CORAL REEFS AND MARINE BENTHIC HABITAT MAPPING USING HYDROACOUSTICS METHOD

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ABSTRAK

PEMATAAN TERUMBU KARANG DAN HABITAT BENTIK MARIN DENGAN KAEDAH HIDROAKUSTIK

Sebuah sistem pengkelasan dasar laut akustik RoxAnn™ telah digunakan pada bulan Mac 2001 untuk kerja pemetaan keseluruhan terumbu pinggir di Pulau Baik, Lahad Datu, Sabah. Kerja pemetaan secara terperinci ini telah mencatatkan sejumlah data dasar laut yang setara dengan jarak transek sepanjang 53 km. Sebanyak 18 kelas dasar laut telah dikenalpasti. Dalam pada itu, 9 kelas merupakan karang hidup yang terdiri daripada 3 bentuk pertumbuhan yang utama, iaitu karang masif, foliosa dan bercabang. Keadaan terumbu di pulau tersebut adalah baik dengan peratus penutupan karang hidup sebanyak 20%, manakala 35% lagi merupakan campuran karang hidup dengan substrat bukan-karang seperti pasir dan rumpai-laut. Kebanyakan karang di Pulau Baik adalah terdapat pada bahagian utara, terutamanya di kedua-dua struktur terumbu yang tercapah dari hujung pulau. Berdasarkan kepada kelimpahan karang jenis foliosa dan bercabang yang rendah dan juga ketumbuhan rumpai-laut atas kelikir karang yang luas, maka adalah dipostulasikan bahawa terumbu di Pulau Baik pernah dilanda oleh ribut 'Greg' pada hujung tahun 1996 dan kini sedang berada dalam peringkat pemulihan. Sistem yang sama juga digunakan untuk kerja pemetaan am habitat marin di Teluk Darvel. Lebih daripada 70% kawasan penyelidikan mempunyai dasar jenis berlumpur. Namum, tompokan terumbu kecil adalah kerap ditemui berhampiran dengan pulau-pulau dan juga di kawasan yang berhampiran dengan Kunak. Keadaan tompokan terumbu yang dekat dengan kepulauan adalah lebih baik berbanding dengan terumbu yang berdekatan Kunak kerana terumbu di sini mengandungi lebih karang mati. Pada kawasan pesisiran pantai, terumbu karang didapati bersebelahan dengan hutan paya bakau. Rumput-laut dan rumpai-laut agak kerap ditemui di bahagian timur Lahad Datu. Selain daripada pemetaan, penilaian ketepatan ke atas peta habitat terumbu Pulau Baik yang dijanakan juga dilaksanakan pada bulan Oktober, 2001. Dua jenis pendekatan telah digunakan iaitu dengan kaedah plot kuadrat dan kaedah pensampelan setempat. Cara pertama telah menghasilkan keputusan yang kurang memuaskan kerana limitasi kaedah; manakala pendekatan kedua berjaya mencatatkan nilai ketepatan dalaman sebanyak 78%. Ujian statistik U dan analisis regreasi menunjukkan bahawa tiada pengaruh yang ketara dari orientasi pantai dan kedalaman pada tapak kajian ke atas prestasi sistem pengkelasan laut. Peta habitat terumbu karang Pulau Baik yang dihasilkan daripada kajian ini mempunyai ketepatan lebih daripada 80%, maka peta seumpama ini boleh digunakan dengan yakin untuk tujuan pengurusan sumber alam, pengawasan dan pemantauan.

ABSTRACT

CORAL REEFS AND MARINE BENTHIC HABITAT MAPPING USING HYDROACOUSTICS METHOD

The entire fringing reefs of Pulau Baik, off Lahad Datu, Sabah were mapped in March 2001 using a RoxAnn™ Acoustic Seabed Classification System (ASCS). A total of 53 km track length was surveyed during this fine scale mapping, discriminating 18 distinct benthic classes. Half of these classes were of living coral substrates comprising 3 major coral growth forms, notably massive, foliose and branching. Reef cover in Pulau Baik was good with 20% healthy corals. Thirty-five percent (35%) was a mixture of live corals with other non-coral substrate i.e. sand and algae. Corals of Pulau Baik were mainly found on the north of the island, diverging into 2 extended reef structures. Based on the relatively low abundance of foliose and branching corals, as well as the presence of large algae mats on rubbles, it was postulated that the reefs at Pulau Baik was damaged by storm Greg in 1996 and it is now in its recovery stage. A broad scale mapping using the same system was conducted in the same time frame to discriminate the general substrate types at Darvel Bay. More than 70% of the surveyed areas were of muddy bottom. Small patch reefs were commonly found around the islets within the bay, as well as waters near Kunak. Generally, coral patches nearer to the islets were in better condition, while more dead corals were found adjacent to Kunak. In coastal areas, corals were found in close proximity to the mangrove forest. Seagrass and brown algae were also a common feature in the shallow areas, east of Lahad Datu. An accuracy assessment was performed in October 2001 to evaluate the integrity of the reef habitat map of Pulau Baik. The internal accuracy assessment was performed using ten 10mx50m test plots method and point sampling method. Due to technical limitations, the results of the test plot method were unsatisfactory. However, point sampling method yielded better internal accuracy at 78%. Both U-test and Regression Analysis showed that orientation to shore and depth within the study area do not have any significant influence on the system performance. The resulting Pulau Baik reef habitat map has high repeatability with map accuracy of more than 80%. Therefore such maps can be used confidently for resource management and monitoring purposes.

ABBREVIATION

ANZECC	-	Australian and New Zealand Environment and Conservation Council
ASCS	-	Acoustics Seabed Classification System
BOBP	-	Bay of Bengal Programme
CASI	-	Compact Airborne Spectrographic Imager
CPUE	-	Catch Per Unit Effort
DANIDA	-	Danish International Development Agency
DEM	-	Digital Elevation Model
DGPS	-	Differential Global Positioning System
E1	-	First Echo Return
E2	-	Second Echo Return
EMS	-	Electro-Magnectic Spectra
FAO	-	Food and Agricultural Organization
GCRMN	-	Global Coral Reef Monitoring Network
GIS	-	Geographical Information System
GPS	-	Global Positioning System
ICRI	-	International Coral Reef Initiative
ICZM	-	Integrated Coastal Zone Management
IUCN	-	The World Conservation Union
km	-	Kilometer
m	-	Meter
MPA	-	Marine Protect Area
Nat	-	Natural Neighbour
NN	-	Nearest Neighbour
NOAA	-	National Oceanic and Atmospheric Adminstration (USA)
NRSMPA	-	National Representative System of Marine Protected Areas
PC	-	Personal Computer
PCA	-	Principal Components Analysis
QC	-	Quality Control
TP	-	Test Plot
Trk	-	Trackline data
UMS	-	Universiti Malaysia Sabah
UNESCO	-	United Nations Educational Scientific and Cultural Organisation
USCRTF	-	US Coral Reef Task Force
USP	-	Ultrasonic Signal Processor
WRI	-	World Reef Institute

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KEY WORDS

Hydroacoustics

Seabed classification system

Habitat mapping

Accuracy assessment

Coral growth forms

CHAPTER 1

INTRODUCTION

1.1 Coral Reefs – valuable yet vulnerable

Coral reefs are geological structures of calcium carbonate built over time by tiny living organisms called polyps. Such structures are generally found in the shallow tropical ocean between the Cancer (23°N) and Capricorn (23°S) belts. Based on fossil records, corals first appeared some 500 million years ago during the Ordovician Period of the Paleozoic Era (Gosliner, *et al.*, 1996). However, the currently existing corals represent only a developmental episode of less than 5000 years (Allen & Steene, 1999).

A healthy reef will thrive with sunlight and clear water with temperature around 27°C and 35 ppm salinity. Corals grow very slowly. According to Smith (1983), the average coral growth rate is approximate at 3mm/year (Barnes & Chalker, 1990).

The existence of coral reefs is not unknown to human kind. For centuries, coral reefs have been the important fishing ground to the local communities and proffer shelter from tropical storms and coastal erosions. Coral reefs, which are sometimes referred to as the underwater rainforests, are the world's most biologically diverse ecosystems. It supports countless variety of marine live forms, provides pharmaceutically important materials, while generating income from tourism.

Coral reefs are valuable resources yet vulnerable. In spite of the advantages that human continue to benefit from coral reefs, the ecosystem has been subjected to serious anthropogenic threats over the past five decades or more. As most of the world's reefs are found adjacent to the coastline and majority of such areas fall in developing countries, non-sustainable activities and developments have inevitably caused rapid degradation to the ecosystem (De Silva, 1983). Activities such as blast fishing, mining of coral for building materials, and other threats like sedimentation, pollution and erection of new structures in coastal areas are diminishing the ecosystem. The outbreak of Crown-of-thorns starfish which is speculated as an indirect effect of anthropogenic pollution adds on to reef damage (Ridzwan, 1993). With the recent global climate change, coral bleaching and mortality have become more frequent, adding to a new major threat to the well being of the world's coral reefs.

Besides human induced disturbances, coral reefs are also subjected to storm damage and natural predators. Damages from natural causes are normally localized and short term. For reefs further from human reach, they have the ability to regenerate over time as there are less stress from human factor (Grigg & Dollar, 1990).

Generally, reefs in a healthy and unstressed condition are able to recover from even fairly major damage. It is estimated that the reef corals will take decades to recover fully, based on their average growth rate and the assumptions that the disturbance is of short duration and there are no additional concurrent disruptions (Wells & Price, 1992). Unfortunately, the two assumed scenarios rarely occur in parallel these days. In real fact, the inherent slow growing rate of corals does not permit them to restore quickly thus reef corals continue to disappear from their natural ground.

According to Achituv & Dubinsky in 1990, the estimated world coral cover was at about 2,000,000 km^2 of tropical oceans. In year 2000, National Geographic Society and Veron quoted the area for the world's reefs at less than 600,000 km^2 and 250,000 km^2 respectively. On the other hand, the World Resource Institute (WRI) claimed that the actual extent of the present coral reefs is unknown due to rapid degradation (http://www.wri.org/wri/indictrs/rr-fore.htm). Such degree of variation to these estimated numbers reflects the need for a concerted effort to determine the total area of one of our last natural treasures in the world.

Over recent decades, conservation efforts from the scientists have managed to generate increasing awareness among the policy-makers and the public. Numerous organizations have been set up for the conservation and monitoring of coral reefs e.g. Global Coral Reef Monitoring Network (GCRMN), International Coral Reef Initiative (ICRI), WRI, United Nations Educational Scientific and Cultural Organisation (UNESCO), The World Conservation Union (IUCN), etc.

However, the lack of comprehensive database has always been one of the limiting factors in coral conservation and management efforts. The first and foremost issue which should concern the scientists and the resource managers is the need to know the location, extent and the status of these coral reefs.

1.2 Need for mapping coral reefs

Recognizing that there is no room for total preservation and protection of coral reefs, an alternative sustainable management plan which incorporates Integrated Coastal Zone Management (ICZM) strategy would be more appropriate. It is a complex task that requires information input from ecological, environmental, social and economic aspects (http://www.townplanning.sabah.gov.my/iczm/Reports/CoastalProfile Sabah/ch01/01-INTRODUCTION.html). These information used to come in the form of texts and graphs in their respective disciplines. As time passes, modern technologies such as the Geographical Information System (GIS) allows the transformation of these traditional data presentation format into multi-layered, contiguous digital map whereby several theme maps are stacked. Compared to discrete data, the composed map is able to convey almost instantaneous understanding of the ecosystem not only to scientists but also resource managers, policy makers and the public. It shows the distribution of the target resource and other related information. Such maps are generally referred to as resource maps.

Resource maps with appropriate scales showing the spatial distribution of the various habitats are in high demand, especially for resource managers and conservationists (Kenchington, 1978; Conradsen *et al.*, 1998) to formulate a sustainable development plan. Habitat is generally described as a specific type of environment inhabited by organisms. By having a synoptic knowledge of the coral reefs, it helps to identify the distribution of sensitive zones and therefore enable proper zonation; designation of the resource utilities which is an important aspect in ICZM. Besides, it will also allow a comprehensive understanding of the ecological process involved, thus facilitating the effort to combat possible adverse impacts from environmental pollution.

Therefore the production of a digital coral reef map has become one of the priorities among the conservationists and scientists. This sentiment is reflected among organizations including the Australian Conservation Agencies, the US Coral Reef Task Force (USCRTF) and National Oceanic and Atmospheric Administration (NOAA) who are taking active roles in setting the guidelines for broad scale resource mapping and coral mapping respectively. The Australian and New Zealand Environment and Conservation Council (ANZECC), under its National Representative System of Marine Protected Areas (NRSMPA) Action 8 program has a detailed outline of the protocol needed to generate various scales of resource maps according to the management needs (ANZECC, Task Force on MPA, 1999). As for the USCRTF, a join effort with the NOAA is taking place with the aim to map all the coral reefs in the United State waters, latest by year 2009 (USCRTF, 1998; http://www.coris.noaa.gov/activities/actionstrategy/04_goal_01.pdf).

In spite of the urgent need to produce an appropriately scaled digital coral reef map, the current achievement is rather inadequate. Currently, digital coral reef maps are produced in coarse resolution via data fusion and remote sensing methods, mainly to cater to ICZM and Marine Protected Area (MPA) management plan; biodiversity inventory, monitoring, etc (e.g.: http://terraweb.wr.usgs.gov/projects/CoralReefs/; http://www.wcmc.org.uk/data/database/reefbase.html; http://biogeo.nos.noaa.gov/projects/mapping/caribbean/; Robinson *et al.*, 2004). As stated by Conradsen *et al.* (1998), there is a vital need to develop methods and technology dedicated to deliver high resolution information from marine habitats in general.

1.3 Coral reef coverage assessment methodologies

The mapping of coral ecosystem should be at a scale that is adequate to depict information on the distribution of the major coral reef substrates. Nevertheless, the current reef research methodologies and the conventional remote sensing are still unable to fulfill this need. This is mainly due to the high cost involved and inherent shortcomings of the technologies as discussed later. Relatively speaking, it is much simpler to produce an accurate (good and reliable) map on terrestrial feature as compared to submerged marine terrain.

The conventional coral reef research methods used include the line transect method, belt transect method, quadrat plot and manta tow survey (e.g.: De Silva & Ridzwan, 1982; Dodge *et al.*, 1982; De Silva, 1984; UNESCO, 1984; English *et al.*, 1994). These methods are used to deriving both quantitative and qualitative data of coral reefs on a localized and small scale basis. In order to produce contiguous, broad scale resource map, scientists have explored since the 1970's the possibility from general census to underwater videography, airborne and satellite images (Aronson & Swanson, 1997; Vogt *et al.*, 1997; UNESCO, 1978; Green *et al.*, 2000). Each survey method yields different degrees of resolution and accuracy depending on the cost, time and effort invested in both ground truthing and post processing.

While Vogt *et al.* (1997) concluded that underwater videography has the potential for fast quantitative estimates of reef benthos, others find it useful in monitoring and detecting localized changes (e.g. Dotten & Florida, 1999; Miller, 1997) instead of generating coverage map as compared to airborne and satellite images.

Airborne and satellite derived images are commonly referred to as remote sensing methods. The research on the capability of satellite images for mapping coral reef environments was pioneered by Smith *et al.* in 1975 (Kuchler *et al.*, 1988). The practice of resource mapping using this technology was originally designed for terrestrial application. When applied to map submerged marine resources, a number of limitations become obvious. Cloud cover, light attenuation, sensor resolution, and inherent shortcomings in software for digital image analysis etc. are the main factors preventing clear delineation of the habitat boundaries thus deterring accurate map production. In spite of these drawbacks and extensive ground truthing efforts, present remote sensing technology is able to detect general reef structures to a maximum depth of 25 m (Knight *et al.*, 1997; Mumby *et al.*, 1997). This technique is also widely used in deriving information from surface water e.g. ocean color imagery, (Stumpf *et al.*, 2000a; 2000b), sea surface temperature and current patterns (Barnes, 1984; http://www.sstol.com/; http://sgiot2.wwb.noaa.gov/ COASTWATCH/ products.htm;).

Airborne imageries such as the CASI (Mumby *et al.*, 1998; Ripley *et al.*, 1998) and high resolution satellite images from the IKONOS (Zhou & Li, 2000; Green *et al.*, 2000) have shown better results in detail mapping of coral reefs but at a substantial cost and limited depth.

Since coral reefs are sensitive to environmental change, a technique which would allow rapid assessment of the coral coverage has to be devised. Further, this should be able to produce high resolution coral maps to a scale where reef habitats can be defined. Underwater acoustic techniques offer a compromise in compensating for many shortcomings of remote sensing techniques. It is not limited by light attenuation as it operates based on sound waves. This technique allows for large area coverage in greater details within a shorter time at a relatively low cost as compared to maps generated by satellite or airborne remote sensing methods.

1.4 Research background and justification

The Acoustic Seabed Classification System (ASCS) was first introduced to Malaysia in 1995. Based on its theory of operation and ability to discriminate sediment types, the system was tested by the author to map coral substrates at Port Dickson, Negeri Sembilan (Lee, unpbl). The result was encouraging where the ASCS was able to pick up distinct echo when ensonifying over coral substrates. The ASCS was then used to map out damaged coral area in Semporna waters (Begg and Lee, 1996) for the Department of Fisheries, Sabah. It was the first recorded achievement although the results were not officially published. Mapping on seagrasses was also conducted in Sg. Pulai, Johor with unexpectedly reliable results (Lee, unpbl).

More in-house experiments were conducted then by the author to refine the coral mapping methodology. It was found that the ASCS could differentiate coral growth forms given careful initial classification. A coral resource mapping exercise was conducted to map the coral reefs of Pulau Payar group of islands, the first Marine Mark in Malaysia with funding from the Food and Agriculture Organization (FAO) via the Bay of Bengal Programme (BOBP) and Federal Department of Fisheries (Lee & Chong, 1999). The mapping exercise recorded the coverage of six different coral growth forms. The results was published in the 9th International Coral Reefs Symposium in Bali, year 2000 (Lee, 2002) and it was the first of its kind.

1.5 The Importance of this Study

Although the author had conducted numerous coral reefs and other marine habitat survey work using the ASCS, no attempts were made to explore further the ability of ASCS in generating habitat map of required details, as well as the accuracy of the map generated.

The very system was used in the present study to document the fringing reefs at Pulau Baik in Darvel Bay in fine scale whereas a broad scale approach was adopted for the general benthic substrates of Darvel Bay. The first approach yielded a high resolution habitat map. It is a contiguous map, depicting the distribution of corals based on growth forms. Such maps could be integrated as a basemap for management and impact assessment and control purposes. The latter produced a lower resolution broad scale marine benthic habitat map of Darvel Bay. In view of the rapid development taking place along the coastline especially in Lahad Datu, such habitat map would be a useful tool depicting important decision-support information for ICZM planning. Furthermore, Darvel Bay is known to be one of the important fishing grounds in Sabah, constantly producing quality tiger prawn and broodstock (pers. comm., interviews with local fishermen). A broad scale map could be the first step in determining the correlation between bottom ground types and the broodstock abundance and distribution.

It is also the purpose of this study to scientifically assess the accuracy of habitat maps generated using hydroacoustic method. Previous maps that have been produced and used as reference tool do not provide information on corresponding accuracy. The present study also attempts to bridge this information gap.

1.6 Hypotheses of this study

This study will test two hypotheses whether:

* Hydroacoustic method can be used for coral reefs and other marine habitat mapping according to the preferred level of details;
* Habitat maps produced from hydroacoustic method can be used confidently for resource management and monitoring.

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