Coral Reef
Targeted Research & Capacity Building for Management

Directory of Remote Sensing Applications for Coral Reef Management

Compiled by the CRTR Remote Sensing Working Group

www.gefcoral.org

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Cover: Midway Island. Satellite image by GeoEye

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Introduction

Remote sensing has underpinned coral reef management activities for nearly four decades. The predominant role of remote sensing has been to map coastal resources as part of a marine spatial planning activity. With the advent of new, improved sources of data these maps are now more detailed and accurate than ever before.

However, the boom in satellite information has not simply granted practitioners access to better maps; there now exist a wide range of truly useful tools for managers. Examples include mapping the potential response of reefs to thermal stress, mapping the locations of critical nursery habitats for fisheries, and mapping hotspots of marine diversity.

This directory is part of a suite of tools aimed to help reef managers make better use of remotely-sensed data (see below). The directory is deliberately brief and aims to familiarise managers with the opportunities provided by remote sensing. The overall limitations of the methods are indicated together with major considerations for implementation. Further training and implementation tools are available elsewhere as summarised below.

Directory of Remote Sensing Applications for Coral Reef Management

Aims to familiarise managers with tools available

Tools for Setting Objectives

Reef Observer
Software tool to plan habitat mapping and reef assessment
www.gefcoral.org

Coastal Remote Sensing Toolkit
Online system to identify best types of imagery for habitat mapping
www.gpem.uq.edu.au/cser-rstoolkit

Training Tools

Bilko for Windows
Free training module for habitat mapping (Module 7) & a lesson on mapping thermal stress
www.unesco.bilko.org/software.php

Implementation Tools

Bilko for Windows
Free remote sensing software
www.unesco.bilko.org/software.php

Books & Journals
Remote Sensing Handbook for Tropical Coastal Resourses Assesment and Management (2000) by EP Green, PJ Mumby, AJ Edwards, CD Clark. Unesco CSI Publishing
www.unesco.org/csi/pub/source/rs.htm

Bibliography in Directory of Remote Sensing Applications for Coral Reef Management

Definitions used in summary tables

Acceptance

Indicates whether the technique is expected to work in many environments or whether it remains somewhat experimental, having had limited testing so far.

Extent

Gives an overall impression of the coverage of the main datasets. Some, like sea surface temperature, are global, whereas others can be used for mapping at regional or local scales.

Habitat Mapping

Reef locations

Acceptance	Scales	Extent	Data source	Cost
Widely accepted globally	100s km – m Multiple years	Global - local	Satellite, Airborne	Free – $

Scales

Separated into the range of spatial scales (upper half) and temporal scales (lower half) for which mapping is routinely possible. There are three main categories of temporal resolution. Some satellite products, such as Sea Surface Temperature, are collected regularly and detailed time series can be established ('time series'). Others, such as IKONOS images, are only archived occasionally ('multiple years'), often every few years or so (although new acquisitions can be programmed). Lastly, we use the term 'custom' to indicate activities that usually need a dedicated new acquisition of data (e.g. from a boat or airborne survey).

Data source

Indicates the major types of remotely sensed data that are used.

Cost

Free	Some remote sensing data sources are available online for free
$	Typical imagery sources cost hundreds of dollars
$$	Imagery may cost several thousand dollars
$$$	Imagery may cost tens of thousands of dollars

Habitat Mapping

Reef locations

Acceptance	Scales	Extent	Data source	Cost
Widely accepted globally	100s km – m Multiple years	Global - local	Satellite, Airborne	Free – $

Description

Simple delineation of shallow reef structures, distinguishing them from deep water and vegetated lagoon habitats such as seagrass beds.

Imagery requirements

Coarse to high resolution satellite data including MERIS (200 m), Landsat TM (30 m), SPOT (10 m), IKONOS (4 m), QuickBird (2.4 m). Also possible using aerial photography (<1 m) and airborne hyperspectral (~1 m), but with a much higher cost.

Field data requirements

None required, image visualisation usually sufficient.

Methods summary

Simple image classification or visual interpretation / manual polygon delineation.
www.unesco.org/csi/pub/source/rs.htm

Limitations and notes

Does not provide information on the type of reef or its state. Will only be able to detect gross changes after major events (e.g. ship groundings) or long time intervals of multiple decades.

Habitat Mapping

Mangroves (including nursery habitats)

Acceptance	Scales	Extent	Data source	Cost
Well-established	100s km	Global - local	Satellite, Airborne	Free – $
	Multiple years			

Description

Various aspects of mangroves can be mapped including their location, general zonation (e.g. dwarf *Rhizophora*, fringing *Rhizophora*, *Avicennia*, and *Laguncularia*), height, and leaf area index. Fringing habitats often form nurseries for reef fish and invertebrates as well as possessing a range of unique species themselves.

Imagery requirements

Coarse to high resolution satellite data including MERIS (200 m), Landsat TM (30 m), SPOT (10 m), IKONOS (4 m), QuickBird (2.4 m).

Field data requirements

Depends on specific objective but usually need to record habitat type and canopy height. Paired light sensors are needed to estimate leaf area index.

Methods summary

Use of vegetation indices such as the normalised difference vegetation index followed by simple image classification.
www.unesco.org/csi/pub/source/rs.htm

Limitations and notes

Subtle differences in community type or zonation might be difficult to distinguish, particularly where understory vegetation, such as *Salicornia*, is common. Radar methods can be used where cloud cover is high, but gives less detailed information.

Habitat Mapping

Seagrass beds

Acceptance	Scales	Extent	Data source	Cost
Well-established	100s km – 10s m Multiple years	Regional - local	Satellite, Airborne	Free – $

Description

The extent of seagrass beds can be mapped where seawater is fairly clear (horizontal Secchi distance >10 m). More detailed measurements can be made such as identifying the location of blowouts and mapping the standing crop (above-ground biomass).

Imagery requirements

Coarse to high resolution satellite data including MERIS (200 m), Landsat TM (30 m), SPOT (10 m), IKONOS (4 m), QuickBird (2.4 m). Also possible using aerial photography (<1 m) and airborne hyperspectral (~1 m), but for a much higher cost.

Field data requirements

Depends on objectives. To map seagrass standing crop, field calibration is required: *Mumby PJ, Edwards AJ, Green EP, Anderson CW, Ellis AC, Clark CD. 1997. A visual assessment technique for estimating seagrass standing crop. Aquatic Conservation-Marine and Freshwater Ecosystems 7: 239-251.*

Methods summary

Depth correction can be important as seagrass can be confused with coral or algal beds. Simple image classification or visual interpretation / manual polygon delineation is required and contextual editing can help.
www.unesco.org/csi/pub/source/rs.htm

Limitations and notes

Species cannot be discriminated and very sparse habitats, such as those dominated by *Halodule*, are difficult to distinguish. Seagrass often extends into areas too turbid to map effectively.

Habitat Mapping

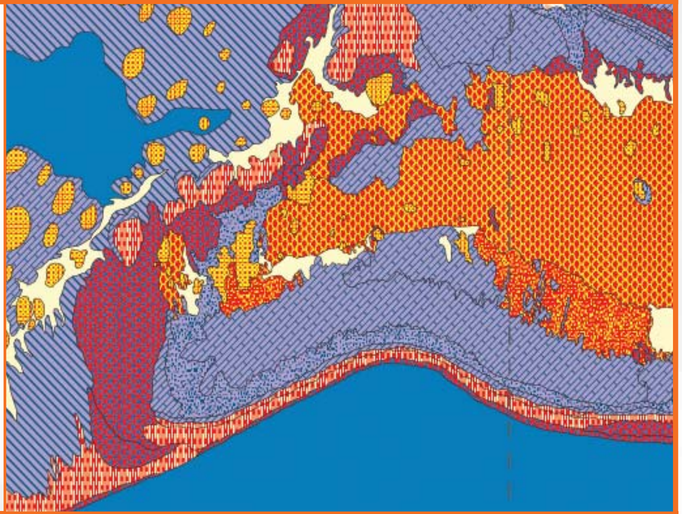
Reef geomorphology/habitats

Acceptance	Scales	Extent	Data source	Cost
Well-established	100s km – 10s m	Regional - local	Satellite, Airborne	$$
	Multiple years			

Description

Major zonation of reefs into backreef, reef crest, forereef, spur and groove formations, large patches of sand, and patch reefs (bommies). No indication of the state or health of habitats or which benthic communities dominate the habitat.

NOTE: the Millennium Coral Reef Mapping project will be producing free global maps of reef structures.



Imagery requirements

Medium to high resolution satellite data including Landsat TM (30 m), SPOT (10 m), IKONOS (4 m), QuickBird (2.4 m). Also possible using aerial photography (<1 m) and airborne hyperspectral (~1 m). Landsat images of coral reefs are available for free:
http://oceancolor.gsfc.nasa.gov/cgi/landsat.pl

Field data requirements

Use a habitat classification and survey the study area using stratified random sampling where stratification might follow major gradients of depth or wave exposure. Take GPS position and depth of at least 30 sites per habitat type. Aerial photography can be used to help stratify the survey.

Methods summary

Simple image classification or visual interpretation / manual polygon delineation. Compensation for variable depth and contextual editing can help.
www.imars.usf.edu/MC/methods.html

Limitations and notes

Will only be able to detect gross changes after major events (e.g. ship groundings) or long time intervals of multiple decades.

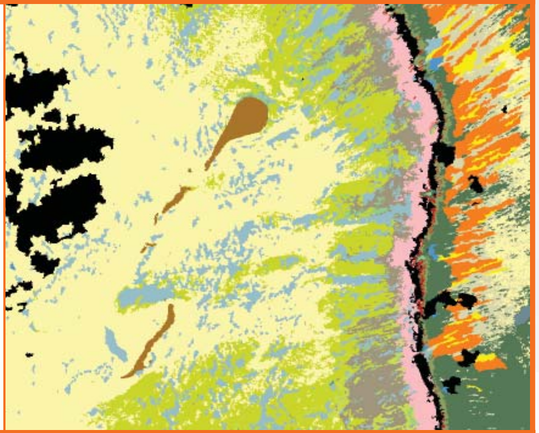
Habitat Mapping

Reef community type

Acceptance	Scales	Extent	Data source	Cost
Fairly well-established	10s km – m Custom	Local	High resolution satellite, Airborne, Acoustic sensors	$$ – $$$

Description

Detailed mapping of the type of reef community that characterises each reef zone. Typical examples might include distinguishing areas dominated by branching corals, massive corals, soft corals, or gorgonians. Different algal communities might also be mapped to discriminate areas dominated by fleshy brown macroalgae (e.g., *Lobophora* or *Sargassum*), blooms of green carpeting algae (e.g., *Microdictyon*), calcareous erect green algae (e.g., *Penicillus*), and cyanophyte blooms.



Imagery requirements

For best results, use airborne multi- or hyperspectral instruments such as the Compact Airborne Spectrographic Imager (CASI) or Hymap, to ensure the availability of as many spectral channels as possible. High-resolution satellite data (e.g., QuickBird) can be used but should ideally be combined with acoustic surveys which quantify seabed roughness and hardness. Acoustic sonar devices like RoxAnn can significantly improve the ability to discriminate reef communities if they are used in conjunction with imagery.

Field data requirements

Acoustic systems towed behind a boat (optional though important if planning to use satellite imagery). Otherwise, field requirements similar to that for habitat mapping but require a more refined habitat classification.

Methods summary

Correction for variable depth important but more advanced methods may help such as taking derivatives from spectral data and using lookup table approaches. Acoustic tracks will need to be interpolated. Airborne data will need atmospheric correction.
www.unesco.org/csi/pub/source/rs.htm
www.ozcoasts.org.au/geom_geol/toolkit/index.jsp

Limitations and notes

This is an advanced objective for remote sensing and will usually be constrained to the shallowest 10 – 15 m of the reef. Clear water is essential.

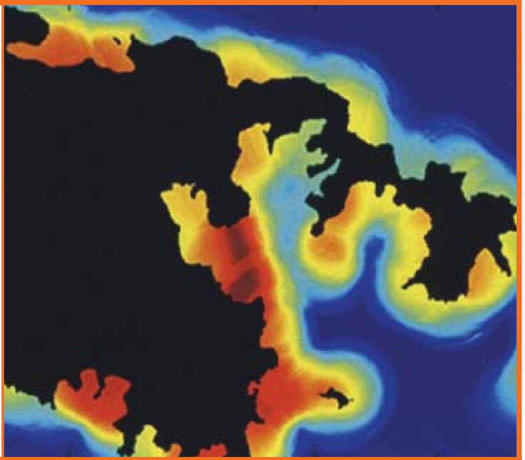
Habitat Mapping

Beta diversity (between-habitat diversity)

Acceptance	Scales	Extent	Data source	Cost
Widely-accepted	100s km – 100s m Custom	Local	Satellite, Airborne, Acoustic	$$ – $$$

Description

Maps of beta diversity (between-habitat diversity) can be useful to quantify the overall level of diversity across the seascape at a particular spatial scale (e.g., at the size of potential marine reserves). One beta diversity metric, developed by Harborne et al (2006), is sensitive to the number of habitats, the difference of the communities among habitats, and the evenness of habitat coverages within the seascape. It takes a maximum value where there are many, very distinct / contrasting habitats, and where each is well represented on the seascape. Maps can help summarise biodiversity statistics for reserve design.



Imagery requirements

High quality map of reef communities from either airborne multi-/hyperspectral or high resolution satellite imagery (ideally in combination with acoustic data).

Field data requirements

In addition to the requirements for mapping reef communities, it is necessary to have detailed quantitative descriptions of each community type. Typically this would involve surveys of species abundance using quadrats or line transects.

Methods summary

Preparation of detailed habitat map (see section on mapping reef habitats and communities). The similarities among community types can be quantified using classification of field data with the Bray-Curtis dissimilarity coefficient. Mapping of beta diversity requires custom programming because a floating window must be passed over the entire map and calculations repeated at each location. *Harborne AR, Mumby PJ, Hedley JD, Zychaluk K, Blackwell PG. 2006. Modeling the beta diversity of coral reefs. Ecology 87: 2871-2881.*

Limitations and notes

By using an average description of the species found in each community type, this approach usually assumes that the species composition of each habitat does not vary systematically over the seascape. In reality there are likely to be some systematic differences in intra-habitat community structure over the seascape as a function of physical gradients, historical disturbance, or the size and specific context of the habitat patch.

Habitat Mapping

Connectivity of fish between mangroves & reefs

Acceptance	Scales	Extent	Data source	Cost
Experimental	100s km	Local	Satellite	Free – $
	Multiple years			

Description

Many reef fishes, particularly those in the families Lutjanidae and Haemulidae, migrate from a mangrove nursery habitat to their adult reef habitat. Maps of mangrove nursery habitat (principally fringing *Rhizophora*) and reef location can be combined to estimate the relative strength of mangrove-reef connectivity for migrating fishes. Three types of map are possible: (i) connectance of mangroves to adjacent reefs, (ii) connectance of reefs to mangrove nurseries, and (iii) potential of non-mangrove habitat to fulfil a nursery role if restored.

Imagery requirements

Maps of mangrove fringes and reef locations, easily available from medium-resolution satellite data such as Landsat TM.

Field data requirements

None, other than those required to map mangroves and reef locations.

Methods summary

Specific algorithms are described in two publications:

1. *Mumby PJ. 2006. Connectivity of reef fish between mangroves and coral reefs: Algorithms for the design of marine reserves at seascape scales. Biological Conservation 128: 215-222.*
2. *Edwards HJ, Elliott IA, Pressey RL, Mumby PJ. 2010. Incorporating ontogenetic dispersal, ecological processes and conservation zoning into reserve design. Biological Conservation 143: 457-470.*

Limitations and notes

The algorithms developed to date have been tuned for Caribbean systems from Mesoamerica. They make a number of assumptions about the distances over which fish migrate (typically <10 km) and the extent of mangrove needed to generate an effect (typically a perimeter of ~50 km). Practitioners should examine the assumptions carefully. Use of the techniques in Indo-Pacific systems is feasible but the underlying science is not yet supported.

Habitat Mapping

Live vs. dead coral cover

Acceptance	Scales	Extent	Data source	Cost
Experimental	km – 10s m Custom	Local	Airborne	$$$

Description

Mapping the state of corals, distinguishing the spectra of live corals from dead (or even recently-dead). To date, the mortality of large *Porites* colonies has been mapped, as have large monospecific beds of dead *Pocillopora*.

Imagery requirements

Requires many spectral bands (>6 in the blue-green part of the spectrum) so requires airborne multi- or hyperspectral data.

Field data requirements

Detailed calibration using surveyed plots (5 m × 5 m) which have been carefully located using either accurate GPS or white plastic markers deployed near the plots during overflights.

Methods summary

Atmospheric correction of airborne data, derivative analysis of spectra, and correction for variable depth. Correction for variable depth will require either an independent bathymetry dataset (e.g., from Lidar or interpolated sonar) or use of computationally-demanding lookup table algorithms.

Limitations and notes

Possibly one of the most technically-demanding objectives for remote sensing and one that is not routinely possible. Live coral cover has been mapped to a depth of approximately 10 m in French Polynesia in calm areas with clear water. Importantly, these reefs had almost no brown macroalgae which might otherwise have been confused with the coral. Practitioners should not routinely expect to be able to map live coral cover and should consult experts prior to embarking on such a campaign.

Habitat Mapping

Reef structural complexity (rugosity)

Acceptance	Scales	Extent	Data source	Cost
Experimental	10s km – 100s m	Local	Acoustic sonar	$$
	Custom			

Description

Mapping the structural complexity of the reef can be used as an index of availability of physical refuges for the associated fauna, the location of likely hotspots of diversity, and for stratifying monitoring. Maps of rugosity can also be used to predict the abundance of various reef fish species (particularly of strongly territorial ones) providing that field calibration has been carried out between fish abundance and rugosity.

Imagery requirements

Acoustic system such as RoxAnn or BioSonics. The system is towed onboard a small boat and extracts data on bottom roughness and hardness from the echosounder returns from the seabed. Bottom roughness has been strongly correlated to standard field measurements of rugosity that use a chain draped over the benthos (i.e. the “chain and tape” method).

Field data requirements

If the objective is to relate measures of structural complexity to alternative measures of complexity (e.g., “chain and tape” rugosity) or living aspects of the reef (e.g., fish density, biomass or diversity) the calibration will have to be undertaken locally.

Methods summary

To map the structural complexity of an area, conduct an acoustic survey to obtain a geo-referenced interpolated surface of the acoustic roughness. This surface can be used in combination with optical data (if available) to generate habitat maps of the study area. To conduct field calibration, measure the rugosity using the “chain and tape” method or a manual alternative and the abundance of reef fish using underwater visual census (UVC).
www.ozcoasts.org.au/geom_geol/toolkit/index.jsp

Limitations and notes

The footprint of the acoustic sensor increases with depth and this should be considered when relating recordings to field data. The approach does require data extrapolation among survey tracks so the density of tracks will influence the quality of the final maps and their ability to discriminate fine-scale patterns of rugosity.

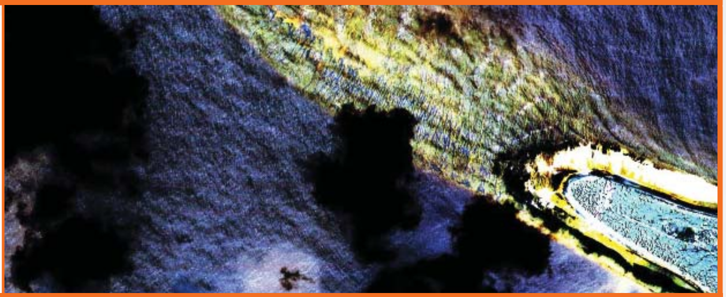
Habitat Mapping

Coral bleaching events

Acceptance	Scales	Extent	Data source	Cost
Experimental	10s km – 10s m	Local	Satellite, Airborne	$ – $$$
	Custom			

Description

Mapping the locations where coral bleaching is in progress and quantifying the intensity of the bleaching event.



Imagery requirements

High resolution satellite imagery such as IKONOS or QuickBird. Airborne imagery such as low-altitude aerial photography or multi- / hyperspectral data should also be able to fulfil this requirement.

Field data requirements

Field verification of bleaching occurrence and severity, possibly using manta-tow methods.

Methods summary

Visual interpretation feasible for low-altitude aerial photography but more complex lookup table methods needed for imagery analysis.
www.ngdc.noaa.gov/dmsp/coral/methodology.html

Limitations and notes

This is an experimental technique and has several important constraints. It will work relatively well at shallow locations that have a high coral cover (e.g., >40%) and where the intensity of bleaching is high. It will be difficult to distinguish situations where coral cover is low but bleaching intensity is high from areas where cover is high but bleaching intensity is low. It is not yet feasible to map the intensity of a bleaching event over large areas and it is recommended that these methods are only used to help verify the extent of intense bleaching in areas for which the coral cover is known to have been quite high prior to the onset of the event.

Physical Environment

Bathymetry (depth)

Acceptance	Scales	Extent	Data source	Cost
Widely-accepted	100s km – m Multiple years	Local	Satellite, Airborne, Acoustic	Free – $$$

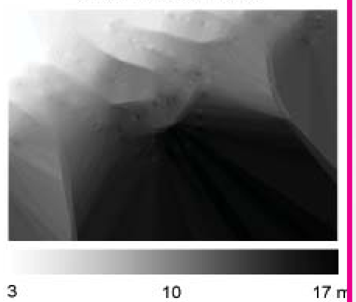
Description

The depth of the reef can be mapped with modest accuracy using a wide variety of methods. Such maps are never recommended for navigation but can be useful for stratifying field surveys and helping to interpret imagery.

Section of an IKONOS image
Glovers Atoll, Belize (Central America)

Track of the boat towing the acoustic sonar.
(Each point indicates a depth measurement)

Depth map for the same section
of the IKONOS image



Imagery requirements

Very accurate (sub-metre accuracy) measures of bathymetry can be acquired over a wide range of depths using towed acoustic sonar (e.g., RoxAnn or BioSonics) or airborne Lidar, but these techniques can be expensive. General patterns of bathymetry that discriminate depths within the top 20 m or so of the water column can be made using various satellite sensors (e.g. Landsat TM, IKONOS, etc).

www.sonavision.co.uk

www.biosonicsinc.com

Field data requirements

Not necessary if making general maps of bathymetry from field data. However, it may be helpful to obtain the coordinates and depths of patches of sand across a range of depth.

Methods summary

Some simple methods exist to extract bathymetry from medium resolution satellite data, but better results might be expected using newer Lookup table methods.

Limitations and notes

These are well established techniques and, if based on satellite data, are usually limited to the top 20 m of the water column.

2

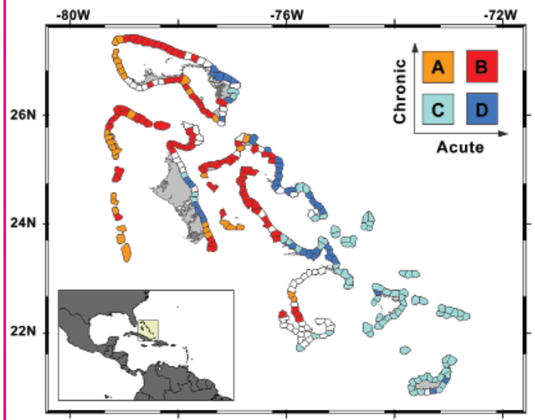
Physical Environment

Mapping corals' sensitivity to thermal stress

Acceptance	Scales	Extent	Data source	Cost
Experimental	1000s km – 1 km Time series	Global to regional	Satellite SST	Free

Description

A climatology of Sea Surface Temperature (SST) can be used to categorise the thermal stress environment that corals experience. Chronic stress can be described by the Maximum Monthly Mean during non-bleaching years whereas acute stress can be quantified for any given bleaching event as the maximum Degree Heating Weeks experienced (see page on "coral bleaching thermal stress"). A simple categorisation of chronic and acute stress imposes thresholds at the upper and lower third of each axis and results in four classes; A, B, C, and D (see inset). Corals that routinely experience high chronic stress (categories A and B) are generally better-prepared to survive a given bleaching event (though this is by no means guaranteed). Further, corals experiencing lower acute stress, often because the warm surface waters are relatively well mixed with cooler waters below, tend to fare well during bleaching events. As a result, reefs of category A should fare best during a bleaching event, followed by reefs in category C, B, and lastly D, which will fare worst. Maps of this kind can help stratify where to invest conservation effort.



Imagery requirements

Source of SST and NOAA's AVHRR pathfinder product has a long history of providing useful data.
www.nodc.noaa.gov/SatelliteData/pathfinder4km

Field data requirements

None.

Methods summary

A detailed description of methods can be obtained from Peter Mumby (p.j.mumby@uq.edu.au).

Limitations and notes

This approach is experimental and while there is some field evidence from the Caribbean that corals respond in this way, the approach needs further testing.

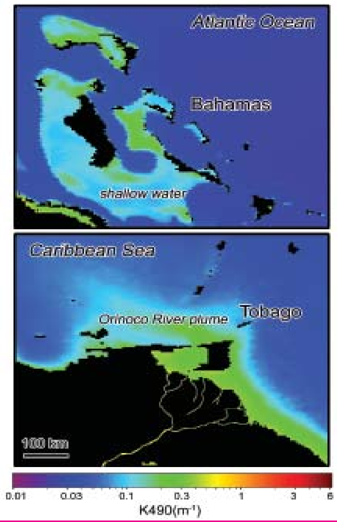
Physical Environment

Water quality

Acceptance	Scales	Extent	Data source	Cost
Experimental	1000s km – 100s m Time series	Global to regional	Satellite ocean colour	Free

Description

The broad view and short return time provided by satellite remote sensing makes it a desirable tool to assess if the area of interest is subjected to poor water quality on a permanent, seasonal, or sporadic basis. Viewed from space, the colour of the sea varies. Satellite instruments perceive subtle changes in water colour and brightness that are related to the contents of the first few meters of the water column such as phytoplankton, suspended sediments and organic matter. Some of the most commonly used water quality parameters are the concentration of chlorophyll (chl a) and the diffuse attenuation coefficient at 490 nm (K490), which provide measures of phytoplankton abundance and water clarity respectively.



Imagery requirements

Ocean colour data from satellites such as the Sea-viewing Wide Field-of-view Sensor (SeaWiFS, 1998-present), the Moderate Resolution Imaging Spectroradiometer (MODIS, 2002-present) and the Medium Resolution Imaging Spectrometer (MERIS, 2002-present).

Field data requirements

None.

Methods summary

By visual interpretation. To date, unless algorithms are developed specifically for the area of interest, water quality should only be assessed in a qualitative way by evaluating the target conditions in a wider context (comparing with nearby locations in order to assess spatial patterns or with other dates to identify sporadic events).

Limitations and notes

Reef areas present several challenges for ocean colour instruments that prevent their use for the accurate estimation of water quality parameters. The complex mixture of components in coastal waters makes the quantification of the separate constituents very difficult, and shallow bottoms can look very similar to heavily turbid regions. Further technological development is needed before this tool can be used to its full potential in most shallow coral reef settings. Although imperfect, remotely sensed data allow describing the ocean colour patterns within an area in a qualitative way, and this tool has been used to identify the influence of algal blooms, resuspension, and river plumes on coral reef communities.

Physical Environment

Wave exposure

Acceptance	Scales	Extent	Data source	Cost
Experimental	1000s km – m Time series	Global to regional	Satellite winds and coastline	Free – $

Description

Exposure to waves is an important attribute to characterize a reef landscape. Wave exposure has been related to the structure of coral and fish communities, habitat complexity, and beta diversity. Exposure maps also provide information about key ecosystem processes in coral reefs. Through mixing of the water column, wave energy favours the decrease of thermal stress and promotes the flushing of toxins, providing protection during bleaching events. Vertical mixing also increases the nutrient flux and productivity in the reef. Areas with high productivity and faster algal growth would be more vulnerable to over-fishing of herbivores because even a modest reduction in grazing will rapidly result in algal blooms. Conversely, areas of low wave exposure and naturally-low algal growth are more likely to recovery rapidly after a disturbance and be more resilient, constituting high-priority conservation areas.

Imagery requirements

Detailed digital coastline can be derived from high resolution satellite imagery (e.g. Landsat TM, SPOT, IKONOS, or QuickBird) or from shoreline databases freely available online (e.g. Global Self-consistent, Hierarchical, High-resolution Shoreline Database at about 200 m resolution). Radiometer and scatterometer satellite wind sensors, or merged products (e.g. the Cross-Calibrated, MultiPlatform ocean surface wind product) provide maps of wind speed and direction (a climatology is needed). Synthetic Aperture Radar is an ideal data source, because it measures the waves directly, instead of assuming the waves travel in straight lines.

Field data requirements

None.

Methods summary

Wave exposure is governed by the distance of open sea that the wind has blown over to generate waves and the strength and incidence of the winds. A commonly used method can be found in: *Harborne AR, Mumby PJ, Zychaluk K, Hedley JD, Blackwell PG. 2006. Modelling the beta diversity of coral reefs. Ecology 87:2871-2881*

Limitations and notes

Satellite wind imagery is subject to a lack of data and inaccuracies in near-shore areas due to contamination by land. High spatial resolution products filtered using land contamination removal algorithms should be used to guarantee accurate data.

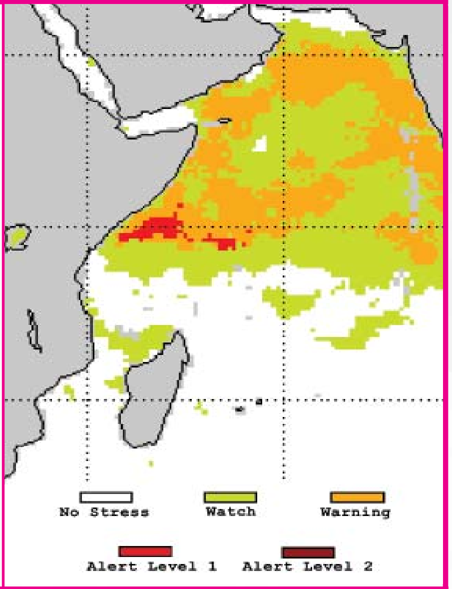
Physical Environment

Coral bleaching thermal stress

Acceptance	Scales	Extent	Data source	Cost
Widely-accepted	50km Time series	Global	Satellite	Free

Description

NOAA's Coral Reef Watch (CRW) program pinpoints areas under thermal stress that leads to coral bleaching. The basis of the system is global 50-km satellite measurements of sea surface temperature. When the temperature is warmer than the local bleaching threshold, corals become stressed and could bleach. Images are available for free on the web, with updates twice a week. An important tool for managers is the automated e-mail alert system covering more than 190 reef locations around the world. Anyone can sign up for free e-mails to warn them when their reefs of interest are at risk of bleaching. CRW also offers an experimental bleaching outlook that attempts to predict the potential for bleaching conditions over the next three months.



Imagery requirements

Free images are available:
www.coralreefwatch.noaa.gov

Field data requirements

Not necessary for general use of the bleaching alert products. However, the coarse resolution of these products means that *in situ* measurements of temperature and coral bleaching are very important for interpreting local variability within the 50km pixels.

Methods summary

If the current SST is more than 1˚C above the mean temperature for the warmest month, corals are experiencing thermal stress (HotSpots). This stress is accumulated over a 12-week period to pinpoint areas at highest risk for coral bleaching (DHW).

Limitations and notes

Areas within 50km of land are masked, but CRW provides experimental products with coverage no further than 9km from the coast:
www.coralreefwatch.noaa.gov/satellite/e50/index.html

2

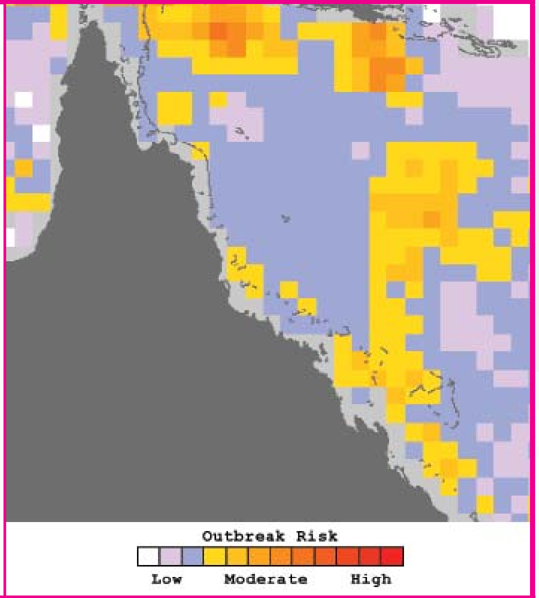
Physical Environment

Coral disease risk maps

Acceptance	Scales	Extent	Data source	Cost
Experimental	50km Time series	Regional	Satellite	Free

Description

There is growing evidence that some coral diseases are related to water temperatures. NOAA's Coral Reef Watch program is developing a new product that uses satellite Sea Surface Temperature (SST) to estimate the risk of a coral disease outbreak. This is a regional experimental product currently available for the Great Barrier Reef and Hawaii.



Imagery requirements

Source of SST and NOAA's AVHRR pathfinder product has a long history of providing useful data.
www.nodc.noaa.gov/SatelliteData/pathfinder4km

Field data requirements

Not necessary, except to ground-truth this highly experimental product.

Methods summary

Outbreak risk is assessed by looking at the coldest and warmest times of the year, both of which have been shown to relate to coral disease outbreaks. SST is used to calculate a Winter Pre-Conditioning metric, issued at the end of the cold season, and Current Summer Outbreak Risk, updated throughout the warm season. The system was calibrated using white syndrome observations from Australia.

Limitations and notes

Areas within 50km of land are masked. This is an experimental technique that may not be applicable to other diseases and other areas.
www.coralreefwatch.noaa.gov/satellite/research/dz_index.html

2

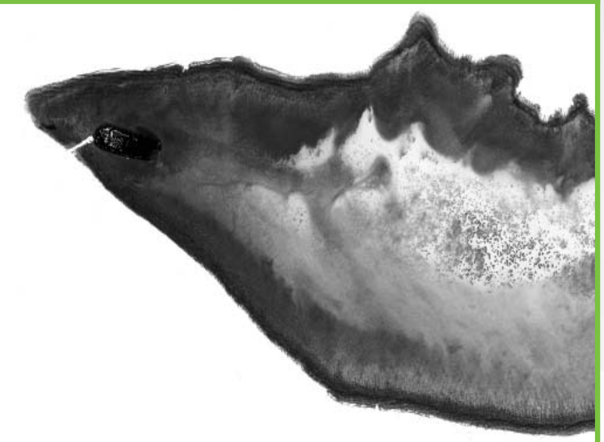
Technique

Physical inversion methods

Acceptance	Scales	Extent	Data source	Cost
Experimental	10s km – m	Local	Airborne or satellite	$ – $$$
	Custom			

Description

These experimental methods aim to simultaneously estimate multiple physical and biological parameters, such as depth and benthic type cover. The methods work by "inverting" a mathematical model of light received at the remote sensing instrument by using a pre-calculated look-up tables or a numerical optimisation technique.



Bathymetric map of Heron Island, Australia. (darker areas are deeper)

Imagery requirements

Works best with hyperspectral airborne imagery, some limited analyses may be possible with high quality multispectral satellite data (e.g. QuickBird). In all cases good radiometric and atmospheric correction is required and high spatial resolution is preferred (< 10 m).

Field data requirements

Pre-measured spectra of known benthic types. Optionally, measuring the optical properties of the water (scattering, absorption, attenuation, and fluorescence) can also be utilised to improve the model.

Methods summary

Currently no off-the-shelf processing software is available and algorithms often have to be individually tailored. Interested parties should contact Dr John Hedley.
Hedley JD, Roelfsema C, Phinn SR (2009) Efficient radiative transfer model inversion for remote sensing applications. Remote Sensing of Environment 113: 2527-2532.

Limitations and notes

Experimental and requires custom software. Some parameters work better than others, for example depth estimation is fairly reliable but benthic type mapping is more challenging.

Easy access to satellite data

Effective management requires good information about conditions that influence marine systems. Satellites can provide useful information, but access to data is often difficult. Data sets are scattered across many websites, but some key sites offer "one-stop shopping."

NOAA Coral Reef Watch provides a list of online data resources for coral managers, with links to the original data sources. Its collection includes global variables such as: sea surface temperature, chlorophyll, winds and currents, topography, precipitation, cloud cover, UV, Landsat imagery, etc. (**www.coralreefwatch.noaa.gov/crtr/data_resources.html**). Free software is available from NOAA (**http://coastwatch.noaa.gov/cwn/cw_software.html**) and Bilko (**www.noc.soton.ac.uk/bilko/**) for image analysis and visualization.

To use these data sets, it is often necessary to download data files and analyse locally, a difficult and time-consuming process if you are using data with different formats and resolutions. Some online tools allow simple access to remote sensing data, requiring only a Web browser. Subsets can be acquired to obtain local maps or time series. Output can be downloaded in various formats: raw, GIS, images, or Google Earth.

NASA's Giovanni tool has data for oceans, atmospheres, and land measurements:
http://disc.sci.gsfc.nasa.gov/giovanni

NASA's POET tool provides archives for a wide variety of oceanic data:
http://poet.jpl.nasa.gov

NOAA's OceanWatch tool is focused on current conditions, rather than archived data:
http://las.pfeg.noaa.gov/oceanWatch/oceanwatch.php

Giovanni	Maps time series graphs, and Hovmoller diagrams. Formats: image, raw data, or m ovie	Rainfall	3-hour	0.25°	Jan 1998
		Sea surface temperature	Monthly	9 km	Jul 2002
		Ocean colour (chlorophyll a, attenuation coefficient)	8-day	9 km	Aug 1997
POET	Maps and time series graphs. Formats: image, scientific, GIS, raw data, or movie	Sea surface temperature and anomalies	Daily	4 km	Jan 1985
		Ocean surface topography, significant wave height	5-day	1°	Oct 1992
		Ocean winds	Daily	0.25°	Jul 1999
		Ocean currents	5-day	1°	Jan 1993
Ocean Watch Live Access Server	Maps, time series graphs. Format: image, scientific, GIS, raw data, or Google Earth	Sea surface temperature	Daily	0.05°	Jan 1985
		Ocean surface chlorophyll a	Daily	0.05°	Sep 1997
		Ocean winds	Daily	0.25°	Jul 1999
		Ocean currents, surface height	Daily	0.25°	Oct 1992

Glossary of terms

Most definitions from the Remote Sensing Handbook for Tropical Coastal Resources Management:

www.unesco.org/csi/pub/source/rs15.htm
or from the NOAA CoRIS glossary:

www.coris.noaa.gov/glossary
or from the Canadian Centre for Remote Sensing:

www.ccrs.nrcan.gc.ca/glossary/index_e.php

accuracy: The probability that an assessment from remote sensing data is correct (e.g. the probability that a pixel classified as a particular habitat on the image is actually that habitat).

acoustic survey: The irregular reflection, refraction, or diffraction of a sound in many directions.

airborne sensor: Remote sensing instrumentation carried on aircraft, as opposed to satellites or in-water devices.

algorithm: A statement of predefined steps to be followed in the solution of a problem, such as a set of image processing steps (each a mathematical manipulation of the image data) to bring about a desired outcome.

atmospheric correction: Techniques to remove the signal (scattering, absorption, attenuation, etc) from the earth's atmosphere, so that properties of the earth's surface can be remotely sensed from above.

Bilko software: Bilko is a complete system for learning and teaching remote sensing image analysis skills. Current lessons teach the application of remote sensing to oceanography and coastal management, but Bilko routines may be applied to the analysis of any image in an appropriate format, and include a wide range of standard image processing functions. Supported by UNESCO, Bilko is available to registered users absolutely free.

BioSonics: Private company that builds acoustic instrumentation for scientific uses.

brightness: Magnitude of the response produced in the eye by light.

calibration: The process of comparing measurements made by an instrument, with a known standard.

channel (or band): (1) A selection of wavelengths. (2) Frequency band. (3) Absorption band. (4) A group of tracks on a magnetic drum. (5) A range of radar frequencies, such as X-band, Q-band, etc.

climatology: Long-term average conditions.

Compact Airborne Spectrographic Imager (CASI): Compact Airborne Spectrographic Imager. A digital airborne multispectral sensor.

contextual editing: The use of non-spectral information, e.g. location or depth, to improve classification of spectrally overlapping classes.

depth correction: Techniques for removing the influence of shallower or deeper water column, so that habitats at different depths can be distinguished from each other. When light penetrates water its intensity decreases exponentially with increasing depth.

echosounder: Acoustic analogue of radar, but using sound instead of radio waves.

footprint: The field of view that a sensor covers.

GIS: Geographic Information System.

GPS: Global Positioning System. A network of 24 radio transmitting satellites (NAVSTAR) developed by the US Department of Defense to provide accurate geographical position fixing.

habitat classification: Techniques to classify the places or environments where particular organisms, populations, or species live.

Hymap: Commercial brand of a hyperspectral instrument that is flown in airborne remote sensing.

hyperspectral: The simultaneous acquisition of images of the same area in many (usually 100 or more), narrow, contiguous, spectral bands. As opposed to multispectral, which measures in various distinct wavelength bands.

IKONOS: Commercial earth-observation satellite with high-resolution data, operated by GeoEye.

image classification: Grouping image pixels into categories or classes to produce a thematic representation.

interpolation: A method that estimates an intermediate value of a dependant variable as a function of an independent variable.

Landsat: A series of unmanned earth-orbiting NASA satellites (formerly called Earth Resources Technology Satellite – ERTS).

LIDAR (Light Detection And Ranging): A remote-sensing technique that uses a laser light source to probe the characteristics of a surface target.

line transect: A line of specified length laid out within a study site. They are generally positioned parallel to the shore along depth contours.

look-up table: A table used to convert data (digital numbers) from one distribution to another during image pre-processing or processing.

manta-tow method: A technique used to provide a general description of large areas of reef and to gauge broad changes in abundance and distribution of organisms on coral reefs. The technique involves towing a snorkel diver at a constant speed behind a boat.

marine spatial planning: A public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that usually have been specified through a political process (UNESCO).

MERIS (MEdium Resolution Imaging Spectrometer): Instrument on the European Space Agency's Envisat platform, whose main objective is to observe ocean colour.

multispectral: A scanner system that simultaneously acquires images of the same scene in various distinct wavelength bands—as opposed to hyperspectral which measures continuous data across the electromagnetic spectrum.

normalized difference vegetation index (NDVI): An index of vegetation biomass.

pixel: Contraction of "picture element." In a digitized image this is the area on the ground represented by each digital value. Because the analogue signal form the detector of a scanner may be sampled at any desired interval, the picture element may be smaller than the ground resolution cell of the detector.

quadrat: A square or rectangular sampling unit of known area within which organisms are counted or measured.

QuickBird: Commercial earth-observation satellite with high-resolution multispectral data, operated by DigitalGlobe.

radar: Radio Detection and Ranging.

remote sensing: The collection of information about an object or event without being in physical contact with the object or event. Remote sensing is restricted to methods that record the electromagnetic radiation reflected or radiated from an object, which excludes magnetic and gravity surveys that record force fields.

resolution: The ability to distinguish closely spaced objects on an image or photograph. Commonly expressed as the spacing, in line-pairs per unit distance, of the most closely spaced lines that can be distinguished.

roughness: Variation of surface height within an imaged resolution cell.

RoxAnn: Commercial remote sensing hydro-acoustic sensor providing seabed classification data to produce seabed bottom type maps, produced by SonaVision.

satellite: A vehicle put into orbit around the earth or other body in space and used as a platform for data collection and transmission.

Secchi distance: The depth at which a Secchi disk disappears from view as it is lowered in water. A Secchi disk a white disk 20-30 cm in diameter, used as a qualitative way of measuring water clarity.

spectrum: (1) In physics, any series of energies arranged according to wavelength (or frequency); (2) The series of images produced when a beam of radiant energy is subject to dispersion. A rainbow-coloured band of light is formed when white light is passed through a prism or a diffraction grating. This band of colours results from the fact that the different wavelengths of light are bent in varying degrees by the dispersing medium and is evidence of the fact that white light is composed of coloured light of various wavelengths.

SPOT: Satellite Pour l'Observation de la Terre. A French satellite carrying two pushbroom imaging systems (originally Système Probatoire de l'Observation de la Terre). The capabilities of the two pushbroom scanners (HRVs for SPOT 1-3, HRVIR for SPOT 4 and HRG for SPOT 5) vary from satellite to satellite. SPOT 4 and 5 also carry Vegetation instrument with swath width of 2250 km and 1 km spatial resolution.

Synthetic Aperture Radar (SAR): A coherent radar system that generates high resolution remote sensing imagery. Signal processing uses magnitude and phase of the received signals over successive pulses from elements of a synthetic aperture to create an image.

stratified sampling: Dividing up a heterogeneous sampling area into subareas that are internally homogeneous, then sampling within each subarea.

thermal stress: Stress caused by warmer-than-normal water temperatures that can cause corals to bleach.

underwater visual census: Technique for determining fish populations, carried out by divers identifying and counting fish of various species.

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The Coral Reef Targeted Research & Capacity Building for Management (CRTR) Program is a leading international coral reef research initiative that provides a coordinated approach to credible, factual and scientifically-proven knowledge for improved coral reef management. The CRTR Program is a partnership between the Global Environment Facility, the World Bank, The University of Queensland (Australia), the United States National Oceanic and Atmospheric Administration (NOAA) and approximately 50 research institutes and other third-parties around the world.