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Realization of a local coral reef monitoring system in the Red Sea using Landsat7 ETM+ data

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ABSTRACT: Remote sensing gives us important information about four aspects of coral reefs: it is useful for determining the configuration and the composition of the coral reef; for monitoring the biophysical parameters of the seas and oceans in which the coral reefs occur and for tracking possible changes over time of these elements. Coral reefs in the Red Sea -offshore Hurghada, Egypt- have been studied using a Landsat7 ETM+ data set dating from 2000. A bathymetric map and a sea bottom-type classification have been made based on different remote sensing techniques supplemented with data derived from field sampling in the study area. Also a change indication map has been constructed, based on the comparison with the ecological situation in 1987 as derived from a Landsat5 TM data set of that year. This basic remote sensing derived information has been combined with other information about elements important to the reefs into a “Coral reef GIS”. This GIS forms the base for integrated coastal zone management and the protection of the precious Egyptian corals. A risk prediction map, on which the location and potential risk factor for each coral reef is indicated, is made based on this GIS. This risk map shows that of the coral reefs in the vicinity of Hurghada, approximately 86% of the reef systems have a medium to high risk potential.

1 INTRODUCTION

Coral reefs are considered as one of the most spectacular marine ecosystems on earth. They are characterised by a tremendous biodiversity and, in many places like the Red Sea (Head, 1987), a high level of endemism. Coral reefs are also a unique marine ecosystem as they are highly productive although often surrounded by water poor in nutrients necessary for primary production (Hoegh-Guldberg, 2000).

But coral reefs not only need our attention because of the importance of their biodiversity and their key role in the tropical marine biosphere. They are also very valuable socio-economic resources. As coral reefs are main fishing grounds and attractors of large numbers of tourists, they generate important contributions to the national income of many, especially, developing countries. Costanza et al. (1997) estimated the total yearly value of resources and services provided by reefs at about 375 billion USD. Coral reefs are also protecting the adjacent coastline against erosion, surges and other impacts of waves and storms. As such they also create an ideal environment for typical coastal habitats like mangroves or wetlands (Bryant et al., 1998). Furthermore, corals are becoming more and more studied by pharmaceutical companies in their search for new medicines (Adey, 2000).

Despite this natural wealth and socio-economic advantages, many threats are posing stress on coral reefs. According to Bryant et al. (1998) 58% of the coral reefs in the world are potentially under threat. The greatest worldwide threats generated by human activities are indicated to be pollution, sedimentation and unsustainable fishing activities (Bryant et al., 1998; Spalding et al., 2001). These negative influences are mainly due to coastal development, inland pollution and erosion, marine pollution, overexploitation and destructive fishing (Bryant et al., 1998). Besides anthropogenic disturbances also natural hazards can destroy the coral reef. A few examples are coral bleaching, storms and outbreaks of crown-of-thorns starfish, *Acanthaster planci* (Souter & Lindén, 2000).

One long-term threat is becoming increasingly worrisome, namely global climate change. The negative effects associated with global change range from an increase of the sea surface temperature, a rising sea level to a greater frequency and intensity of tropical storms (Wilkinson & Buddemeier, 1994; Bryant et al., 1998). These changes will alter the natural environment in which the coral reefs occur and push them to the edge of their ecological thresholds. In that way the coral reefs become more vulnerable to other natural or human disturbances (Wilkinson & Buddemeier, 1994).

Although a lot of research has already been done on coral reefs and their degradation, there is still "a critical need for detailed monitoring and assessment of reef habitats in order to better document where and how coral reefs are threatened and to understand what measures are needed to safeguard them" (Bryant et al., 1998). The ideal approach would be 'multilevel sampling' (Bryant et al., 1998) where detailed, locally sampled information is extrapolated to wider areas using satellite imagery. Four categories of information can be extracted from remotely sensed data: the configuration and composition of the coral reefs, the biophysical parameters of the seas and oceans in which the coral reefs occur and the changes of these elements over time (Phinn et al., 2000).

We have used a Landsat7 ETM+ data set to derive some basic information about the coral reefs in the vicinity of Hurghada, Egypt. The data set has been used to localize the coral reefs, to make a bathymetric map (Vanderstraete et al., 2003a), to map the main geomorphological reef structures (Vanderstraete et al., 2004) and to make an ecological classification in which the main bottom-types occurring in the region (sand, macro-algae, coral and seagrass) are discriminated (Vanderstraete et al., 2004). A Landsat5 TM data set has been processed in a similar way in order to detect possible changes in coastal zone development and related shifts in bottom type composition (Vanderstraete et al., 2003b).

A Geographic Information System (GIS) is best suited for integrating these obtained remote sensing derived products with other data sources. Additional data related to coral reef monitoring can be: socio-economic data about the number of tourists coming to the area, the effective or proposed legislation, the urban development of coastal settlements, detailed information gathered during field trips and underwater monitoring, reported damage sites, information about natural hazards, predator or virus outbreaks, data concerning changing environmental conditions due to local factors or changes due to global change.

The 'Coral Reef GIS' can be used for understanding the spatial characteristics of the coral reefs, for modeling different spatial and temporal processes, to evaluate various proposed management scenarios or to determine potential risk zones that mark the localization of the reefs under potential stress due to changing conditions (Knight et al., 1997; Stanbury & Starr, 1999; Freire, 2001). The result of risk zone mapping is shown in this paper.

The outcomes from the Coral Reef GIS can help as baseline information to support managers in making ecosystem-based decisions (Stanbury & Starr, 1999) for example in identifying multi-use marine protection areas, monitoring coastal development, assessing environmental impacts of natural hazards or legislative decisions, oil spill contingency planning or assessing new fishing grounds (Knight et al., 1997; Stanbury & Starr, 1999; Freire, 2001). These GIS products are also very useful tools in the communication to the general public (Knight et al., 1997). If integrated coastal zone management (ICZM) also covers several additional issues such as information management, capacity building and environmental awareness and education, it will form the key process in the sustainable development of the coastal, in casu coral reef, resources (Wilson et al., 1998).

2 METHODOLOGY

2.1 *Study area*

As test site for the development of a local monitoring system, the coral reefs near Hurghada, Egypt, (27°14'N, 33°54'E) situated in the northern part of the Red Sea, are chosen (Fig. 1). These coral reefs have been selected because they are easily accessible and located in a unique environmental setting. The enclosed Red Sea is completely surrounded by deserts, has almost no water input from rivers and hence very stable physical characteristics such as salinity, temperature and water quality (Edwards, 1987). Although the coral reefs are not under great natural threat, they are suffering from the negative effects of booming tourism and from urban coastal development projects mainly for tourist accommodation and in support of the Egyptian relocation policy.

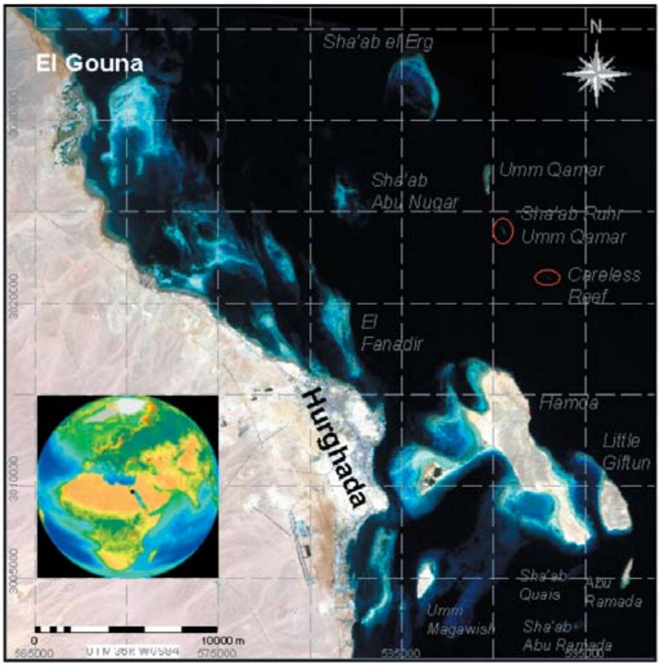

Figure 1. Localisation of the main coral reefs in the study area: Hurghada (Egypt)
Landsat7 ETM+ True Colour Composite (1, 2, 3)
Inset: SeaWiFS Biosphere Globe (http://seawifs.gsfc.nasa.gov/cgibrs/biosphere_globes.pl)

2.2 *Data*

2.2.1 *Field surveys*

Three field surveys have been completed in the Hurghada study area respectively between August 25th, and August 31st, 2001; between March 28th, and April 4th, 2002 and between August 24th, and August 27th, 2003. During these campaigns, more than 600 observations were made at sea. Emphasis was put on depth measurements in the first two campaigns and on bottom type observations during the third. X- and Y-coordinates were measured using a GPS (Garmin GPS 12 XL) in the UTM36-WGS84 coordinate system.

2.2.2 *Satellite data*
A level-1G Landsat7 ETM+ data set (ID: LE7174041000025450; path/row: 174/041) dating from September 10th, 2000 is used to generate the different remote sensing products for the Hurghada study area. Wavebands 1, 2 and 3 are used as the radiation within these wavelengths is not totally absorbed by the water column. The ILWIS 3.0–software is utilised to georeference a sub-scene covering the study area. As ground control points, 27 out of a total of 66 GPS-points measured on land during the field surveys, are used. The georeference, based on a specific UTM-coordinate system (UTM R36–WGS84) using a 'full second order' equation, has a RMSE of 0.311. Rudimentary atmospheric corrections have been applied; as well as corrections for the effect of the water column before bottom type classification.

A Landsat5 TM data set dating from August 14th, 1987 has also been processed, mainly for bottom type classification, in order to detect possible changes occurring in the Hurghada test site. The same preprocessing steps have been taken as with the Landsat7 ETM+ data set and the Landsat5 TM data set has been georeferenced to the master Landsat7 ETM+ data set with a RMSE of 0.396.

2.3 *Remote sensing and coral reefs*

2.3.1 *Bathymetry*
Different methods have already been developed to map bathymetry using remote sensing. We have implemented a modified 'depth of penetration' mapping method (Jupp, 1988; Green et al., 2000) on the Landsat7 ETM+ data set (Vanderstraete et al., 2003a). Some 420 depth measurements were used for groundtruthing and accuracy testing. The accuracy test revealed that with a Pearson-coefficient of 93%, the general trend of the sea-bottom surface is clearly detected. In the main, depths are slightly overestimated (mean error of -1.13m with a standard deviation of 1.84m). These errors are depth dependent, meaning that the mean error increases with depth. Nevertheless, the bathymetric result gives a good overview of the localization of the coral reefs near Hurghada.

The bathymetric map combined with a True Color Composite of the Landsat7 ETM+ data forms also the base for a visual, on screen, digitalization of the geomorphologic features recognizable on the different reef systems (Vanderstraete et al., 2004).

2.3.2 *Bottom type classification*
A supervised classification of the Landsat7 ETM+ data set has been made in order to identify the different bottom types (macro-algae, coral, seagrass and sand) occurring on the reefs offshore Hurghada (Vanderstraete et al., 2004). Before classification, the radiance values received at sensor are corrected for atmospheric and water column effects. 'Depth-invariant bottom indices' (Lyzenga, 1987; Green et al., 2000) are calculated. Combined with texture layers derived from the data set using a 3 by 3 variance filter, these layers form the base for classification. After contextual editing of the bottom type classification by using the geomorphological classification, both results are combined into an open-ended hierarchical classification scheme. An overall accuracy of 58% is attained which is in accordance with other classification results based on Landsat data (Green et al., 2000). This relative low value is mainly due to discordance between field and satellite data. Some of the ground truth points are taken over small coral or seagrass patches which are not recognizable on the image due to its medium resolution of 30m.

2.3.3 *Bottom type change detection*
The Landsat5 TM and Landsat7 ETM+ data sets are used to examine the changes in composition of the coral reefs offshore Hurghada. A multi-component change detection procedure (Pilon et al., 1988; MacLeod & Congalton, 1998) is applied to define the occurring changes (Vanderstraete et al., 2003b). Preliminary results show significant coastline changes during the period 1987-2000 as well as changes in coral reef composition. The direct impacts are clearly shown, but it is less straightforward to link the changes in coral reef composition to indirect impacts of the changing land use / land cover.

2.3.4 *Additional information*

One example of additional information that can be derived from satellite imagery is the development of the coastal zone. The road network and the extension of the urban areas on both the 1987- and 2000-data set are vectorized on screen. This gives an impression of the rapid urban development of Hurghada during this period. Besides, also the coastlines are digitized. A cross table was made of the 1987- and 2000-data sets in order to determine the areas of coastline change. It was proven that the coastline north an south of Hurghada was drastically changed during this period resulting in important bottom type shifts on the coral reefs (Vanderstraete et al., 2003b).

2.4 *Coral Reef GIS*

2.4.1 *Integration of remote sensing results into a GIS*

All the derived remote sensing products are combined together with the additional information, extracted from satellite data and other sources, into a Coral Reef GIS. Figure 2 shows a schematic overview of the different sources and products which can be combined to form the base for coral reef monitoring. The Coral Reef GIS will form the main working tool within this monitoring system and can be used to deliver different decision support products to come to ICZM.

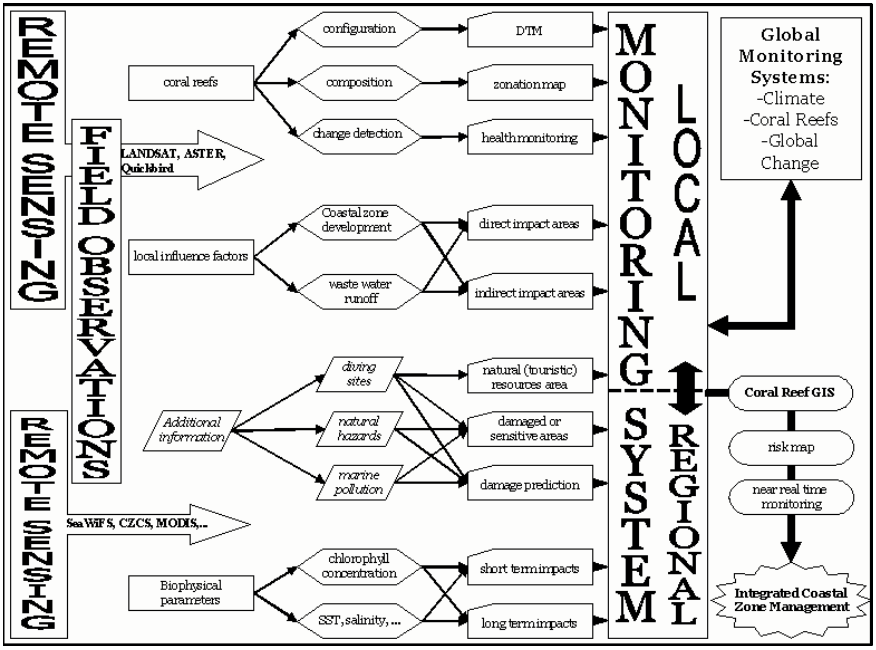

Figure 2. Schematic overview of the integration of remote sensing derived products together with additional information into a local monitoring system linked with 'Coral Reef GIS'

2.4.2 *Risk assessment mapping*

The Coral Reef GIS is used to examine the input products and derive additional information out of them. One such derived product is a risk assessment map in which is shown to what potential stress the different coral reef systems are up to, caused by the different potential threat factors recognized in the region. To determine these risk zones, parameters are defined to delineate the extent to which negative influences from a certain threat will reach. Like Bryant et al. (1998) we have made a differentiation between three risk classes: low risk, medium risk and high risk. We have started from the parameters defined by the Reefs at Risk-team (Bryant et al., 1998) (Table 1) and have added some other parameters as well, for example a perimeter around the main mooring sites. Dixon et al. (1994) have seen that in Bonaire National Park most divers seldom go further than 300m from the mooring site (Jameson et al., 1994). So we have determined a zone of high potential risk for physical damage to the reefs up to 100m from the mooring site and a zone of medium risk between 100 and 300m.

Table 1. Parameters used for delineation of risk zones (adapted from: Bryant et al., 1998; *Dixon et al., 1994)

Component indicator	Qualifier	High risk	Medium risk
Threat factor: Coastal Development			
Cities	population < 100 000	/	within 8km
Airports and military bases	military and civilian airports	/	within 10km
Tourist resorts	including diving facilities	/	within 8km
Threat factor: Marine Pollution			
Ports	small size	/	within 10km
Oil tanks and wells	any size	within 4km	within 10km
Threat factor: overexploitation and destructive fishing			
Population density	information lacking		
Threat factor: inland pollution and erosion			
not applicable to Hurghada			
Additional parameter: dive site perimeter*			
Known mooring place	any type	within 100m	within 300m

3 RESULTS AND DISCUSSION

For each parameter summed up in table 1, a risk map can be made. These different data layers can be combined to form an overall risk map of the area (Fig. 3). The different parameters are combined as in Bryant et al. (1998): if the reef area is classified as high or medium risk for one of the indicators, this area is assigned to the overall high, respectively medium, risk class. Only areas which are assigned to the low risk class for all indicators, are classified as subject to overall low risk.

Different areas can be discriminated in figure 3. A high risk zone can be seen in the north of the study area due to the presence of two nearshore drilling platforms. The common medium risk zone up to 10km offshore is due to the presence of tourist resorts and urban settlements along the entire coastline in combination with the presence of an airport, a harbor, etc. The small spots of high and medium risk all over the area are linked to some of the most important known diving sites. This shows that physical damage to the coral reefs by divers is relatively localized by potentially severe.

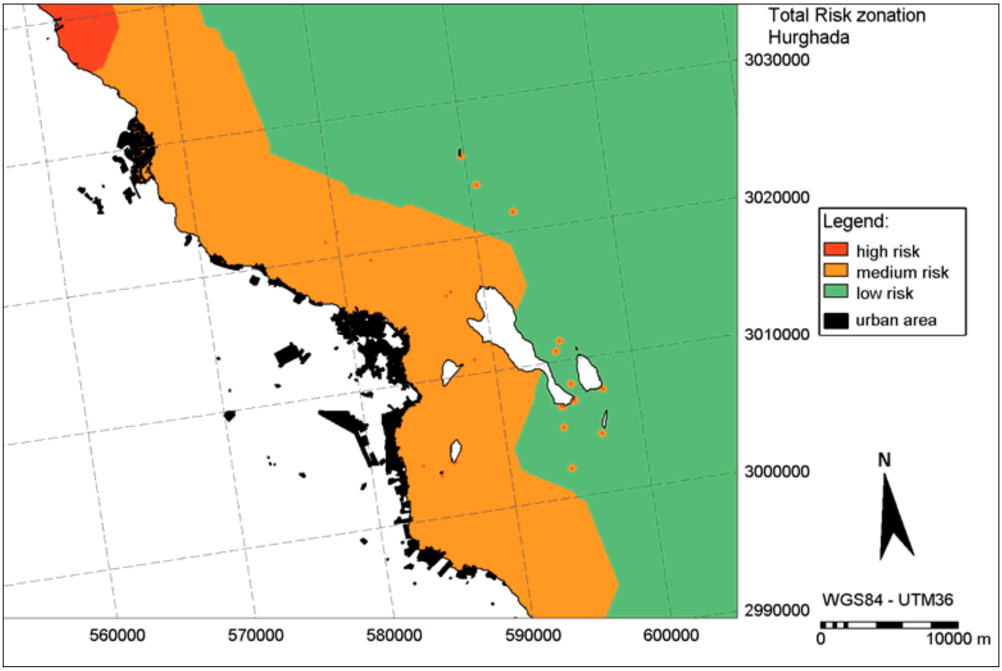

Figure 3. Overall risk map for the Hurghada study area

If the overall risk map in figure 3 is compared with the bottom type classification (Vanderstraete et al., 2004) of the Hurghada study area, differentiation can be made of the impact of the coastal development on each bottom type. As can be seen in table 2, in general 6% of the coral reef systems is under high threat, 80% under medium threat and 14% under low threat of being damaged by one or more factors. If this is split up to the different bottom types than it can be seen that seagrass is the most threatened ecosystem in this area, closely followed by coral and macro-algae. These high values can be explained by the fact that the urban coastal zone development sites are situated all along the coastline of the study area and that, due to the relative narrow continental shelf in this part of the Red Sea, most of the coral reef systems are within short distance of the coastline. In this way they become subject to the potential negative influences of the human, coastal activities.

Table 2. Overall risk assessment for the main bottom types occurring in the study area

overall risk %	*low risk*	*medium risk*	*high risk*
Coral	12	77	11
Macro-algae	12	78	10
Seagrass	5	83	12
Sand	16	80	4
TOTAL	14	80	6

4 CONCLUSIONS

It can be concluded that remote sensing is a powerful tool for studying coral reefs. In this paper, results about satellite derived bathymetry, bottom type classification, coastal development estimations, dive site localization, etc. have been combined into a Coral Reef GIS in order to give risk assessment predictions on the coral reefs offshore Hurghada. From the overall risk assessment map it is seen that a relatively broad medium risk zone is stretching out all along the coast north and south of Hurghada. In consequence, 86% of the coral reef systems are under medium to high risk of being damaged by negative consequences of human coastal activities. Care should thus be taken in future coastal development projects if coral reefs, which are the main attractors of tourists in the region, are to be protected from the possible devastating consequences of coastal alternations.

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