USING REMOTE SENSING AND GIS FOR INTEGRATED COASTAL ZONE MANAGEMENT A CASE STUDY: THE CORAL REEFS IN THE NORTHWESTERN RED SEA (HURGHADA, EGYPT)*

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ABSTRACT

Remote sensing is very suitable for coral reef monitoring as it provides information about the configuration and composition of the coral reef; enables the monitoring of the biophysical parameters of the seas and oceans in which the coral reefs occur; and supports the detection of changes over time of these elements. This remote sensing-derived data is integrated in a Geographic Information System (GIS) together with additional environmental information. The GIS not only forms an inventory of all available information but is also used as a tool to analyze this information in order to support integrated coastal zone management (ICZM). The example is given of a risk assessment map constructed for the coral reefs offshore Hurghada, Egypt, indicating the coastal zones most endangered by human activities. It is shown that about 86% of the marine, coastal area near Hurghada is at medium to high risk of being deteriorated.

1. INTRODUCTION

Already since the late 1960s, aerial and spaceborne photographs have been used to detect submerged features, to retrieve the seabed composition, and to map bathymetry (Ackleson, 2003). Since the first Landsat data became available in the mid 1970s, numerous attempts (e.g. Smith et al., 1975; Hammack, 1977) have been made to explore the possibilities of remote sensing in coral reef science and management (Mumby et al., 1997; Ackleson, 2003). Many studies ever since have shown the usefulness of remote sensing to provide baseline information on coral reefs (Green et al., 1996; Bryant et al., 1998; Mumby and Edwards, 2000).

According to Phinn et al. (2000), four categories of information can be extracted from remote sensing data. Applied to coral reef studies, these categories include information about the configuration and the composition of the reef structures; the biophysical parameters of the seas and oceans in which the coral reefs occur; and changes over time of these elements. Information about the configuration of a coral reef encompasses its localisation - planimetric and bathymetric- as well as a classification of the reef's geomorphological structure. On the ecological level, remote sensing provides information about the dominant reef communities, benthic habitats or bottom-types, which compose the reef system. One of the most elaborate applications in marine remote sensing is the study of biophysical parameters. This data is generally gathered at a relative coarse scale and include information about for

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example sea surface temperature; water quality (chlorophyll concentrations, sediments, C-DOM[1]); salinity; or waves and currents. As remote sensing data is gathered at regular time intervals and is available for the last two to three decades, it is ideally suited to detect changes in the above elements. Especially in the frame of changing environmental conditions, remote sensing can be very helpful to monitor and detect shifts in community structure and/or the health status of the coral reefs (Mumby et al., 2004).

Previous papers by the authors have shown the usefulness of Landsat data in the study of coral reefs offshore Hurghada, Egypt. The broad-scale coral reef structure was accurately mapped using two Landsat datasets, respectively acquired in 1987 and 2000. The Landsat 7 ETM+ dataset of 2000 was used to localize the main coral reef structures; to make a bathymetric map (Vanderstraete et al., 2003a) of the study area; to map the main geomorphological reef structures (Vanderstraete et al., 2004); and to make an ecological classification in which the dominant bottom-types occurring in the region (sand, macro-algae, coral and seagrass) were discriminated (Vanderstraete et al., 2004). Besides, a Landsat 5 TM dataset dating of 1987 was processed in order to detect land use/land cover (LULC) changes and related shifts in bottom-type composition over this period (Vanderstraete et al., 2003b).

The use of remote sensing in coral reef studies has some clear advantages if compared to conventional, *in situ* survey methods. Regardless of the protocol applied, field-based surveys are spatially very heterogeneously distributed and cover only small fractions of the reef systems under investigation (Hochberg and Atkinson, 2003). Remote sensing, in contrast, is synoptic by virtue. It is therefore suited for mapping coral reefs on a local to global scale. The remote sensing approach is also more cost-effective[2], even if the additional costs of hardware, software and trained employees are taken into account (Mumby et al., 1999). This is especially important for developing countries, where most of the coral reefs occur. Besides, remote sensing offers the possibility to study coral reefs which are too remote to visit or which are inaccessible due to physical constraints, for example shallow reef crests and reef flats (Kutser et al., 2003); political instability; or any other restraint.

While, initially, studies were usually restricted to one specific aspect of the coral reef, nowadays remote sensing in combination with GIS becomes more and more appreciated as a tool for ICZM. A GIS, in the first place, is well suited for integrating the different remote sensing-derived products with other data sources. Additional data related to coral reef monitoring may include: 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; and much more. Secondly, but at least as important, such a '*Coral Reef-GIS*' is also used as a tool to analyze the different data layers. This is very valuable for understanding the spatial characteristics of the coral reefs; for modelling different spatial and temporal processes; to evaluate various proposed management scenarios; or to determine specific risk zones which mark those reefs under potential stress (Knight et al., 1997; Stanbury and Starr, 1999; Freire, 2001).

The outcomes of these analyses may be used by coastal managers to support ecosystem-based decisions (Stanbury and 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 and Starr, 1999; Mumby and Edwards, 2000; Freire, 2001). These decision support products are also very useful tools in the communication to the general

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[1] coloured dissolved organic matter

[2] effectiveness is defined in terms of overall map accuracy (Mumby et al., 1999)

public (Knight et al., 1997). If 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, 1998).

The objective of this paper is to investigate how coral reef-related information derived from optical, passive remote sensing data can be combined in a Coral Reef-GIS in order to contribute to the sustainable development of the Red Sea area. The example is given of a risk assessment map which indicates the marine, coastal areas that are under different levels of risk of being degraded by human activity. This map will support managers or other user's groups in determining which coral reef systems need to be conserved and/or protected from the negative impacts indicated.

2. STUDY AREA

The coastal zone near Hurghada (Egypt) (27°14'N 33°54'E), situated in the north-western part of the Red Sea, is chosen as test site (Figure 1). These coral reefs are located in a unique natural environment as the 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 urban coastal development projects mainly for tourist accommodation and in support of the Egyptian relocation policy (Wilson, 1998).

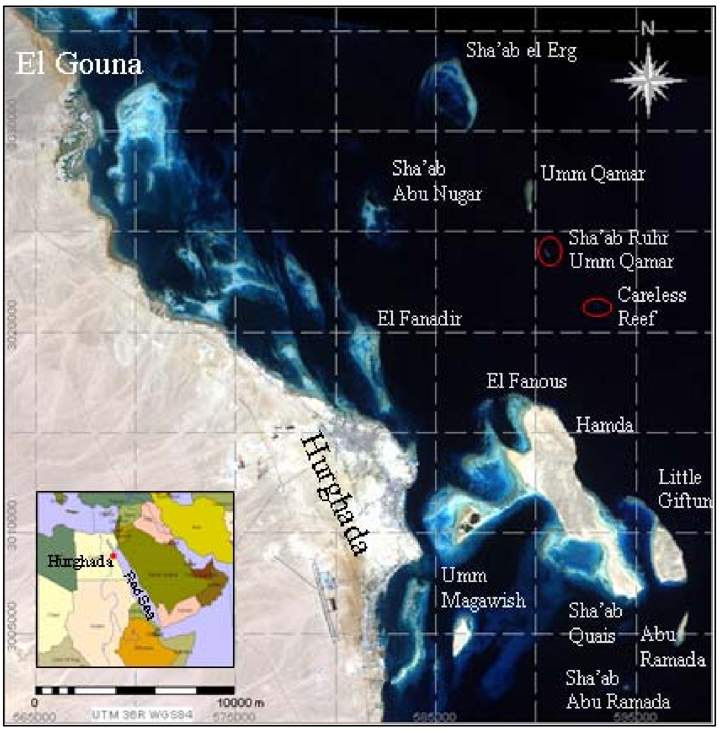

Figure 1. Overview of the Study Area on a Landsat 7 ETM+ True Colour Composite

3. METHODOLOGY

3.1 INTEGRATION OF REMOTE SENSING-DERIVED PRODUCTS INTO A GIS

Figure 2 gives an overview of some remote sensing-derived products and additional information resources useful for monitoring the status and health of a coral reef system. Based on these data layers, a local or regional coral reef monitoring system is set up. The Coral Reef-GIS forms the main working tool within this monitoring system. It not only collects all available information, but is also used to analyse the different input products and delivers different decision support products to come to ICZM.

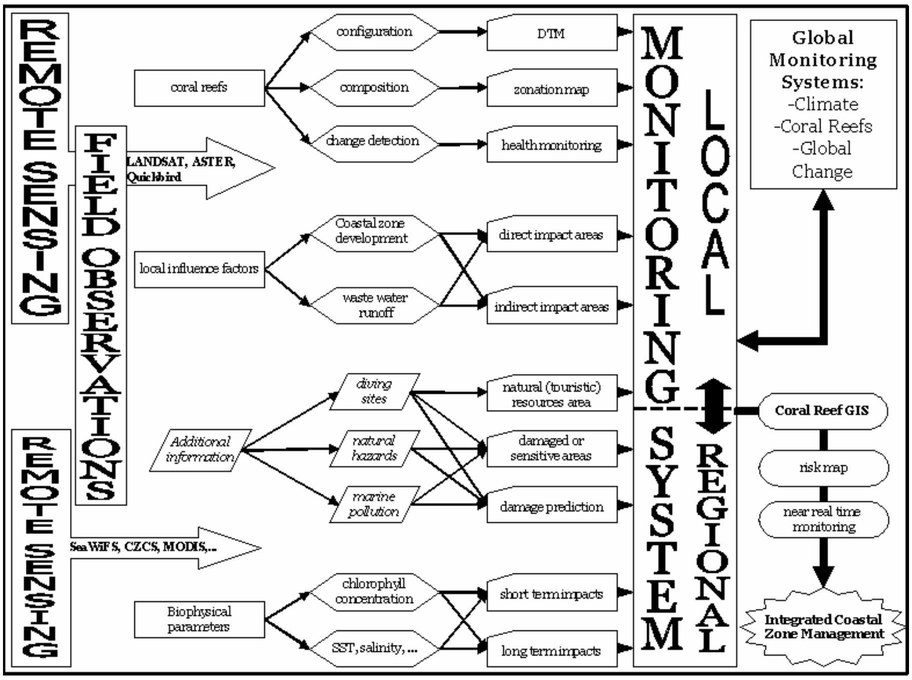

Figure 2. Schematic Overview of the Integration of Remote Sensing-Derived Products Together with Additional Information into a Monitoring System linked with a Coral Reef-GIS

3.2 RISK ASSESSMENT MAPPING

One of these decision support products is a risk assessment map in which is shown to what level of stress the coral reef systems are potentially up to due to the human activities in the coastal area. According to Bryant et al. (1998), these risk levels are commonly grouped into three classes, being: ‘low risk’, ‘medium risk’, and ‘high risk’. Several local threats were determined based on the list proposed by the “Reefs at Risk”-team (Bryant et al., 1998). The extent to which the negative influence of a certain threat is expected to reach, was used to delineate the different risk zones (Table 1). Some other threat factors were added such as, for example, the physical damage caused by SCUBA-divers. In Bonaire National Park, Dixon et al. (1994) noticed that most divers seldom go further than 300m from the mooring site (Jameson et al., 1999). Based on these observations, a perimeter around each main mooring sites in the study area was constructed in which a zone of high potential risk was discriminated up to 100m from the mooring site, while a zone of medium risk was created between 100 and 300m (Table 1).

Table 1. Parameters used to Delineate 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**			
Mooring site	any type	within 100m	within 300m

For each threat summarized in table 1, the risk zones were delineated. Subsequently, these different data layers were combined to form an overall risk assessment map. The individual risk parameters were combined as in Bryant et al. (1998): if the reef area was assigned to the high or medium risk class for one of the threats, this area was assigned to the overall high, respectively medium, risk class. Only areas which were assigned to the low risk class for all indicators, were attributed to the overall low risk class.

4. RESULT AND DISCUSSION

Two main risk zones could be discriminated on the overall risk assessment map shown in figure 3. A high risk zone is present in the north of the study area due to the occurrence of two nearshore drilling platforms. The common medium risk zone up to 10km offshore is mainly caused by the presence of tourist resorts and urban settlements along the entire coastline. The small spots of high and medium risk distributed over the area are linked to the most important known diving sites. This shows that physical damage to the coral reefs by divers is relatively localized but potentially severe. Remark that a ‘no risk’ class was not distinguished. As the Red Sea is an important shipping route and oil exploitation area, the entire coastline is considered at low risk of oil pollution or a shipping accident.

Table 2. Overall Risk Assessment for the Study Area, the Middle East*, and the World* (* Bryant et al., 1998)

	Low Risk (%)	**Medium Risk (%)**	**High Risk (%)**
Study Area	14	80	6
Middle East (Red Sea and Gulf)	39	46	15
Global	42	31	27

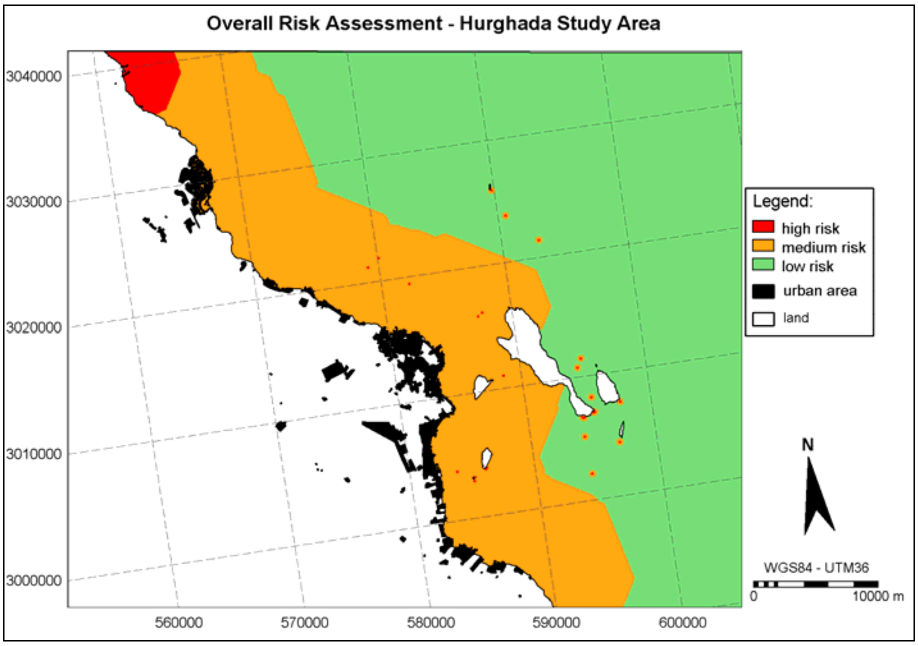

Figure 3. Overall Risk Assessment Map of the Hurghada Study Area

By combining the overall risk assessment map with the bottom-type classification (Vanderstraete et al., 2004) of the Hurghada study area in the Coral Reef-GIS, an estimation was made of the coral reefs impacted. As shown in table 2, 6% of the coral reef systems in the study area are at high risk, 80% at medium risk and 14% at low risk of being degraded by one or more local threats. If compared to the global and regional risk assessments made by Bryant et al. (1998), fewer coral reefs systems in the study area are highly stressed by a local negative impact, although on the whole -i.e. if the high and medium risk class are combined- the marine coastal area is seriously endangered by human activities. The restricted occurrence of highly stressed areas could be explained by the absence of damaging activities such as oil drilling, except in the north of the study area, large industrial ports or densely populated cities. On the other hand, smaller urban development sites are situated all along the coastline of the study area, so that hardly any part of the coastline is unaffected. Besides, due to the relative narrow continental shelf in this part of the Red Sea, most coral reefs are within short distance of the coastline and therefore subject to the medium risk impacts of the occurring human activities.

Remark that the impact of large scale, global, environmental changes was not included in this risk assessment map. First of all, these effects would equally impact the entire study area and, therefore, a local differentiation was useless. Secondly, the north-western part of the Red Sea is not considered at immediate risk of environmental changes caused by global change. For this reason, the effect of global change could be included in the overall low risk zone attributed to the Red Sea.

5. CONCLUSIONS

Remote sensing, in combination with GIS, is a powerful tool for managing coral reefs sustainably. In this paper, remote sensing-derived information about bottom-type composition, coastal development estimations and mooring sites have been analysed in a Coral Reef-GIS in order to give a risk assessment on the coral reefs offshore

Hurghada. The overall risk assessment map shows the presence of a relatively broad, medium risk zone along the entire coastline north and south of Hurghada. In consequence, 86% of the coral reefs are under medium to high risk of being damaged by the negative impacts of human coastal activities. This is exceptionally high when compared to global or regional percentages. Care should thus be taken with coastal development in the study area if coral reefs, which are the main attractors of tourists to the region, are to be conserved for future generations.

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