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Development of a strategy to guide the use of remotely sensed information in the management of coral reef environments

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Abstract. We have developed a strategy to guide the use of remotely sensed information in the management of coral reef environments in developing countries. The strategy includes development of a habitat map using satellite imagery, investigation of stakeholder receptivity to the habitat map, linking management issues to specific habitat types, and context-appropriate illustration of mapped data. The strategy was developed using IKONOS 4x4 m multi-spectral satellite imagery and interview data from dive operators, fishermen, and managers of Bunaken Island, Indonesia. The potential for this strategy to address coral reef management issues is wide-reaching and strongly depends on interaction between scientist and manager.

Key words: Remote Sensing, Local Knowledge, Coral Reef Management, IKONOS.

Introduction

Within the field of coral reef remote sensing, researchers have for many years been developing coral reef habitat maps (Riegl and Purkis 2005; Mumby et al. 2004; Andrefouet et al. 2003; Maeder et al. 2002). Each map contains a collection of habitat types, which are defined by their combined structural framework and biological composition (Veron 2000). These combined characteristics permit identification and delineation of the habitats within high-spatial satellite imagery (Mumby et al. 2004; Holden 1999; Knight et al. 1997). Within the last decade, these habitat maps have, in some places, contributed to coral reef management. This should be expected from habitat maps that delineate management-relevant information.

Until recently, however, there has been little interest in utilizing coral reef habitat maps for management in less-developed countries. There are many reasons for this: cost, available expertise, and general knowledge about the applicability of the information. In addition, there have been few opportunities for local communities to use such maps mainly because these communities have been removed from decision-making processes. In Indonesia, however, recent decentralization of the government has brought about increasing decision-making power to local levels, especially to small island communities (Nickerson and Olsen 2003; Erdmann et al. 2004). In the northern regions of Sulawesi, small island communities can now influence, more directly, management efforts (Erdmann et al. 2004).

If remote sensing-based coral reef habitat maps are to contribute to these management efforts, logically, it is necessary that the habitat maps illustrate information that is relevant to decision-makers. To this end, decision-maker knowledge must be integrated to the mapping procedure. In this study, we present a procedure that could be used to integrate decision-maker knowledge, to link this knowledge to the information in the habitat map, and to illustrate those habitats that are relevant to management. This procedure transforms habitat maps into ‘management maps’.

Materials and Methods

This study involved the development of stages that together resulted in the development of management maps. To develop these stages, both the remote sensing and social contexts were considered. It was assumed that implementation of the stages would be facilitated by a remote sensing scientist. Therefore, we assume that the remote sensing scientist must engage in active research and collect and assess qualitative data. This means that the scientist is challenged to collect both physical and social science research and to integrate the information in an appropriate way.

Study Area

The study site for this research was Bunaken Island, which lies off the Northeast point of Sulawesi, Indonesia near the city of Manado. The island is surrounded by well-defined tropical coastlines, which include a tidal flat, reef crest, reef slope, and reef wall. In some areas, the tidal flat extends up to 0.5 km from the shoreline. At the reef wall, the water depth drops down to the continental slope at 1840 metres. In the waters surrounding Bunaken Island, there are a minimum of 58 general and sub-genera of corals and approximately 2,000 species of fish (Mehta 2000).

According to the 2005 consensus there are three villages on the island of Bunaken: Alung Banua (population: 807), Tanjung Parigi (population: 610), and Bunaken (population: 2000). The people living in the villages are descendents of fishers who used Bunaken Island as a stopover location before heading out to sea. Dive operators also occupy the island and, at the time of this study, 15 are established and 11 are operating.

Bunaken Island was the first island in Bunaken National Park to be assigned a zonation system. The system includes three primary zones: core conservation zone, tourism use zone, and village use zone and is one of five islands situated within Bunaken National Park (BNP), which is 89,056-hectare in size.

In addition to the zonation plan, coral reef management activities include the placement of ecoreefs in shallow water coastal areas that have experienced considerable blast fishing. The coral reef crest environment nearby Alung Banoa Village and Fukui dive site now hosts over 60 ecoreefs that were provided by Seacology and implemented by NRM III personnel, local fishers and dive operators. An additional coral reef management activity that is gaining momentum is reef monitoring. Several dive operations have added a monitoring component to the Open Water, Rescue Diver, Dive Master, and Dive Instructor courses that involves quantitative assessments of health at various dive sites. Other management efforts include monitoring grouper species at identified Spawning Aggregation Sites (SPAG).

Research Methods

The research methods in this study are grounded in the broad methodological fields of remote sensing habitat map development and community participation in project development.

Qualitative data gathering tools included informal interviews, focus groups, and participant observation. The tools were selected using assistance from on-site researchers and from the Socioeconomic Manual for Coral Reef Management (AIMS, 2000). The qualitative data collection processes followed the principles laid down in Participatory Rural Appraisal (PRA) methodologies (Chambers and Guijt, 1998).

Based on the social context and the information available by the remotely-sensed habitat map the following four stages were identified: the first stage is to develop a habitat map; the second stage is to acquire stakeholder feedback to the habitat map; the third stage is to link the stakeholder feedback with habitat data; and, the fourth stage is to illustrate the linked information using stakeholder-identified cartographic elements. Each of these four stages was conducted in sequence and is described below.

Stage One: Development of a habitat map

First, two 4-metre multispectral and 1-metre panchromatic IKONOS satellite images of Bunaken Island were captured for July 7th, 2001 and June 6th, 2004. Both images were acquired with full 11-bit radiometric resolution and at 18-degrees off-nadir angles. Both images were acquired under conditions of light haze, < 20% cloud cover, and minimal surface water roughness. Image preprocessing included radiometric and geometric corrections, which were conducted by Space Imaging.

Field data included a library of ground observation points that were collected in both 2001 and 2004 for the purpose of sea-truthing the satellite images. A ground observation point represents one point on the ground, covering an area of 4 x 4 metres, from which geographical coordinates, water depth, substrate type and cover, and photographs were collected. Most points were selected randomly throughout all geomorphological zones (reef flat, reef crest, and reef slope) and all management zones (core, tourism, and general). Some points lie at half-metre intervals along transects that were placed over areas of interest, beginning at the shoreline and extend to the reef crest. Along transects, video surveys were conducted.

Initially, both images were georeferenced using GPS measured control points. The two images were then compared to each other. Areas of land, clouds, boats, and deep water outside the reef crest were then masked out. A basic atmospheric correction was applied to the imagery that involved sampling a large number of pixels from the 'deep water' area. A depth correction was then carried using Lyzenga's model.

For each image, over 600 ground observation points where then used to develop training areas, encompassing each of the six classes in all geomorphological zones. The training areas were input in a supervised maximum likelihood classifier. The final habitat map classes included coral (< 5m deep), coral (5-15 m deep), sparse seagrass, dense seagrass, silt, sand. The resulting habitat maps had overall classifications accuracies of 78% (2001) and 81% (2004).

Results

Stage Two: Investigation of stakeholder receptivity to the habitat map

The objective of stage two is to investigate stakeholder receptivity to the habitat map. Using informal interviews, focus group discussions, and participant observation techniques stakeholder receptivity to map content, map presentation, and map applicability to current and future management projects was investigated.

Qualitative data were collected in 2004 and the total number of respondents interviewed was 36, the total number of focus group discussions was 5, and participant observation was conducted regularly throughout the field period.

The following results were established. Generally, stakeholders agreed that a habitat map should contain no more than three to four habitats types. If the map contains more habitat types it is unlikely to be used. A habitat map should contain only those habitats that are relevant to each stakeholder group. In terms of map presentation, a habitat map should contain (1) the local names of the habitats, (2) land, deep water, and local references, and (3) standard cartographic elements such as a north arrow, scale, title, and legend that are written in the local language. In terms of map applicability, the habitat map should contain only those habitats for which known linkages between habitat and management issue are well know and established within the community.

Stage Three

The objective of stage three is to conduct an objective and systematic approach to linking management issues identified in stage two with habitat types identified in stage one. The researcher and research assistants deconstructed the feedback by using heir knowledge of the physical and social environments, and identified a degree of association between indicator and habitat. The 'degree of association' provides a means of quantitatively assessing the strength of association between indicator(s) that were identified by stakeholders and habitat(s) that were delineated in the IKONOS satellite imagery.

Results include a list of indicators, identified by stakeholders that describe the feature of interest such as a particular coral or fish species. The location and time period of interest was also identified. Results also include a list of habitats, which were delineated in the habitat map, that can be matched to the indicator. Then, a degree of association was calculated for all matches and results illustrate that 66% of the time, the habitat map contains habitat types that are relevant for addressing management questions.

Stage Four

A multitude of techniques is available for applying cartographic elements to a habitat map; however, the methods presented here focus on integrating general structure, reference features, habitat type illustration, and map format. Stakeholders created these categories: each category was identified as 'critical' to recognition and understanding of the mapped information. The categories were then used as a guide in the development of management maps.

Features of interest to each stakeholder group were highlighted or polygons were drawn around the feature. The legend of each map included the location of docks, villages, places of worship, and markets. A permanent feature in every map was the location of dive sites and the location of management zones. More specific features of interest, identified in stage two, were applied to each respective stakeholder map.

Discussion

It is important to note that throughout each field season for this research several key themes emerged.

(1) Tradeoff between cost and scale. For example, the fishermen on Bunaken Island are familiar with the spatial location of seagrass and, in many places, how the concentration of seagrass has changed through time. The cost of having this same information illustrated in a temporal management map at a fine spatial scale may far exceed what fishermen can contribute and may far outweigh the real use of the information. A more cost effective approach may involve acquisition of free satellite imagery, with coarse spatial resolution, investigation of seagrass concentration change using multiple images, and development of a temporal management map that illustrates only those regions with a considerable gain or loss in seagrass. This method provides the same information as is provided by a change detection analysis with IKONOS satellite imagery, however, the cost of the imagery is removed from the overall budget. Generally, in the future, it will be important to assess whether the cost of acquiring fine spatial scale information outweighs the cost of the imagery.

(2) Communication between scientist and manager. Considerable effort was made by the researcher to learn the local language and local terminology that is used to describe the coral reef environment. Though, at times, simply knowing the terms was not enough to capture the context and essence of the message communicated by the manager. To enhance communication, shared experiences (scientist-manager) are critical. Workshops, field trips, and joint presentations create a collaborative environment, one in which both scientist and manager can ask questions of each other and work together to target the same objective/interest. Field trips, for example, are an excellent opportunity to expose the manager to the

environment in which remotely-sensed field data are collected. Explanations on how the habitat data are collected and measured can be demonstrated, while in exchange the manager can ask questions and provide stories or explanations for certain locations or the state of specific portions of the coral reef environment.

(3) Community-based research approaches. An important key theme in this research is that community-based research approaches warrant attention, investigation, and inclusion in the strategy. To both capture and utilize the local processes of environmental management, it is critical to know how community-based research is employed, what information is deemed relevant and useful, and how the information is used. Without knowledge of these factors, it is nearly impossible to integrate foreign information or processes. However, identification of this information is challenged by communication and physical barriers. In some instances, meetings are closed to the public, to foreign researchers or students, or to personnel that are not directly involved in a project. During such instances, effort must be made to attend, to provide some skill or product in exchange for attendance. Because, it is often during such meetings, that decisions are made and the process of how these decisions are made is critical information.

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