Change detection in coral reef communities using Ikonos satellite sensor imagery and historic aerial photographs

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Abstract. For decades, aerial photographs have been the only source of very high spatial resolution data for coral reef researchers. With the launch of the Ikonos satellite in 1999, imagery with a 4 m spatial resolution in multispectral mode can now be combined with historical aerial photographs for change detection. We demonstrate this potential by combining two aerial photographs (1981 and 1992) and an Ikonos image (2000) to detect change in the coral reef communities for Carysfort Reef, Florida, USA. The results show a loss of 'coral-dominated' bottom from 52% (1981) to 16% (1992) to finally 6% (2000), a trend similar to *in situ* observations.

1. Introduction

Representative of the changes occurring in coral reefs in the last 20 years, Carysfort Reef (Florida Keys, USA) has undergone severe live coral cover loss since 1982 principally due to disease outbreaks (Porter and Meier 1992, Dustan *et al.* 2001). *In situ* data estimated the loss in percentage terms of live coral from 50% in 1982 to 4% in 1999. This is a decrease of 92% overall. Similar dramatic live coral losses in various regions worldwide prompted numerous monitoring activities, generally carried out using *in situ* survey techniques, but very few sites benefit from the long-term time series of *in situ* data. Conversely, regional, state and local organizations worldwide house a variety of aerial photographs (APs) at different scales and from different time periods. Aerial photography has been used extensively for mapping and change detection purposes for many years in coral reef environments (Hopley 1978, Yamano *et al.* 2000, Lewis 2002). With the launch of Ikonos in 1999, a satellite sensor can now provide very high spatial resolution data.

Ikonos acquires both 4 m spatial resolution multispectral and 1 m spatial resolution panchromatic data (table 1). The multispectral data consist of four bands, three in the visible (red, green and blue) and one in the near-infrared; the wavelength

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Table 1. Spatial and spectral properties per each Ikonos band.

Band	Spatial resolution (m)	Spectral resolution (nm)
Blue	4	445–516
Green	4	506–595
Red	4	632–698
Infrared	4	757–853
Panchromatic	1	450–900

range of these bands is comparable to the first four bands of the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors.

In this letter, we assess the potential of Ikonos imagery combined with APs to detect change in a coral reef community, using Carysfort Reef as a case study.

2. Methods

Two APs acquired on 5 February 1981 and 17 January 1992 and one Ikonos image acquired on 15 October 2000 provide the basis for a multi-source change detection study of Carysfort Reef. The 1981 AP was acquired at 1:24 000 scale. The 1992 AP was acquired at 1:48 000 scale. Both APs were scanned at a spatial resolution of 300 dpi. The images were resampled to 2 m pixel size. Images were geo-corrected using the Ikonos image as a reference. The Ikonos image was delivered in Universe Transverse Mercator Zone 17, radiometrically corrected, by Space Imaging, Inc. No atmospheric corrections were made since classification of the images would be made from statistics acquired separately from within each image (Song *et al.* 2001).

An area of interest (AOI) was designated for the shallowest section of Carysfort Reef (depth of less than 1.2 m) (Dustan *et al.* 2001). Carysfort Reef has three distinct structural areas that are visible in each image (figure 1). These structures are defined by the darker areas within the lighter patches. There are two smaller areas in the centre (A2) and to the north (A1) of the AOI that are roughly the same size. The third area (A3) is close to twice the size of the first two and is located furthest to the south. This area contains a lighthouse tower, which can be seen as a set of black pixels in the Ikonos image.

Four classes of bottom-types represent the main benthic communities on and around Carysfort Reef. They are: 'sand', 'coral-dominated', 'bare substrate' and 'covered substrate' (table 2). Each image was studied separately to obtain training pixels for each of the four classes. The training pixels were chosen according to a large *in situ* database available for each year discussed. For example, *in situ* transect data from 1982 were overlaid onto the 1981 AP to give examples of the location of each of the four classes. A Mahalanobis Distance classifier (Venables and Ripley 1999) was applied for each image: 1981 (figure 2(a)), 1992 (figure 2(b)) and 2000 (figure 2(c)). The blue, green and red bands of the Ikonos image were the inputs of the classifier.

In situ data and protocols to measure live coral cover have been presented elsewhere (Dustan and Halas 1987). Briefly, the evaluation of live coral cover came from estimations along transects (25 m wide, 300 m long) and four permanent Environmental Protection Agency monitoring sites. It must be stressed that *in situ* monitoring data provided information on live coral cover, considering individual

Figure 1. Location map of Carysfort Reef (red star) and Ikonos image of Carysfort Reef displaying location of the three distinct structural areas (A1, A2, A3). Carysfort Reef AOI is delineated in yellow.

Table 2. Components of classes used for classification. Quantification of components and characteristics within each classification.

Classes	Major components, > 50%	Minor components
Coral-dominated	branching, i.e. <i>Acropora</i> sp. boulder, i.e. <i>Montastrea</i> sp.	bare substrate algae
Sand	carbonate sand	rubble seagrass
Covered substrate	leafed algae encrusting algae turf algae	coral substrate
Bare substrate	dead coral/rubble	algae live coral sand

coral colonies. Conversely, remote sensing data informs on the coral-dominated area that can be mixed (table 2), at the community-scale.

3. Results and discussion

The three classified images provide a similar trend to that of the *in situ* data, i.e. a loss of community-scale 'coral-dominated' pixels (remote sensing data), and

Figure 2. Mahalanobis Distance classification images of Carysfort Reef. Images are from (a) 1981, (b) 1992 and (c) 2000. A mask is placed around the Carysfort Reef AOI.

colony-scale live coral cover (*in situ* data). The 'coral-dominated' class, as estimated from the number of 'coral-dominated' pixels inside the AOI, declines from 52% in 1981 to 16% in 1992 to 6% in the 2000 Ikonos image (figure 3). This shows a total

Figure 3. Live coral cover trend displayed over 19 years. Percentage of live coral cover or 'coral-dominated' pixels from aerial photography (1981 and 1992) and Ikonos image (2000) compared to *in situ* data.

loss of 88% over a 19-year time period (4.7% per year), for an estimated total lost area of 25 650 m². This compares well to the *in situ* data that demonstrate a loss of 92% over 18 years (5.1% per year). As pointed out previously, these methods and datasets measure the coral cover at different scales, and a correlation was expected. This is confirmed by the results, that show that habitat loss is echoed by the loss of the dominant benthic feature in the same proportion.

The three structural areas mentioned above (A1, A2 and A3) can be seen more distinctly as areas largely classified as 'coral-dominated' or 'covered substrate'. The specific shape and location of the lighthouse can still be detected in the classified APs, classified as 'covered substrate' (due to its dark colour) amid a larger area of 'coral-dominated' pixels.

Loss in 'coral-dominated' bottom can be detailed spatially as follows.

- The southernmost and largest area loses the greatest level of 'coral-dominated' area to the south, east and north.
- The 'coral-dominated' pixels in this area remain centred on the location of the lighthouse.
- The centre area changes from being covered with 'coral-dominated' pixels (1981) to having nearly zero 'coral-dominated' pixels in 2000.
- The northernmost area displays a large 'coral-dominated' area in 1981 as patches east and west of the centre, to close to zero 'coral-dominated' pixels in 1992, to finally zero 'coral dominated' pixels in 2000.
- The loss of 'coral-dominated' pixels causes a shift to 'covered substrate' pixels in the subsequent image.

4. Conclusion

The trend of 'coral-dominated' area decline can be examined by the combination of colour aerial photography and Ikonos imagery. The direct comparison of the trends between *in situ* and remotely sensed results must be done carefully since *in situ* and remote sensing data convey information at colony and habitat scales respectively. However, both datasets highlight a consistent trend in coral decline across the same time period with similar rates of loss (4.7% and 5.1% per year respectively).

Therefore, Ikonos imagery appears to be a relevant source of information when used in conjunction with historic colour aerial photography to show change and fragmentation in an initially compact coral reef community. The degree of generalization of this approach must be cautiously stated due to the high diversity of reef configurations worldwide.

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