Remote Sensing as a Tool for Integrated Management of Coral Reefs in the Red Sea

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Abstract – Some examples are given of remote sensing-derived coral reef data, which form baseline information for the creation and management of a marine protected area (MPA) in the Red Sea. The importance of a Geographic Information System (GIS) for the collection and analysis of the different data layers is also shown. The example is given of a risk assessment map for the study area (Hurghada, Egypt) that indicates the marine, coastal areas which are under different levels of risk of being degraded by human activity. This map supports managers and other user's groups to determine which coral reef systems are best suited to form the core area of a multi-use MPA.

Keywords: coral reefs, Landsat 7 ETM+, Red Sea, Integrated Coastal Zone Management

1. INTRODUCTION

Coral reefs are not only important for their biodiversity and their key role in the tropical marine biosphere; they are also very valuable as a socio-economic resource. Despite these natural and socio-economic assets, many human-induced threats, including overfishing, inappropriate fishing practices, coastal development and pollution, are posing stress on the coral reefs. In recent years became clear that almost 58% of the coral reefs worldwide are threatened to some extent by human activities (Bryant et al., 1998). Besides, since the 'Mass Coral Bleaching'-event of 1997/1998 linked to one of the severest El Niño/Southern Oscillation (ENSO)-cycles in recent history, the impact of global change can no longer be ignored either (e.g. Wellington et al., 2001).

The United Nations Educational, Scientific and Cultural Organization (UNESCO) is aware of the major consequences of the disappearance of these valuable ecosystems, not only for the marine ecological realm but also for the livelihoods of many millions of people depending on the reef systems for food and security. Different conservation programs may incorporate the coral reef ecosystem. Currently, UNESCO enlists 611 cultural sites, 154 natural sites and 23 mixed sites on their World Heritage List (WHC, 2005). 19 of them contain coral reefs, although only few are specifically intended to protect the coral reefs. UNESCO also recognizes 459 Biosphere Reserves in their Man and Biosphere (MAB) program. 74 Biosphere Reserves are specifically aimed at the marine environment, with 20 of them including coral reefs (MAB, 2005). Besides, a specific 'Coral Reef Programme' has been established under the auspices of the CSI-Unit (Environment and Development in Coastal Regions and in Small Islands).

If compared to the total number of conservation sites, marine ecosystems, and coral reefs in particular, are seemingly underrepresented. Sensible of their importance, UNESCO seeks to integrate more vulnerable coral reef areas in their conservation network. The *World Heritage Convention* is especially considered "as a unique legal tool for achieving conservation of marine and coastal ecosystems and for enhancing international co-operation of such work" (WHC, 2003).

UNESCO also recognizes the usefulness of remote sensing to manage and monitor their World Heritage sites and Biosphere Reserves (WHC, 2005). Four categories of information concerning coral reefs can be extracted from remote sensing data (Phinn et al., 2000). These 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. In this paper some examples are given of remote sensing-derived data obtained by processing a Landsat 7 ETM+ dataset, covering the Hurghada coastal area, situated in the northwestern part of the Red Sea.

Remote sensing combined with GIS becomes more and more appreciated as a tool for integrated coastal zone management (ICZM). A GIS, in the first place, is well suited for integrating the different remote sensing-derived products with other data sources. At least as important, such a '*Coral Reef-GIS*' is also used to analyze the different data layers. This is very valuable e.g. for understanding the spatial characteristics of the coral reefs; for modeling different spatial and temporal processes; for evaluating various proposed management scenarios; or for mapping specific risk zones (Knight et al., 1997; Stanbury and Starr, 1999; Freire, 2001). The example is given of a risk assessment map which indicates the marine, coastal areas which are potentially endangered by human activity (Vanderstraete et al., 2005).

2. STUDY AREA

The Red Sea is an ideal environment for coral growth. It 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,

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1987). However, since the 1960s, human interference with the natural environment is steadily increasing, leading to negative impacts on the health and status of these coral reefs (Pilcher and Alsuhaibany, 2000). The situation becomes especially worrisome in the northwestern part of the Red Sea, where the main threats are coming from the booming tourism industry and the urban coastal development projects mainly for tourist accommodation and in support of the Egyptian relocation policy (Wilson, 1998). For this reason, the coastal zone near Hurghada (Egypt) (27°14'N 33°54'E), is chosen to test the possibilities of remote sensing and GIS as a tool to derive baseline information for the sustainable development of the coastal area.

3. SATELLITE DATA

A level-1G Landsat 7 ETM+ dataset (path/row: 174/041) dating from September 10th, 2000 was analyzed in the ILWIS 3.2 software-package. Only the first three wavebands were used as the radiation in the other wavelengths is almost totally attenuated by the water column. The dataset was geocoded to a specific UTM-coordinate system (UTM36–WGS84) based on 27 ground control points measured during three field surveys made in the study area. Based on a 'full second order' equation, a root mean square error (RMSE) of 0.311 was obtained. First order atmospheric corrections have been applied to correct for path radiance. Before bottom-type classification, the effect of the water column was accounted for by calculating 'Depth-Invariant Bottom-Indices' (DIBs) (Lyzenga, 1978).

4. METHODOLOGY

4.1 Remote Sensing

a. Bathymetry (Vanderstraete et al., 2003)
A modified 'Depth of Penetration' mapping method (Jupp, 1988; Green et al., 2000) was applied on the Landsat 7 ETM+ dataset to obtain information about the variation in depth. Depths up to 21m were estimated. The accuracy test revealed that with a Pearson product correlation coefficient of 93%, the general trend of the sea-bottom surface was clearly detected. However, in the main, depths were slightly overestimated (mean residual error of -1.13m with a standard deviation of 1.85m). Nevertheless, the result gives a good overview of the bathymetric structure of the coral reefs in the study area.

By combining the bathymetric map with a true color composite of the Landsat 7 ETM+ dataset, an ideal base was formed for the visual, on screen, digitalization of the geomorphological structure of the coral reefs (Vanderstraete et al., 2004).

b. Bottom-Type Classification (Vanderstraete et al., 2004)
The three DIBs determined during the pre-processing of the Landsat 7 ETM+ dataset were complemented with three textural neo-channels derived from the DIBs by applying a 3 by 3 variance filter. A supervised classification was performed on this expanded dataset in order to identify the dominant bottom-types (macro-algae, coral, seagrass and sand) occurring on the reef systems. Subsequently, the bottom-type classification was edited by applying a set of contextual rules. These rules were based on the association between some bottom-types and the geomorphological reef structure. The bottom-type classification map was restricted to a depth of 21m as this was the maximum depth at which reflection of the seabed was no longer recorded by the sensor. An overall accuracy of 60% was obtained which is in accordance with other classification results based on Landsat data (Green et al., 2000).

c. Additional Information Layers
Additional information concerning coral reef monitoring which is derived from remote sensing data may include the localization of local threat factors such as airports, harbors, industry, urban development sites or important dive sites, as well as information about changing biophysical parameters such as sea surface temperature, salinity or water quality, which may affect the health of the coral reef systems.

4.2 GIS Analysis: Risk Assessment Mapping

Subsequently, all available information was integrated into a 'Coral Reef-GIS' which was also used to analyze the data. One of the outcomes of such an analysis is a risk assessment map (Vanderstraete et al., 2005). Different local threat factors and the range of their negative impacts on the coral reefs, were determined as proposed in Bryant et al. (1998). Some other threat factors were added such as, for example, the level of physical damage caused by SCUBA-divers related to the distance from the mooring site. For each threat factor, three risk zones were delineated, being 'high risk', 'medium risk' and 'low risk'. Afterward, these different data layers were combined to form an overall risk assessment map. 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.

As seen on figure 1, the overall risk assessment map was combined with the bottom-type classification, in order to define the risk level of each reef system. A high risk zone is present in the north of the study area due to the occurrence of two nearshore drilling platforms. A common medium risk zone is distinguished up to 10km offshore which is mainly caused by the presence of tourist resorts and urban settlements along the entire coastline. Small spots of high and medium risk are distributed over the area and are linked to the most important known diving sites. Only those reef systems further offshore are less endangered by devastating human activities. The "deep water" class represents depths greater than 21m. At these depths, the sand substrate is dominant and negative effects of human activities are usually minimal.

5. DISCUSSION

The use of remote sensing in coral reef studies clearly has some 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. The remote

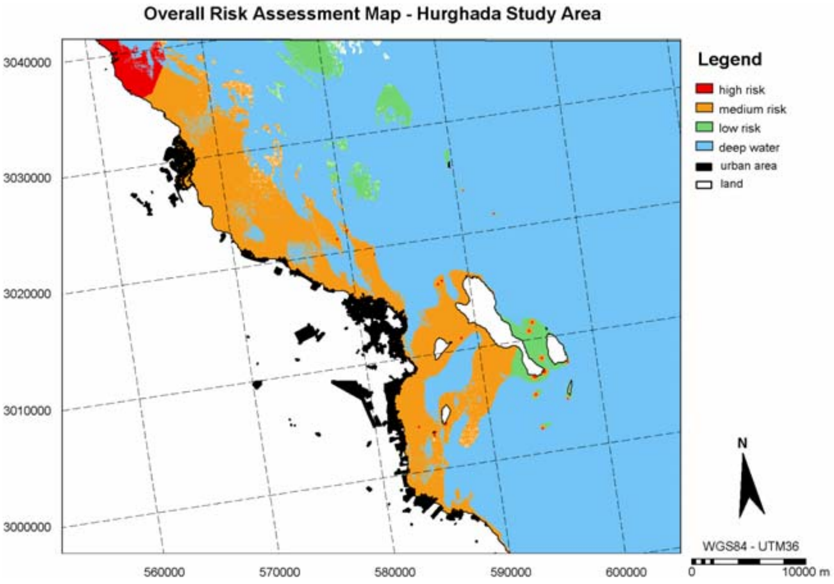

Figure 1. Overall risk assessment map for the Hurghada area showing the level of risk for the reef systems distinguished

sensing approach is also more cost-effective, even if the additional costs of hardware, software and trained employees are taken into account (Mumby et al., 1999). Besides, remote sensing offers the possibility to study coral reefs which are too remote to visit or which are nearly inaccessible (Kutser et al., 2003). 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 shifts in the community structure and/or the health status of the coral reefs as well (Mumby et al., 2004).

Some examples of basic information about the configuration and composition of the coral reefs derived from remote sensing data were given in this paper. Based on high resolution Landsat data, a general, broad-scale overview was obtained. Basically, the whole range of available sensors can be integrated in a coral reef monitoring system. Low to medium resolution sensors, like SeaWiFS or MODIS, are useful for tracking changes in the physical reef environment which may be linked to global climatic changes. On the high resolution level, e.g. Landsat or SPOT, regional to local overview mapping of the main reef characteristics can be performed. If more detail is needed for a specific, small-scale study area, e.g. the size of a MPA, very-high resolution sensors like IKONOS, or airborne, hyperspectral sensors such as CASI, could be applied.

This remote sensing-derived information together with additional information layers is then collected and analyzed in a Coral Reef-GIS. The outcomes of the GIS-analyses may be used by coastal managers to support ecosystem-based decisions (Stanbury and Starr, 1999) for example in identifying multi-use MPAs; 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).

The risk assessment map presented in this paper is an example of such a decision-supporting GIS-product. This map gives baseline information for the demarcation of a MPA. It clearly is pointless to create a highly protected area in the northern part of the study area as here the reefs are at high risk of oil pollution. In the Hurghada area almost the entire coastline has been built, so nearshore pristine coral reef systems are likely to be sparse. On the other hand, the zone between the Giftun Islands is largely protected from negative impacts of coastal activities, and would be ideal for full protection. This zone could form the core area of a multi-use MPA in which this zone is highly protected and only accessible for scientific research. The nearshore area could be designated to SCUBA-diving taking into account the localized but potentially severe physical damage and the carrying capacity of the reef system.

Remark that this risk assessment map only indicates potential damage sites and does not give any information concerning the present health status of the reefs. Other information layers should therefore be consulted before working out the effective planning and management approach. If additional issues such as information management, capacity building and environmental awareness and education are taken into account, it will form the key process in the sustainable development of the coastal, in casu coral reef, resources (Wilson, 1998).

6. CONCLUSION

Remote sensing, in combination with GIS, is a powerful tool for integrated coastal zone management of coral reef areas. In this paper, some examples are given of remote sensing-derived information on the configuration and composition of coral reefs near Hurghada, Egypt. The collection and analysis of these data layers in a GIS, eventually combined with additional data concerning the health and status of the reef systems, forms a solid base for ecosystem-based decisions. A risk assessment map which indicates the marine, coastal areas which are potentially endangered by human activity is given as an example of such a decision-supporting product. This information would support the sustainable planning and management of a multi-use MPA in the area.

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