Remote Sensing Monitoring and Assessment

of Bleached Coral

Alexis Robinson

0127159

Dr. Ulf Runesson

OUTD-4415-WA/ FORE 4217

March 12, 2004
# Table of Contents

Figures 3

Introduction 4

Background Information 5

Coral Reef Ecosystems 5

Coral Health and Environmental change 6

Coral Reef Bleaching 6

Reflectivity 7

Define Reflectivity and Spectral Reflectance 7

Healthy Coral 8

Bleached Coral 8

Issues with Reflectivity and Spectral Analysis 9

Radiative Transfer Theory 10

Role of Remote Sensing 11

Detection 12

Determining the Rate of Coral Bleaching 12

Long Term Monitoring 13

Limitations of Remote Sensing 14

Capabilities of Sensors 16

Conclusion 17

References 18
List of Figures

Figure 1. Radiative Transfer Theory................................................................. 9

Figure 2. Radiative Transfer Modelling, which depicts the scattering of light in the coral reef community................................................................. 10

Figure 3. NOAA/NESDIS Hot Spots (1998) -- higher than normal sea surface temperature values that could help identify areas of coral bleaching. ................. 14
Remote Sensing Monitoring

Introduction

Coral reef bleaching is a major scientific and environmental issue. Reports of reef degradation worldwide are fuelling interest in and debate over the causes of temporal shifts in community structure over longer time scales. Over the last 20 years the health of coral has markedly declined (Call, Hardy, & Wallin, 2003). Coral reefs are often remote, relatively large, and shallow. Therefore, optical remote sensing techniques can provide an efficient and cost-effective approach to mapping and monitoring the condition of coral reefs. Conventional methods used to determine community structures include field surveys which include in situ quadrats, line transects, and manta tows (Hochberg, Atkinson, & Andrefouet, 2003), which are techniques used to observe a specific area over a short period of time. However, these are not feasible for accurate determination of spatial distributions over large areas or temporal scales.

Coral reefs provide a variety of ecosystem services including the provision of shelter for marine species from tropical storms, a wealth of biodiversity, and important nurseries (Mumby & Edwards, 2002). Therefore as reefs experience increasing stress from global anthropogenic processes, scientists and resource managers must look to larger-scale methods of ecosystem assessment such as remote sensing. This paper will cover coral reefs and coral bleaching, the reflectivity of healthy coral and bleached coral, and problems associated with spectral reflectance. It will also cover the role of remote sensing, and detail a few examples where and for what purpose remote sensing is currently being used.
Background Information

Coastal habitats can be manageable units and large-scale maps allow managers to visualise the spatial distribution of habitats, therefore aiding the planning and monitoring of marine protected areas, especially networks of marine protected areas. The extent of coral degradation needs to be documented and monitored. Therefore in order to initiate global research, awareness of present and future problems and vulnerabilities must be increased. In terms of coral reefs, they are dynamic organisms that are affected by a vast range of processes that span scales from millimetres to thousands of kilometres.

Coral Reef Ecosystems

Coral reef communities are largely mosaics of coral, various algae and carbonate sand, and knowing their distributions is fundamental to the assessment of reef status. Reefs are trans-boundary resources. Some reefs may be net sources of larvae to reefs downstream, whereas other reefs may be net larval sinks, reliant on sites upstream for their larvae supply (Mumby & Harborne, 1999). The connectivity between coral reefs and other systems can also modify the local environment through the transfer of pathogens, pollutants, nutrients, and sediments. Therefore poor urban sanitation practices can affect coral reefs downstream and possibly go beyond regional borders and into international boundaries.

The productivity of a coral reef is often attributed to an individual coral’s mutualistic relationship with its symbiotic dinoflagellate algae, or zooxanthellae (unicellular algae living endosymbiotically within coral-host tissue) (Holden & Le Drew, 1998). The algae contributes organic carbon from photosynthesis, and the sleratinian, or reef building, coral contributes inorganic nutrients to the construction of massive, wave-
resistant reefs that dominate shallow tropical seas (Holden & LeDrew, 1998). This mutualistic relationship of coral is sensitive to environmental stresses (UV-B radiation, elevated temperature, and pollution).

Coral Health and Environmental change

As the influence of human populations on coastal zones increases, so does the need to create and generate awareness of the social, technical, political, and ecological problems associated with coral reefs. Coral reef degradation is the result of both natural and anthropogenic causes. Natural phenomena such as hurricanes and disease contribute to reef degradation, but so does the influence of such resource uses that are beyond sustainable levels.

Corals appear to be the first organism to react to natural and anthropogenic environmental changes, such as increased ultraviolet radiation, extreme sea surface temperatures, heavy sedimentation, eutrophication, and thermal pollution (Holden & LeDrew, 1998; Call, Hardy, & Wallin, 2003).

Coral Reef Bleaching

Bleaching frequency has increased since the early 1980s, and a severe global bleaching event took place in 1997 and 1998 (Yamano & Tamura, 2004). The possible reason for the increased frequency of bleaching might be related to high sea surface temperature, which is caused by global warming.

Coral reef bleaching occurs when environmental conditions are altered and the stress placed upon the coral causes it to expel either its symbiotic zooxanthellae or experiences a decrease in photosynthetic pigment concentration within the zooxanthellae (Holden & LeDrew, 1998). The result if both reactions lead to a loss of colour since the
coral tissue becomes translucent without its pigment. When corals bleach, they usually lose 60-90% of their zooxanthellae or the zooxanthellae may lose 50-80% of their photosynthetic pigment (Holden & LeDrew, 1998). If the bleaching is not too severe, corals often recover, but the extent of zooxanthellae loss and coral tissue damage is unknown. The complete loss of algae and pigments occur during extreme mass bleaching events, but bleaching is usually not uniform over a single colony, community, or zone.

Reflectivity

The useful signal that is used for remote sensing of coral environments is between 400 nm and 600 nm (Lubin, Li, Dustan, Mazel, & Stamnes, 2001). Longer wavelengths are offset by the strong water column attenuation, so that radiances for wavelengths longer than 600 nm are very small and the radiance contrasts between scene types are poor. Between 400nm and 600nm, most scene types remain distinct from one another, for example sand and coralline algae are the brightest while coral species are considered to be noticeably darker (Lubin, et.al, 2001).

Define Reflectivity and Spectral Reflectance

Spectral reflectance is a combination of the light flux that is not absorbed by the bottom-types and the light fluoresced by the bottom-types (Hochberg, et.al., 2003). Coral and zooxanthellae pigments have been shown to fluoresce (Hochberg, et.al., 2003). It is the spectral absorption by pigments that determines the overall shape of the spectral reflectance. There are common features in spectral reflectance that are common to all bottom-types. Low values at blue and green wavelengths are largely the result of absorption by photosynthetic and photoprotective compounds. Similarly, higher values at
red wavelengths indicate a lack of absorption or presence of active fluorescence (Hochberg, et.al., 2003).

Healthy Coral

In healthy coral chlorophyll absorption is apparent near 675nm, and the effect of strong near-infrared reflectance is apparent at 700nm (Hochberg, et.al., 2003). The presence of fluorescent pigments in coral tissue is sometimes apparent as subtle positive features at blue and green wavelengths in healthy coral classes. With regards to health coral in shallow water the wavelength that should be utilised is between 560 and 575 nm on Landsat TM band 2 (Call, et.al., 2003). With regards to deep corals the wavelength is between 590 –600 nm and Landsat TM band  2 (Call, et.al., 2003). This is the suggested wavelength since chlorophyll reflectance is between 550 and 570 nm and its absorption falls in the ranges of 400-500nm and 670-680nm (Holden & LeDrew, 1999). Chlorophyll fluorescence signal is linked to cell physiology and can vary with nutrient status, species composition and growth rate.

Bleached Coral

The loss in pigmented zooxanthellae from corals during bleaching events results in an optical signal that is strong enough for remote sensing to detect (Yamano & Tamura, 2004). The spectral reflectance of bleached coral resembles that of carbonate sand (Hochberg, et.al., 2003), since the loss of zooxanthellae combined with the decrease of host pigmentation, results in the optical exposure of the coral carbonate skeleton (Hochberg, et.al., 2003). Call, et.al. (2003), suggests that for bleached coral the wavelength to use is 560-590nm and the Landsat TM band is TM 2.
Issues with Reflectivity and Spectral Analysis

In a study done in the Pacific and Indian Oceans coral types were misclassified as other corals (Hochberg, et.al., 2003). For example soft/gorgonian corals miss-classified as brown coral, however the reverse was not true (Hochberg, et.al., 2003). Another problem with remotely sensed measurements is that the atmospheric path between the object and sensor will modify characteristics of the received radiation (Holden & LeDrew, 1999). The sea-air interface contributes to third complicating factor, since the amount of energy transmitted into the sea versus that which is reflected off the surface depends on the sea surface state, wind speed, and sun angle. A final problem is the difficulty of separating the water column signal from the substrate signal (Holden & LeDrew, 1999). This can be corrected with radiative transfer theory algorithms. Figure 1 shows that airborne reflectance of spectra are composites of reflectance between the atmosphere, sea surface, water column, and the bottom (sediments, seagrass, and coral).

Figure 1. Radiative Transfer Theory
Source: NASA, 2003
Radiative Transfer Theory

This theory provides a connection between inherent (scattering, absorption) and apparent (upward radiance, downward irradiance, reflectance) optical properties (Holden & LeDrew, 1999). Figure 2 depicts light scattering in the coral reef community, including scattering in the water and atmosphere. Inherent properties depend upon the medium and are independent of the ambient light, while apparent properties depend on both the medium and geometric structure of the ambient light field (Holden & LeDrew, 1999).

Figure 2. Radiative Transfer Modelling, which depicts the scattering of light in the coral reef community

Source: NASA, 2003
Role of Remote Sensing

Coastal habitat maps are a requirement for establishing coastal management plans. Management plans should include aspects of conserving and monitoring reef diversity, maps can also provide detail on the inventory of habitat types and their statistics, the location of environmentally sensitive areas, allow representative networks of habitats to be identified, identify hot spots of habitat diversity, permit changes in habitat cover to be detected, and allow for boundary demarcation of multiple-use zoning techniques (Mumby & Harborne, 1999). Remote sensing and satellite imagery is being used for cartographic base mapping, detecting change in coastal areas, environmental sensitivity mapping, charting bathymetry, fisheries management, and stock assessment. Remote sensing has been widely used for the mapping and inventory of coastal resources (Mumby, Green, Edwards, & Clark, 1997).

Field surveys are often time consuming and expensive to conduct over a continuum of scales, but remote sensing can be used to scale-up field observations. It can be used to identify the causes of degradation and can then be used to monitor key disturbance factors and attempt to match the scales of pattern (change in community structure) to candidate processes (Mumby, Skirving, Strong, Hardy, LeDrew, Hochberg, Stumpf, & David, 2003). These processes cannot all be measured directly, but many of the environmental and ecological processes can be measured using remote sensing. This includes sea surface temperature, chlorophyll-a, suspended sediment, precipitation, solar radiation, salinity, wind speed, and algae blooms.
Detection

Optical remote sensing methods can penetrate clear waters to approximately 15-30 metres (Mumby, et.al., 2003). However light penetration is wavelength dependent, the degree of penetration depends upon the optical properties of the water (e.g. suspended sediment). Yamano and Tamura (2004) found that the maximum detection depths were 28, 21, and 3.0 m for bands 1, 2, and 3 of Landsat TM, respectively.

Descriptive resolution is used to identify the level of habitat detail that remote sensing methods describe as the bottom layer of the ocean otherwise known as the benthos. (Benthos is defined as a region including the bottom of the sea and littoral zones, photosynthesis still occurs in this region.) Therefore, based upon descriptive resolution, a coarse resolution would identify coral reefs from seagrass beds whereas a finer resolution would differentiate different coral species (Mumby & Harborne, 1999).

Determining the Rate of Coral Bleaching

A coral’s health can be determined several ways: change in growth rate, metabolism, biochemistry or reproduction, behavioural response, disease, or loss of zooxanthellae. To determine the rate of coral bleaching, habitat maps of coral reef ecosystems are needed. Coral reef habitat mapping is often achieved using optical remote sensors. The spatial and spectral resolutions of a sensor determine which aspects of the benthos (bottom of lake or ocean) are mappable, and therefore the appropriate definition of habitat. In order for remote sensing to be useful in mapping community structure, the remote sensing system must have the abilities to spatially resolve reef bottom-types and to spectrally discriminate between them (Hochberg, et.al., 2003). Except that the systems that provide spectral information have poor spatial resolution; for example, the systems
that have the ability to spatially resolve reef bottom-types (e.g. Landsat, Ikonos at 30- and 4-m pixel resolutions, respectively) have bands that provide poor spectral data for reef bottom-type discrimination (Hochberg, et.al., 2003).

Long Term Monitoring

Interest is growing in using remote sensing to monitor reef health. Several studies have been done that model the feasibility of detecting a bleaching event using remote sensing, but a detailed empirical study on the Great Barrier Reef found that very small pixels (0.1-0.8 m) are required to quantify accurately the percentage of bleached coral (Mumby, et.al., 2003).

Summer images are often used for the monitoring of bleached coral, since bleaching is often a result of high sea surface temperatures under incident light from the higher solar elevation angles (Yamano & Tamura, 2004).

Long term monitoring can involve the measurement of sea surface temperature (thereby looking for hot spots in a reef location). Hot spots can provide a measure of the intensity of the thermal stress as shown in Figure 3. Solar radiation can also be monitored since it underpins the primary production on coral reefs and contributes to the phenomena of coral bleaching (Mumby, et.al., 2003). Satellites can provide global time series measurements of incident ultraviolet (UV) radiation. The satellites that monitor UV radiation are polar orbitors this means that it has the ability to over fly the same point on the Earth’s surface every few days. This might be an advantage for monitoring specific scenes (Lubin, et.al., 2001).
Figure 3. NOAA/NESDIS Hot Spots (1998) -- higher than normal sea surface temperature values that could help identify areas of coral bleaching.

Source: NOAA, 2002

At meso-scales, changes in water quality beyond reefs are detected on a daily basis using observations from ocean colour sensors such as SeaWIFS or MODIS (Mumby, et.al., 2003). The observations from these sensors are used to track water masses and aid with the understanding of the connectivity of coral reefs.

Limitations of Remote Sensing

Remote sensing is subject to several limitations including highly turbid environments (Mumby, et.al., 2003), cloud cover, optical similarity of reef features, wavelength-specific water column attenuation, and the spatial and spectral resolution of
the sensors (Call, et.al., 2003). It should be mentioned that atmospheric attenuation can never be eliminated, but radiative transfer algorithms are available to remove the effects if the atmospheric variables are known.

White (cited in Mumby, et.al., 2003) mentions that in order to overcome optical sensor limitations scientists can employ acoustic remote sensors. These active sensors are usually towed behind a boat and measure the depth of the water and components of surface roughness and hardness (White cited in Mumby, et.al., 2003). Compared to optical methods, the advantages of these sensors are: greater depth of penetration, not constrained by optical water properties (such as light scattering), and measurement of sea bed structure. However these active sensors cannot be deployed in shallow water (<0.5m), cannot provide synoptic measurements over large areas, and are unable to discriminate between benthos on the basis of pigment (Mumby, et.al., 2003). Recent studies are acknowledging that there are possibilities with regards to combining spectral and acoustic methods.

Since coral reefs are heterogeneous, detection limits can be constrained. The spatial resolution of currently available, widely used satellite imagery (e.g. Landsat TM, SPOT) is considered to be too coarse to map reefs in detail (Yamano & Tamura, 2004). Coral reef studies have often suggested that it is difficult for satellite sensors to detect coral bleaching due to low spatial resolution (~30 m) relative to the scale of reef heterogeneity (Holden & LeDrew, 1998; Yamano & Tamura, 2004). A study of aerial photographs taken during the 1998 bleaching event concluded that information on bleached corals can be obtained only from sensors with high (<2 m) spatial resolution (Andrefouet, et.al., 2002).
Other limitations include; coarse spatial resolution which means that spatial features cannot be detected within pixels, coarse spectral resolution that means that the research is unable to detect small spectral characteristics, variable water attenuation which means that there is confusion between deep water and dark substrate, cloud cover, high costs of imagery, hardware, software, and expertise, and finally inadequate user training (Holden & LeDrew, 1999). There are solutions to these problems such as spectral unmixing, analytical techniques, radiative transfer correction, airborne imagery, co-operation between governments, and communication to list a few.

Capabilities of Sensors

With regards to Landsat 7, the onboard recorders cannot be programmed to collect data everywhere; there is often a scarcity of data over remote tropical regions where many coral reefs have yet to be identified, or even monitored (Lubin, et.al., 2001). It was found by Mumby and Edwards (2002) that Landsat TM was the most cost effective sensor for mapping coral reefs with regards to price and mapping accuracy. However it is limited to sites that have particularly high coral cover over large areas (Yamano & Tamura, 2004).

The heterogeneous nature of coral reefs, might lead to better detection of coral bleaching with the use of higher spatial resolutions with sensors such as Ikonos or Quickbird. It was found that thematic accuracy increased using Ikonos, spatial resolution is 4 m (Yamano & Tamura, 2004; Mumby & Edwards, 2002), which would contribute to detailed coral mapping.

It was found by multiple studies that the utilisation of Landsat TM imagery, can provide a cost-effective and relatively accurate means of classifying coarse descriptive
resolution substrate types, where as the higher resolutions can provide finer resolution but at a higher cost.

Conclusion

Coral reef ecosystem health is becoming a pressing issue with regards to coral bleaching. Coral bleaching is leading the deaths of many reef ecosystems and it is estimated that in 50 years there might not be many coral reefs left in the world. Coral reefs are dynamic ecosystems that are symbiotically linked to many microorganisms. It has been found that mass bleaching events are a result of elevated sea surface temperature and increased UV radiation both as a result of natural and anthropocentric changes in the environment. Coral reef bleaching can be monitored through remotely sensed data. There are limitations that included coarse data that cannot discriminate spectral and spatial data, water and atmospheric attenuation, and problems with standardization. Despite the limitations of satellites and airborne sensors, they are useful for benthic substrate mapping, monitoring ecological change, and reef management.
References


