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Status and monitoring the health of coral reef using Multi-temporal remote sensing - A case study of Pirotan Coral Reef Island, Marine National Park, Gulf of Kachchh, Gujarat, India

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Abstract. The health status for Pirotan reef (22^{o}60' N, 70^{o}40' E) located in the Gulf of Kachchh, India, has been assessed using health indicators. Indicators of Pirotan Reef health are temperature rise, increase in macro-algae, over-fishing, high sedimentation rate, human influences, and deposition of mud over reef. Field data was carried out on the reef to collect information about the status and to map benthic cover using the line transect method. Indian Remote Sensing Satellite LISS III sensor data of periods 1998, 2000 and 2005 were analysed to zone the eco-morphological zones of the reef into nine classes with an accuracy of 89% to 92% at 90% confidence level. NOAA AVHRR average monthly SST data was analyzed from 1998 to 2005 (March, April, May and June) to identify the effect of temperature rise on coral reef bleaching. Depositions of sand and mud have increased owing to the high sedimentation rate, sand mining and cutting of mangroves. Coral bleaching and stress have resulted in increased macro-algal growth. The Pirotan reef is under severe degradation as is apparent from the indicators of health. Integrated data of multi-temporal and spectral remote sensing data, SST and field data are important to asses the health of Pirotan coral reef. Although not all deleterious processes can be measured directly (e.g. overfishing), many environmental and ecological coral properties can be measured using remote sensing.

Key words: Coral reef health, multi-temporal, Pirotan Island, remote sensing, sea surface temperature

Introduction

Changes in coral reef health and vitality are sensitive indicators of environmental change. The overall coral death is owing to the thermal stress by anthropogenic global warming, new virulent pathogens, chemical pollution, macro-algal competition and high sedimentation.

A "healthy reef" can be characterized as one with high cover of live corals and short algal turfs and low cover by fleshy algae. Associated indicators of a healthy reef are thus high cover of corals, optimum cover of calcareous algae, short algal turfs, low cover of fleshy algae and good fish diversity. The indicators of a degrading reef include decrease in coral cover, increase in massive rounded corals, increase in coral bleaching, increase in coral disease and macro-algae overgrowth. So, the indicators of the healthy reef are the opposite of a degrading coral reef. Understanding the benthic community structure is central to understanding coral reef health. Measuring the percentage of live coral cover for assessing reef degradation is important indicator for comparisons among coral reef health (Burke et al. 2002).

There are also temporal challenges from the heterogeneous and dynamic variations in coral reef communities over time, requiring long time-series observations with enough frequency to determine the state of health of coral reef ecosystems. Satellite sensors have proved to be useful in providing information on reef geomorphology, and broad scale ecological information such as the location of coral, sand, algal and seagrass habitats with accuracies of around 70% (Green et al. 2000). Satellite and airborne sensors are useful for benthic substrates mapping (Bina et al. 1978) and monitoring ecological change (Zainal et al. 1993).

The sensitivity of reef corals to abnormal elevations in water temperature has been known for many years (Jokiel and Coles 1990). Large-scale bleaching episodes indicate that coral reefs are likely to be one of the first ecosystems damaged or destroyed by global climate change (Hayes and Goreau 1991).

We have evolved an indicator-based approach for monitoring health of reefs (mainly satellite-derivable indicators). The indicators tell about the damage already done, current ecological condition and early warning to the reefs. Early warning indicators are sea surface temperature anomaly, turbidity, and the onset of algae. The ecological indicators are diversity (both floral, faunal and habitat), percentage cover of live and dead corals and the damage indicators are the deposition of mud and sand on the reef, erosion, and phase shift. The non-aligned coral zone (NACZ) is on reef tops normally receiving lower wave energy, where the reef flat is commonly formed from randomly scattered ovoid coral colonies with intervening sand patches (Hopley 1982).

The overall aim of this research paper is the development of a health model for coral reef ecosystems based on remote sensing information. This monitoring system should enable not only the efficient mapping of coral reefs, but also the identification of the reefs that are most endangered. This information will significantly contribute to the progress of protecting and restoring the coral reef environments and will in this way add to the sustainable development of these valuable natural resources.

Material and Methods

The Gulf of Kachchh has an assemblage of different ecologically sensitive ecosystems consisting of coral reefs, mangroves, seagrasses, algae/seaweeds (Fig. 1). Due to its rich diversity and fragile nature, the Government of Gujarat in 1983 declared an area of about 457.92 sq km as the Marine Sanctuary and 162.89 sq km as Marine National Park. Pirotan Island is an Arabian Sea island in the Marine National Park, Jamnagar district of Gujarat state, India. It is located 22 km off the coast, consisting of mangrove, coral reef, seagrasses, algae, invertebrates and low-tide beaches, and has an area of 3 sq km. The center of the island is at 22^{o}60'N, 70^{o}40'E. The Marine National park consists of 42 islands. Pirotan Island is the most popular and is one of the only two islands where visitors are normally permitted.

IRS LISS III data (23 m resolution, with 4 spectral bands: green, red, NIR and MIR) of 1998, 2000 and 2005 have been used for mapping the reef in order to know its ecological status. Required sub-images were extracted from all the data sets and were subjected to geo-referencing using Survey of India topographical maps (base maps). The images were subjected to radiometric corrections and atmospheric correction in the ERDAS IMAGINE environment, prior to implementing a supervised classification. The digital number (DN) values were converted to radiance values using the standard published gain and offset values for the LISS III sensor (Nayak et al. 2003). The images were then subjected to atmospheric correction (Green et al. 2000). We have employed here the Dark Pixel Subtraction (DPS) method. High tides modify and reduce the signature coming from the reef-scape, so it is preferred to select data acquired at low tides and clear sky conditions. We used only the low tide satellite images of the study area, so we did not perform a water column correction.

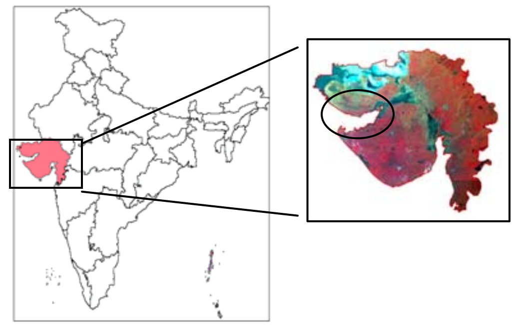

Figure 1: Location of the Gulf of Kachchh study area.

The coral reef habitats were classified using the eco-morphological classification system evolved earlier at the Space Applications Centre, Ahmedabad (Bahuguna and Nayak 1998). On the basis of the spectral properties of the reef features, supervised classification using the Maximum Likelihood classifier was performed for images of all dates. Digital classification accuracy was ascertained by estimating the overall classification accuracy and Kappa Coefficient. Error matrices were generated and the percent accuracy was estimated (at 90% confidence level) based on the number of points verified on ground and the number of failures. During the study period, we collected Line Intercept Transect data (Nayak et al. 2003). Line intercept transects of various lengths ranging from 100 m to 500 m were laid on the reef stretching from the beach seawards to the edge of the reef. After every 20 m, or at each change in zone, observations were recorded. The geographic locations of different points sampled along transect were noted using pre-calibrated Magellion GPS (stand-alone GPS) instrument with accuracy of 10 m. Substrate characteristics were recorded from each sampling location: depth of water, percentage coral, algae and seagrass cover, coral species, size of coral colonies, column of water, and sea surface temperature. We have been collecting ground data for the coral reefs in the Gulf of Kachchh every year since 1998. We collected all the ground data during low tide conditions. During low tide water depth is below 1 m and it is easy to walk on the coral reef from landward to the seaward side (along the transect).

The NOAA/NASA AVHRR Oceans Pathfinder Monthly Sea Surface Temperature images were used to calculate the maximum monthly sea surface temperature of the summer season (March, April, May and June) for 1998, 2000 and 2005.

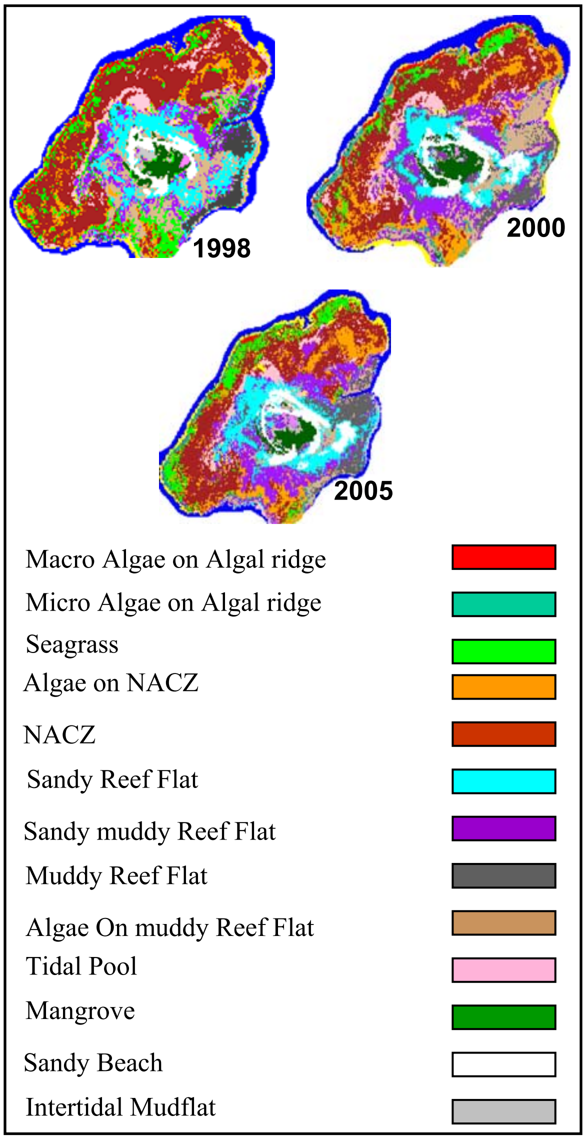

Figure 2: Eco-morphological maps of Pirotan Island reef for 1998, 2000 and 2005.

Results

Reef areas with live coral are predominantly located on the northeastern, western and southwestern areas of Pirotan Island. The entire eastern side has mud deposition. The island itself, located in the center of the study area, is mainly comprised of a horseshoe shaped sand beach, the inward side of which is occupied by mud and mangroves. The reef appears to have been an atoll in earlier times, which has been filled up with mud. The different zones classified using the satellite data were clearly distinguished: algal ridge, mud over reef, sandy muddy reef flat, NACZ, seagrass, algae on NACZ, algae on muddy reef flat (Fig. 2; Table 1). Seventy seven points were verified on the Pirotan reef for the years 1998, 2000 and 2005. There were only five failures in 1998 and 2000 and four failures in 2005. The accuracy was thus estimated to be 89% in 1998 and 2000 and 92% in 2005, all at 90% confidence level. Overall kappa coefficients were 0.85 in 1998 and 2000, and 0.89 in 2005. Major errors in misclassification were because the mangrove class got merged with seagrass, algae and algal ridge, and because muddy reef flat merged with the degraded NACZ.

The NACZ includes the live coral colonies. Live coral cover was determined by using the field data as well as the decrease cover of NACZ by eco-morphological maps during the successive years. Live coral colonies of large sizes and their high percentage are mainly confined to the seaward region of the reef. Maximum coral diversity was observed in the western area followed by northern and northwestern areas. The eastern region is most degraded as indicated by the absence of an algal ridge, presence of thick mud on the reef flat and matty algae on the NACZ.

Eco-morphological Zones	1998	2000	2005
Algal ridge	19.36	45.55	33.33
Seagrass	93.1	38.19	78.93
Algae on NACZ	56.6	122.15	127.17
NACZ	299.57	250.59	295.5
Sandy reef flat	94.00	70.3	138.97
Sandy muddy reef flat	86.7	132.51	176.53
Muddy reef flat	58.67	63.48	88.45
Algae on muddy reef flat	132.3	107.44	58.56
Sandy beach	37.93	61.95	77.29

Table 1: Area (sq km) occupied by the different zones in Pirotan Island reef of 1998, 2000 and 2005.

The areas occupied by the various eco-morphological zones are shown in Table 1. The NACZ characteristically has 25-80% live coral coverage. As the name implies this zone appears first after the algal ridge. On the reef it occupies the greatest area and is broadest in the southwest. Live corals in this zone are mainly *Porites*, *Favia*, *Favites*, *Montipora* and other species. Apart from live corals it also houses a host of faunal species. The inner part of the NACZ has more coral debris, dead coral boulders, pebbles, sand and mud, with negligible live corals. This inner part is considered in degraded condition. The NACZ was reduced in year 2000, which is attributed to the major factors such as anthropogenic influence, sea surface temperature and high sedimentation rate (Table 1).

Algae on muddy sand substrate were mapped on the inner NACZ. The algae on NACZ have been increasing severely from 1998 to 2005 (Table 1). Muddy reef flat follows the NACZ extending up to the Pirotan Island. It is uniformly distributed on all sides and the mud depositions are quite thick (almost 1-2 m in most of the places). The muddy reef flat is also increasing every year (Table 1).

Carpet and matty algae grows on the muddy reef flat. The algae are found to cover larger areas in 1998 and 2000 as compared to 2005 (Table 1). Sand reef flat surrounds the beach on the seaward side with a larger extent on the northwestern side. Mangroves occupy the inward portion from the beach. They are dense and mainly of *Rhizophora* and *Aviceenia* species. The Sargassum is mainly found in NACZ. Onset of Sargassum has shifted from September-October to early December.

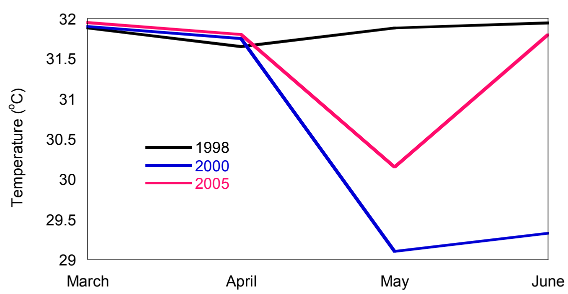

Figure 3: Maximum Sea surface temperature curve of 1998, 2000 and 2005 at the study area.

The effect of elevated sea surface temperature (SST) on the Pirotan coral reef of the Gulf of Kachchh, was monitored during 1998, 2000 and 2005. The temperature varied between 32°C and 29.2°C during summer (Fig. 3). The Pirotan reef areas in the Gulf of Kachchh are shallow, with live coral emerging from the water during low tide conditions. The reefs typically experience comparatively high temperature and seem to be acclimatized to such situations. Nonetheless, the average percentage of bleached corals (12% to 15%) during 1998, 2000 and 2005 has increased. The bleaching of corals occurs in mid March. Massive corals, especially *Porites* sp., were the first to be affected and the other dominant coral species partially/fully bleached were *Acropora* sp. and *Montipora* sp.

Discussion

The results of this study provide several useful points in terms of coral health in the context of reef degradation and disturbance. The recruitment of algal populations is especially critical during coral reef degradation, which usually involves the replacement of hard corals by benthic algae. The loss of live coral cover is often associated with a phase-shift to a system dominated by fleshy algae (Hughes 1994). In the Pirotan reef system the macro-algal (Sargassum) cover on the live coral is increasing every year. During the replacement, algal recruitment is a key but under-recognized step in the invasion and colonization of adult algal populations (Bell and Elmetri 1995). The *Sargassum* on the Great Barrier Reef (GBR), can and will colonize live corals, if conditions such as nutrients or low herbivory are suitable. Available evidence suggests that macroalgal blooms generally will inhibit corals, but also that the mechanisms and outcomes of the interaction vary with different circumstances and life stages. Decline in coral abundance often coincide with increases in macroalgal abundance (Connell et al. 1997). However, other evidence shows variable outcomes of interactions between corals and macroalgae. Corals may also competitively inhibit macroalgal growth (De Ruyter van Steveninck et al. 1988). During the recent massive bleaching on the GBR (early 1998), experimental removal of *Sargassum* canopy showed that the canopy actually protected understory corals from bleaching (Jompa and McCook 1998).

Human impacts, on the other hand, are usually chronic and they degrade water and substratum quality, thus retarding recovery (Wolanski et al. 2003). The concentration of suspended mud, and extent of stickiness and flocculation, can synergistically affect reef benthos organisms after short exposure (Fabricius and Wolanski 2000). In the present study site, the muddy reef flat is increasing due to the heavy discharge of sediments because of human impacts, such as harbor dredging, sand mining, mangrove cutting and overfishing (Nayak et al. 1989; Bahuguna et al. 1992).

River Indus is the major source of the suspended sediments in the Gulf of Kachchh (Deshmukh et al. 2005). Total coral cover was reduced because of the high sediment influx due to cutting mangroves and sand mining (GEC 1997). The eastern side of the gulf exhibits vast areas of dead corals giving a clear indication of mass mortality. Sedimentation is a major controlling factor in the distribution of reef organisms and in overall reef development (Macintyre 1988). Sediment stress has drastically reduced the coral cover and number of species. The effects from sediment influx include partial or total burial of coral colonies, bleaching, and colonization of the coral surface by filamentous blue-green algae and sponges. The reduced light levels also result in domination of the community by deeper fore-reef coral (Acevedo et al. 1989).

Coral reefs are profoundly sensitive to even modest increases in temperature and, in the absence of acclimatization/adaptation, are likely to suffer large declines under mid-range temperature increase (Berkelmans et al. 2004). The Gulf of Kachchh reefs showed an average of 11% bleached coral with no apparent bleaching related mortality. The incidence of bleaching was not uniform every year, in terms of area and depth, but the pattern was the same. The branching corals recovered quickly after temperature reduction, but massive corals took a longer time. Temperatures in the intertidal reefs of the Gulf of Kachchh commonly reach 36^{o}C and higher in reef areas during summer and the bleaching observed could well be attributable to normal summer bleaching related to seasonal temperature rise (Arthur 2000). It is conceivable that coral species in these intertidal reefs are adapted to such seasonal temperature fluctuations (Gates 1990). According to past study conducted in 1995, estimating benthic cover in the Gulf of Kachcch, reported between 1.2% and 1.4% bleached coral in the summer months before the monsoons (Arthur 2000). This suggests that bleaching levels reported in this survey are considerably higher than normal summer bleaching. Elevated temperatures, even below the bleaching threshold may have significant impact on coral health, retarding growth and reproduction (Jokiel and Coles 1990).

These various indicators can be easily derived from remote sensing systems, which are a cost effective monitoring approach. Multi-temporal and spectral LISS III data have been proven effective to monitor and map the coral reef and extract benthic cover information. SST data products are also very important to monitor the temperature around the coral reef areas. So, integration of remote sensing and field data are important tools to obtain the health status of the coral reef. In the next step, selected indicators will be assigned weights based on their relative importance, and used as input to a model of coral reef health.

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