Digitise this! A quick and easy remote sensing method to monitor the daily extent of dredge plumes

Richard Evans[1], Kathy Murray[1], George Shedrawi[1] and Stuart Field[1]

1 Department of Environment and Conservation

Introduction

To complement in-situ biological monitoring of coral reef communities and physical monitoring of the Barrow Island dredge plume the visual interpretation of daily MODIS satellite imagery was seen as a cost-effective, quick, relatively accurate and easy method to implement. The aim of this monitoring project was to gain an understanding of the daily spatial extent of the plume and the temporal frequency impact of the plume (the sum the plume's daily presence). This has the potential to highlight areas most affected by the dredge plume and to gain a better understanding of the impact this environmental change has on monitored sites of high biological significance (Fig. 1). A secondary aim was to build a dataset of daily plume location and size and record associated underlying environmental conditions i.e. tide, wind direction and strengths making a valuable tool for future modeling.

Although the preference is to find a remote sensing method that semi-automates the process of extracting the plume boundaries, in this case it was more important to get a timely and cost-effective understanding of the plume impact. Previous studies and monitoring programs have identified that once trained to interpret the image with ecological and environmental context as well as factoring in the image quality, the human interpretation of a boundary could be more superior than other quantitative methods, such as an semi-automated remote sensing approach (1).

Satellite Sensors

MODIS satellite sensors are well suited for monitoring daily events that occur on a wide spatial scale on a budget. This project found that the daily MODIS true colour mosaic was the easiest and quickest way to observe the plume extent off the coast of Barrow Island.

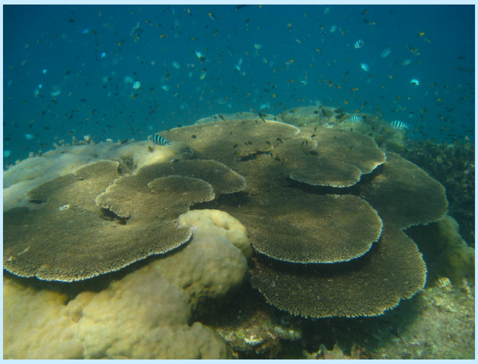

Figure 1. High biological significance: coral reef habitat of the Montebello Barrow Island Marine Park. An example of the sites monitored by DEC. Image taken by Marine Science Program, DEC.

Methods

MODIS imagery was reprojected into GDA94 MGA zone 50 to be displayed in an internal DEC spatial viewer with limited functionality. The interpretation of the dredging plume boundary was represented by digitising (drawing) a vector (digital polygon) around the plume at a scale of 1:450000. Days where no plume was observed or that were obscured because of cloud were recorded. A year of imagery pre dredging was also downloaded and interpreted for naturally occurring plumes.

Interpretation

A set of guidelines were developed for this project for a conservative interpretation of plume boundaries. Key aspects of these guidelines were the comparisons of imagery captured on plume free days under similar conditions and digitising only plume areas that the observer had confidence in i.e. definitely not reef or bottom features. (Fig. 2)

Observers with little or no GIS experience were trained to conduct the visual interpretation, digitising and editing of the daily plume boundary. To assist with training and quality control the month of October 2010 was digitized by four observers and the resulting boundaries compared before the whole dataset was interpreted.

Hotspot analysis

Once digitised a hotspot analysis was run on the daily plume boundaries to provide a dataset describing the number of days the plume was present at any position within the Barrow Island Marine Park and surrounds over 1 year. DEC monitoring sites were buffered by 100m and intersected with the resulting frequency dataset for a year to extract the number of days each site was influenced by the plume in that time.

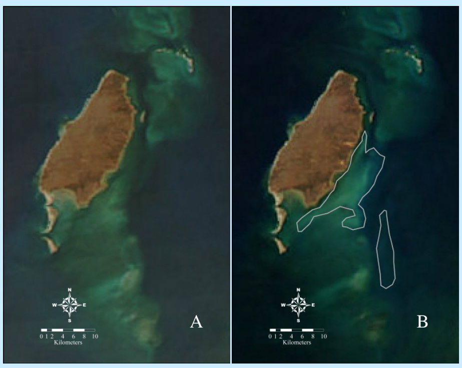

Figure 2. Comparisons of two days of MODIS imagery captured under similar tide and weather conditions. Image A(6 October 2009) was captured before dredging commenced. Image B(24 July 2010) captured during dredging, showed a dredge plume obscuring the shallow bottom features visible in the image A.

Results

Image interpretation

Four observers digitized daily plume events for a period of one month to understand variation between digitizers. Image interpretation and digitization of plumes by resulted in a total average area of 51km^2 with average SD of 12km^2 (23%), a minimum SD of 3.5 km^2 (1.8%) and a maximum SD of 27km^2 (52.4%). This shows some variation between interpretation which was attributed to the fact that 3 of the 4 observers were new to GIS and had just learnt digitizing interpretation skills. Also the observers were told to be conservative in their interpretation but some were more than others and digitized the main plume and not the areas of light plume or areas that were definitely plume not reef (daily example Fig. 3). With the feedback from this exercise one observer could digitize the rest of the year with more confidence.

Figure 3. Comparisons of plume digitization by four observers on 28 October 2010.

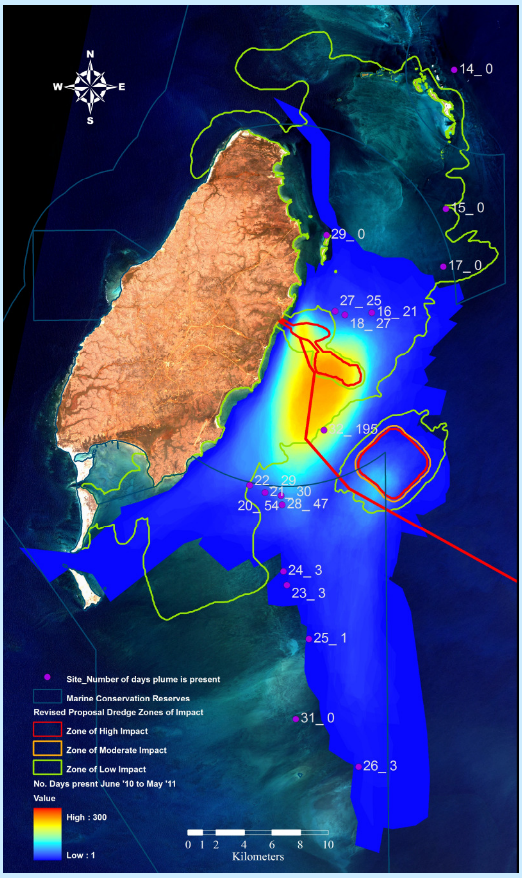

Figure 4. Hotspot analysis of daily digitized dredge plume area originating from the Barrow Island Dredging operations. Purple spots are DEC coral reef monitoring sites; numbers represent the site_number of days the plume was over each site. Lines in red, orange and green represent previously proposed zones of high, moderate and low impact based on modeling before the operations began (*3*). The blue line represents the Barrow Island Marine Management Area (4). Background image was captured by ALOS AVNIR-2, 18 June 2006.

Plume Monitoring

Proposed modeling of plume impacts was 465km2 moving both north and south from the dredging activities depending on the prevalent winds. Our study found that the plume moved predominantly southward with minimal days of northward movement. Plume digitizing showed that 224km2 overlapped with the modeling and 276km2 did not (Fig. 3). The hotspot analysis highlights how often sites of high biological significance are covered by the plume. DEC's coral reef monitoring sites were impacted from 1 to 195 of the 260 days observed (Fig. 4).

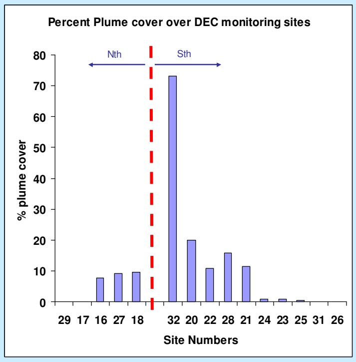

Figure 5. Percentage plume cover over the DEC coral reef monitoring sites around the Barrow Island Dredge Operations. Red line indicates site of dredging. Sites are not evenly distributed away from dredge site (see Fig. 4)

The plume was monitored for a year from 1 June 2010 to 31 May 2011 resulting in 260 days where the plume was observed and digitized. Interpretation was from MODIS Aqua or Terra satellites depending on image quality. Cloud cover and satellite image coverage (i.e. the sensor did not capture the Barrow Island area) were reasons for the other 105 days without digitized plumes. The number of days DEC monitoring sites were covered by the plume ranged from <1% to 73% of the days digitized (Fig. 5).

Discussion

This method proved to be a useful tool for monitoring dredge plume movements in shallow coral reef environments. By digitizing the plume, from visual inspections of MODIS images, one could discern with some level of confidence the differences between shallow reef environment and natural plumes from those generated by the dredging. Other methods such TSS analysis use automatic algorithms which rely on a costly process of atmospheric correction, calibrating and thresholding of each daily image by an officer with the appropriate remote sensing skill set. However, without a masking layer it is difficult to discern between shallow reef habitat and plume (Fig. 6). Whereas the methodology used by this project was found to be time efficient and an achievable approach for an officer recently trained with basic GIS skills.

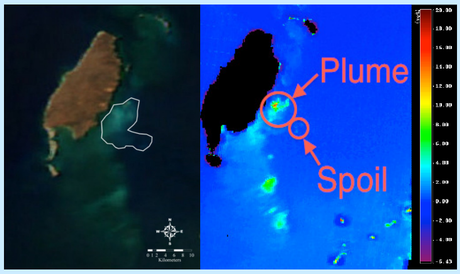

Figure 6. Comparisons of hand digitized and automated TSS modeling of the plume distribution on 29 August 2010. Note the differences in the size of the plume. TSS image provided by P. Fearns and M. Broomhall, Remote Sensing and Satellite Research Group, Curtin University.

The hand digitizing approach is a simple standard method adopted by other government agencies for monitoring and management in terrestrial environments for emergency fire digitizing (*5,6*) and over-flooding on Alaskan ice (*7*) . The area of the expected plume impact represented with MODIS imagery was relatively small and localized in extent with only 1 to 3 polygons digitized per day. Therefore, a digitized visual interpretation of the plume in MODIS imagery was a time efficient option. Focusing on one region allowed the interpreter to quickly become familiar with the appearance of natural benthic features in the imagery under different weather conditions and at times influenced by dredge plume and non dredge plume conditions.

Not only has this project developed a monitoring methodology that can be applied to monitor similar impacts but it has also provided a dataset that can be used to improve future modeling in the region and assist as a reference dataset to improve automated remote sensing methods in the future.

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For more information:

Contact richard.evans@dec.wa.gov.au or kathy.murray@dec.wa.gov.au

Marine Science Program
Department of Environment and Conservation,
17 Dick Perry Avenue, Kensington
6151, WA.

Remote Sensing Unit, GIS Section
Department of Environment and Conservation
17 Dick Perry Avenue, Kensington
6151, WA.

Department of Environment and Conservation

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