to create a visual representation of each transect ray for spatial and temporal comparisons. The hard corals in each photograph were identified to species and surface areas (planar view) determined using Coral Point Count with Excel extensions (CPCe) (Kohler and Gill 2006). The data to be derived from CPCe included percent live coral cover, coral density as individuals per m^2, number of species present, average colony size, size frequency distribution, and diversity indices.

Results

The cyclone disturbance had varying effects on the coral communities depending on site, taxa and colony morphology. The initial assessment of the four monitoring stations in August 2007, two months following Cyclone Gonu, indicated that resilient taxa (i.e. faviids and poritids) were minimally damaged, while the susceptible taxa (i.e. acroporids and pocilloporids) were moderately to heavily damaged. The least damaged sites, Dibba South (DIBB2) and Mirbah North (MIRB1), included areas with massive colonies of *Platygyra* and *Favia* spp. that survived relatively unscathed, showing little or no signs of scouring or partial mortality. Dibba Rock (DIBB1) was a moderately damaged site that included areas of dense monospecific stands of *Pocillopora damicornis* from which individual colonies were dislodged or broken. Mirbah South (MIRB2), an area that had been dominated by tabular *Acropora clathrata,* was the most severely damaged site with large sections being completely razed.

Benthic data collected from the monitoring stations in August 2007 are shown in Table 1. Rugosity ratios (topographical complexity) measured 1.1-1.2, indicating the near flattening of reefs (1.0 indicates a horizontal surface). Live coral cover ranged between 24-45%, primarily due to the survival of massive colonies and the presence of detached fragments with live tissue. Coral densities varied between sites (5.2 – 33.3 colonies per m^2), with higher densities being the result of extensive breakage and fragmentation of branching and bushy colonies. The average colony surface area ranged between 98-452 cm^2, with the lower averages occurring at sites with extensive fragmentation.

Between 7-14 species were inventoried along the transect rays at each site (Table 2). This was higher than anticipated, based on previous site visits, because less common cryptic taxa were now obvious due to the removal of the branching and bushy coral overstories. Four species of massive scleractinians (*Favites pentagona, Platygyra daedalea, Porites lutea, Siderastrea savignyana*) were present at all four monitoring stations.

Table 1: Benthic data collected at monitoring stations in August 2007. Sites are presented from north to south, with DIBB1 being the northernmost site and MIRB2 being the southernmost site.

	DIBB1	DIBB2	MIRB1	MIRB2
Rugosity Ratio	1.1	1.2	1.1	1.1
Live coral cover (%)	45	24	30	33
Coral density (colonies per m^2)	18.7	5.2	9.5	33.3
Average colony surface area (cm^2)	239	452	314	98
Sea urchin density (individuals per m^2)	0.6	2.2	0.6	0.0

Table 2: Taxa present at monitoring stations in August 2007. Species inventories are conducted along the transect rays at each monitoring station.

	DIBB1	DIBB2	MIRB1	MIRB2
Acropora clathrata	X		X	X
Coscinaria columna		X		X
Cyphastrea microphthalma		X		
Favia pallida		X	X	X
Favia speciosa		X		X
Favites pentagona	X	X	X	X
Platygyra daedelea	X	X	X	X
Pocillopora damicornis	X			X
Porites harrisoni	X	X		X
Porites lutea	X	X	X	X
Porites solida			X	X
Porites nodifera		X		X
Psammacora spp.				X
Psuedosiderastrea tamyami				X
Siderastrea savignyana	X	X	X	X

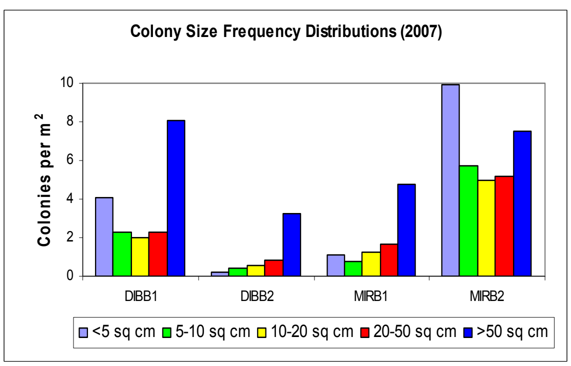

Figure 2: Colony size frequency distributions in August 2007. Large massive colonies (>50 cm^2 diameter) survived at all stations. Large fractions of small individuals (<5 cm^2 diameter) were present where extensive fragmentation occurred during Cyclone Gonu.

Size frequency distributions demonstrated the survival of the large massive colonies (>50 cm^2 diameter) at all monitoring stations (Figure 2). Large fractions of small individuals (<5 cm^2 diameter) were present at DIBB1 and MIRB2 where extensive fragmentation of *Pocillopora* and *Acropora*, respectively, occurred during Cyclone Gonu.

Sea urchin densities ranged from 0.0-2.2 individuals per m^2 along the transect rays (Table 1). Multi-year sampling shall indicate if this is a normal population or if the abundance was reduced by the cyclone. Sea urchin densities are important as these herbivores maintain the standing algal crop that may otherwise outcompete coral recruits for available substrate.

No crown-of-thorn starfish (COTS) were observed along the transect rays or within the general vicinities of the monitoring stations. COTS have been shown to preferentially feed on branching taxa (McClanahan et al 2005). Therefore, the presence of COTS may influence the recovery of taxa that are also susceptible to mechanical damage from cyclones (i.e. acroporids and pocilloporids). If COTS are observed in subsequent surveys, COTS densities shall be calculated for each site and compared with recovery patterns for branching taxa.

Discussion

The results presented herein are from the first of several surveys to be conducted in order to compare the short-term recovery patterns between and among the coral communities offshore Fujairah and Dibba, UAE. Rugosity and coral cover may increase over time if fast-growing species (i.e. acroporids and pocilloporids) recover quickly. Coral densities may fluctuate; increasing if recruits settle onto newly available substrate or decreasing if fragments are transported elsewhere by water movement. Taxa inventories may change with the settling of additional species from distant larval sources or if localized extinctions occur from post-storm circumstances such as algal competition or disease outbreaks. Size frequency distributions are expected to vary primarily based on the outcomes of the *Acropora* and *Pocillopora* fragments since the massive colonies, which grow at rates of ~1 cm per year, are unlikely to move between size classes for the duration of this study. The skewness in size frequency distributions can indicate trends in recruitment, survival and growth of coral communities. Communities skewed to the left (i.e. mostly larger colonies) may indicate strong survival of massive colonies with poor post-disturbance recruitment. Communities skewed to the right (i.e. mostly smaller colonies) may indicate extensive fragmentation or heavy recruitment.

While this study focuses on the short-term recovery of these reefs, future studies will track long-term progression at the permanent monitoring stations.

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