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Comparison of three digital image analysis techniques for assessment of coral cover and bleaching

ERIN JOSEPHITIS [1], SHAUN K WILSON [2,3,#], JAMES AY MOORE [2] AND STUART FIELD [2,3]

[1] Rollins College, 1000 Holt Ave, Winter Park, FL 32789, United States of America

[2] Marine Science Program, Department of Environment and Conservation, Western Australia, Kensington, 6151, Australia

[3] Oceans Institute, University of Western Australia, Crawley, Western Australia 6009, Australia

[#] corresponding author. Email: shaun.wilson@dec.wa.gov.au. Phone: 08 9219 9806

ABSTRACT

Digital imagery techniques for quantifying the benthos are increasingly used to monitor the health of coral reefs. There are many techniques to assess coral habitats from images, but there is no clear answer as to which one is the most effective. The aim of this study was to compare the effectiveness and relative cost (processing time) of three image analysis techniques commonly used to assess coral/benthic cover and coral bleaching. Digital photographs, taken 1 m above the substrate at 1 m intervals along 16 transects (50 images per transect), were used to examine the extent of coral cover and bleaching within coral communities of the Montebello and Barrow Islands in February 2011, following a temperature anomaly event. Each image was evaluated by: 1. assessing habitat under six randomly placed points ('point count'); 2. dividing images into 20 square blocks and recording the dominant item in each block ('block'); and 3. visually estimating benthic cover and bleaching without reference to points or grids ('visual'). Overall, there was a high degree of congruence between the commonly used techniques and there were no significant differences when comparing coral cover or the extent of bleaching. Similarly, there was no detectable difference in the precision of coral and bleaching estimates made using the three techniques. However, analyses carried out using the point count and visual techniques were quicker and therefore more efficient than the block technique. This study demonstrated that the techniques commonly used to assess coral cover and bleaching from digital images are compatible and that they may be combined to provide greater spatial and temporal assessment of coral reef condition.

Keywords: monitoring coral cover, coral bleaching, digital photographs, Western Australia, *Acropora*

INTRODUCTION

Scleractinian corals are the major builders of the coral reef environment (Veron 2000), providing essential habitat for thousands of fish and invertebrate species (Wilson et al. 2006; Pratchett et al. 2008; Plaisance et al. 2011). Corals are, however, threatened by a combination of increasing anthropogenic disturbance and enduring shifts in the oceanic environment brought about by rising levels of atmospheric pollutants (Hughes et al. 2003; Jenkins 2003). Bleaching is a response of corals to environmental stress, where there is a breakdown in the symbiotic relationship between the coral host and photosynthetic zooxanthellae. The reduced abundance of zooxanthellae makes the coral appear pale or 'bleached'. Reports of coral bleaching have increased dramatically over the past 30 years, partially reflecting a greater awareness of this process and an increased number of reef monitoring activities (Oliver et al. 2009). However, increases in sea temperatures over this time-frame also suggest that corals in many locations are living closer to their thermal thresholds than in the past (Hoegh-Guldberg 1999; Eakin et al. 2009; Veron et al. 2009). Moreover, prolonged exposure to abnormally high water temperatures has resulted in several 'mass bleaching' events that have caused extensive coral bleaching and subsequent mortality (Glynn 1983; Brown 1997; Goreau et al. 2000; Berkelmans et al. 2004).

To assess the impact of bleaching and other disturbances on coral reefs it is essential that long-term monitoring programs are developed, using robust and comparable techniques to scrutinize coral health (Hughes et al. 2010). Yet it is difficult to assess the accuracy of techniques used to estimate coral cover (Andrew & Mapstone 1987). For this reason, monitoring programs often use relative measures of abundance to assess spatial and temporal differences and choose methods that have few biases and high levels of precision. The choice of which technique is most appropriate is also based on the spatial scale of the program, level of detail and precision required, as well as the resources available (Hill & Wilkinson 2004).

Some of the most common techniques used to assess coral/benthic cover and bleaching include intensive in-situ observations of quadrats and belt transects (Hill & Wilkinson 2004) or more extensive aerial surveys

(Berkelmans & Oliver 1999). Photographs or video have also been used to assess reef condition, and have the advantage that they provide a permanent record of reef condition and allow rapid collection of data in the field (George et al. 1985). The development of digital image capture (still and video) technologies has resulted in an increase in the use of imagery as a monitoring method, due to their ease of use. The cost of camera equipment and time to process images can, however, make it a relatively expensive method compared with data collected in-situ (Jokiel et al. 2005; Leujak & Ormond 2007). It is therefore important that efficient, yet robust, techniques are used to analyse photographic images. Researchers typically analyse benthic images using techniques such as point count or quadrat estimates, or by digitising shapes from an image to quantify a specific habitat type (e.g. Connell et al. 1997; Smith et al. 2008). There is, however, no clear answer as to which technique is the best, or if information gathered using different techniques is comparable. This is an important question, as many management and research agencies adopt different techniques for assessing coral health and associated threats from digital images.

Previous studies have compared the compatibility of different field techniques to estimate coral cover (e.g. Berkelmans & Oliver 1999; Jokiel et al. 2005; Leujak & Ormond 2007; Wilson et al. 2007); compared field techniques with the analysis of digital images (e.g. Carleton & Done 1995; Long et al. 2008); and determined the number of points needed to robustly estimate benthic cover from images (e.g. Pante & Dunstan 2012) and how these points are arranged (e.g. Carleton & Done 1995). Here we explicitly examine the compatibility of techniques used by different agencies and institutes in Western Australia to evaluate coral cover and bleaching from digital images. We examined the precision of each technique as a proxy for power to detect change, and measured the time it took to process images in order to compare labor costs associated with each technique. The study provided an indication of which technique is most suitable for analyzing benthic images and assessed the validity of combining data from different sources to provide regional-scale evaluations of coral bleaching.

METHODS

Images for this study were collected between 12–16 February 2011 from coral reefs of the Barrow and Montebello Islands, which are located approximately 130 km off the north-west coast of Western Australia (20.798 S, 115.406 E). Corals in this area were subjected to abnormally high water temperatures between December 2010 and March 2011 (Pearce & Feng 2012), which resulted in extensive coral bleaching (Moore et al. in press).

At each of four sites, four 50 m transects at 2–6 m depth were surveyed as part of a routine monitoring exercise. The transects were swum with a Canon G12 camera held ~1 m above the substrate, and an image was taken every metre (50 images per transect; 800 in total). A 1 m length of steel, attached to the camera base and placed at a 90° angle to the substratum, was used to maintain a constant distance between the camera and the reef for each image. For each image, the percentage cover of *Acropora* and non-*Acropora* corals, as well as coral health (bleached or unbleached) were estimated using three different techniques:

1. Point count: EcoPAAS software (Ocean Vision Environmental Research) overlaid six random points on each image and the habitat beneath each point was catagorised as *Acropora,* non-*Acropora* coral or non-coral, providing six data points per image. Corals under points were further classified as unbleached or bleached. This technique is currently used by Western Australia's Marine Monitoring Program, Department of Environment and Conservation, and similar techniques are used in Western Australia by the Australian Institute of Marine Science (AIMS; e.g. Smith et al. 2008), and Commonwealth Scientific and Industrial Research Organisation (CSIRO; e.g. Thomson and Frisch 2010)
2. Block: Transect Measure software (SeaGIS) overlaid a 4 × 5 block grid over each image, forming 20 blocks per image. The dominant item (*Acropora*, non-*Acropora* or non-coral) in each block was identified, providing 20 data points per quadrat. Where corals dominated a block it was also noted if that coral was bleached or unbleached. This technique is currently used by Western Australia's Department of Fisheries monitoring program.
3. Visual: An unaltered image was placed on the screen for a visual estimation of percent cover of *Acropora*, non-*Acropora* coral, non-coral habitat and the bleaching status of corals.

The three techniques were used to assess all images in all transects; however, the order in which each technique and transect was undertaken was randomised to eliminate the possibility that prior knowledge would bias estimates of any particular technique. *Acropora* corals were chosen for analyses because they are the most prominent genera on many West Australian reefs (Dinsdale & Smith 2004; Cassata & Collins 2008), are highly susceptible to bleaching (Marshall & Baird 2000; McClanahan et al. 2004), provide food and habitat for reef-associated fish (Wilson et al. 2008), and are easily identified on digital images. Bleached corals were identified as those where the concentration of algal pigment had decreased, resulting in a fading of coral colour because the white calcareous skeleton became more prominent (Ben-Haim et al. 2003). As there may be problems with the level of light exposure on images and no colour reference was included with each image (sensu Siebeck et al. 2006), we only included corals that were white compared with surrounding benthos and were definitely 'bleached'. A single, trained observer recorded all observations in order to eliminate observer bias among classifications of healthy, bleached or bleaching corals. A timer was used to record the length of time it took to collect data among the different techniques for each image and transect.

Statistical analyses

Habitat composition (*Acropora* and non-*Acropora* corals), and bleaching status (bleached *Acropora* and bleached non- *Acropora*) estimates were calculated for each transect and for each of the three techniques, then compared using PERMANOVA. Data were normalised prior to analysis and PERMANOVA performed on a dissimilarity matrix calculated from the Euclidean distance between replicates (Anderson 2001). The PERMANOVA model included sampling technique (point count, block or visual) as a fixed factor and site (1, 2, 3 or 4) as a random factor, with transects (n = 16) as replicates. The results were displayed using a Principal Components Analysis (PCA)

To further explore comparability of techniques, the mean and standard error for total, *Acropora* and non-*Acropora* coral coverage was calculated for each technique, based on the number of transects sampled (n = 16). Equality between treatments was tested using a Kruskal–Wallis ANOVA by Ranks test at a transect level (n = 16). This non-parametric analysis was chosen because the assumption of normality was not met, even after transformations. A post-hoc multiple comparisons test was performed to further investigate any significant results.

To assess the precision of each technique the co-efficient of variation (standard error/mean) was calculated at a site level (n = 4) for each technique and compared using a Kruskal–Wallis ANOVA. Similarly, the time to process all of the images from a single transect was compared using a Kruskal–Wallis ANOVA.

RESULTS

Differences in the amount of coral cover, *Acropora* and extent of bleaching were largely attributable to differences between the sites, rather than to the technique used to anlayse images. There was no significant difference in habitat composition or bleaching status detected due to analysis technique or the interaction between technique and site (Table 1). Coral cover and extent of bleaching did, however, differ among sites, primarily due to a high *Acropora* coverage and bleaching of *Acropora* corals at site 2 relative to other sites (Fig. 1). Sites 1, 3 and 4 were

Table 1

Statistical results from PERMANOVA comparing coral cover and bleaching status estimates from three techniques and four sites.

	df	MS	Pseudo F	P
Technique	2	1.3	0.9	0.615
Site	3	46.7	45.2	0.001
Technique x Site	6	1.4	1.3	0.203

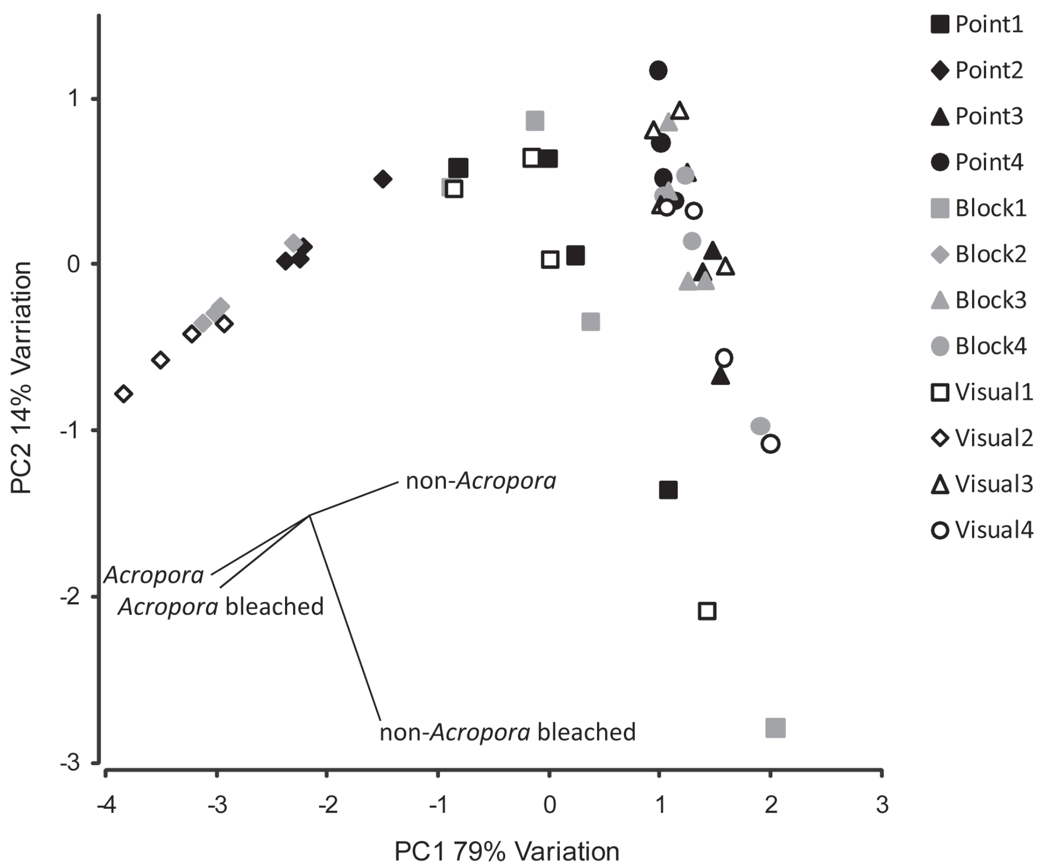

Figure 1. Principal Component Analysis showing habitat composition quantified using the three techniques (point count, block and visual) for assessing digital images. Each symbol represents a single transect at one of four sites.

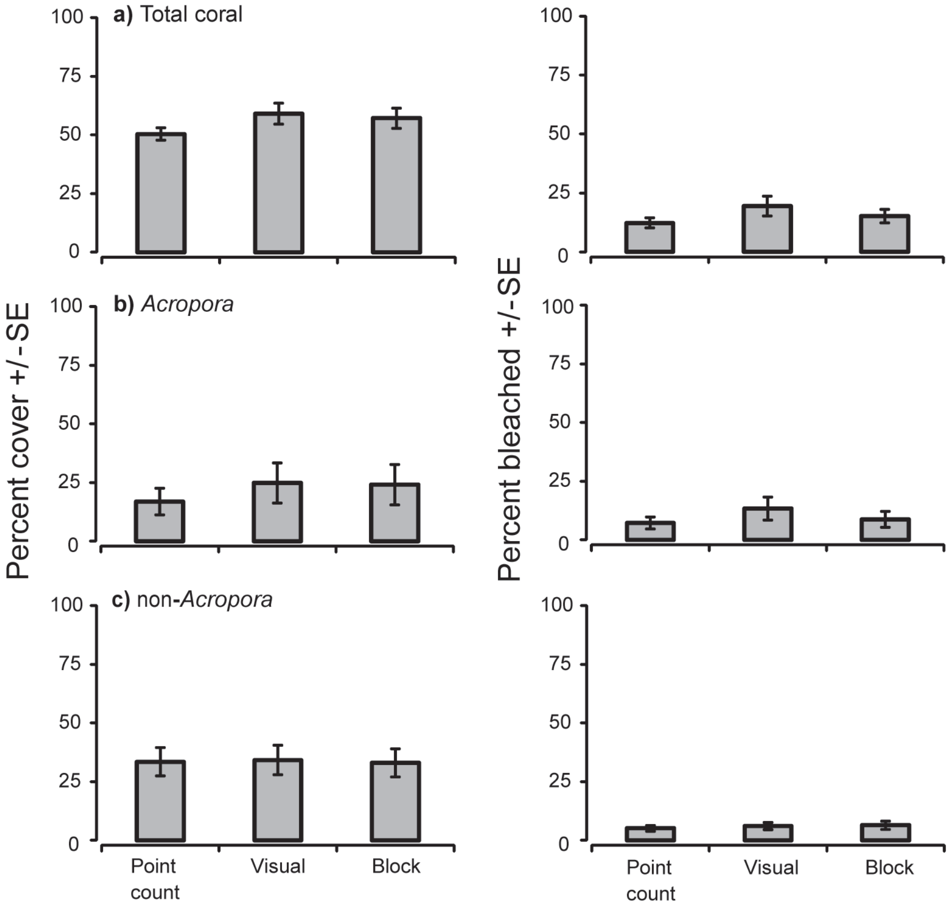

Figure 2. Coral cover and bleaching estimates from the three techniques used to evaluate digital images: percent cover ± SE and percent bleached ± SE of (a) total coral cover, (b) Acropora *cover and (c) non-*Acropora *cover. Standard errors were calculated from 16 transects. There were no statistical differences detected with respect to type of method, bleached or unbleached measures of total,* Acropora *or non-*Acropora *coral cover.*

characterized by high coverage of non-*Acropora* corals, although bleaching extent of these corals varied among transects within sites (Fig. 1).

All three techniques had comparable results with respect to estimations of total (~50–60%), *Acropora* (~15–25%) and non-*Acropora* (~30–35%) coral cover (Fig. 2, Table 2). Approximately 10–20% of all coral was bleached, of which ~5–15% was *Acropora* and ~5% was non-*Acropora* (Fig. 2). There were no significant differences between the three techniques in terms of bleaching assessments or for coral cover (Table 2).

Table 2

Nonparametric Kruskal–Wallis ANOVA by Ranks results for coral and bleaching assessment from the three techniques used to evaluate digital images.

Measurement	$H_{(2, 48)}$	p
% Hard coral	2.38	0.305
% *Acropora*	0.79	0.675
% Non-*Acropora*	0.21	0.902
% Hard coral bleached	1.41	0.494
% *Acropora* bleached	0.85	0.653
% Non-*Acropora* bleached	0.21	0.902

Precision was best when estimating broad categories of total coral cover, with coefficient of variation values ~6 for all techniques. However, as categories became more specific, the coefficient of variation increased, indicating weaker precision estimations for assessments of *Acropora* and non-*Acropora* coverage, as well as their bleaching status (Table 3).

The average time to assess coral health and cover for both the point count and visual technique was ~35 minutes per transect. This was significantly faster than the surveys undertaken using the block technique (Kruskal–Wallis ANOVA by Ranks $H = 10.045$, $p = 0.007$), which took ~50 minutes per transect (Fig. 3).

DISCUSSION

The three techniques investigated provided similar estimates and levels of precision for coral cover and bleaching status. This infers that coral cover and bleaching data collected using these techniques are comparable and may be combined to improve spatial and temporal monitoring of coral reefs. These findings are consistent with those that have shown total coral cover estimates

Table 3

Precision estimates for coral and bleaching assessments from three techniques (point count, visual and block) used to evaluate digital images. Precision calculated as standard error/mean for each of four sites.

Measurement	Coefficient of variation			$H_{(2, 12)}$	*p*
	Point count	*Visual*	*Block*		
% Hard coral	6.7 ± 2.6	6.0 ± 1.7	5.7 ± 2.5	0.500	0.779
% *Acropora*	27.7 ± 11.7	43.4 ± 20.4	39.2 ± 21.3	0.608	0.738
% Non-*Acropora*	17.8 ± 7.6	18.4 ± 9.8	17.2 ± 7.8	0.462	0.794
% Bleached	20.7 ± 3.3	21.0 ± 2.0	24.6 ± 3.3	0.500	0.789
% *Acropora* bleached	32.4 ± 10.6	53.1 ± 18.2	50.6 ± 17.2	1.862	0.394
% Non-*Acropora* bleached	46.9 ± 14.4	48.0 ± 18.9	36.1 ± 11.3	0.808	0.668

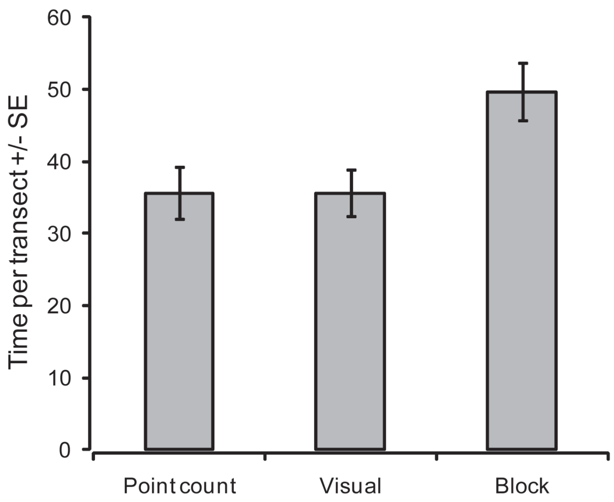

Figure 3. Average time (minutes) to analyze a transect (50 photographs) for three techniques (point count, visual, block) used to assess coral cover and bleaching. Error bars are standard error calculated from 16 transects for each technique.

from different field techniques are generally compatible (Carleton & Done 1995; Jokiel et al. 2005; Leujak & Ormond 2007; Wilson et al. 2007). However, the capacity to compare results collected at finer taxonomic scales (e.g. genera) may be reduced as the resolution at which different techniques effectively collect data may differ (Carleton & Done 1995; Leujak & Ormond 2007). In particular, it has been suggested that estimates of arborescent *Acropora* are often lower when using point-count techniques as points may fall between colony branches and be categorized as non-coral, whereas other techniques consider the entire area encompassed by a colony to be live coral (Long et al. 2008). Furthermore, when compiling and comparing information on coral bleaching it is important to determine at what spatial scale the data was collected (Andrefouet et al. 2002), as techniques used to collect bleaching data at different spatial scales may not be compatible (Berkelmans & Oliver 1998).

When selecting a suitable technique for monitoring, consideration should be given to precision and cost (Quinn & Keogh 2002; Roelfsema et al. 2006). Whilst mean values and precision estimates derived from the three techniques were similar, our results indicated that point count and visual assessments of coral cover and bleaching can be carried out over shorter time frames than block assessments. This partially relates to the number of points or blocks surveyed per image, which were based on the methods used by the monitoring agencies that use these techniques. Hence, it is expected that the time taken to process images using point count and block estimates will be similar if the number of blocks and points analysed per image is the same.

The similarity of coral cover and bleaching estimates obtained from the visual technique with those from point count and block techniques underlines the ability of the human eye to rapidly and reliably compute estimates of coral cover (Long et al. 2004; Clua et al. 2006; Wilson et al. 2007). The visual technique is comparatively simple and requires less equipment or computer software than other techniques. But visual techniques are sensitive to subjective interpretation of images, and standard protocols for assessing images combined with constant training and inter-observer comparison are required to limit the influence of observer bias on results (Miller & De'ath 1996). Although less critical with the point count and block techniques, a level of inter-observer variability is likely to influence all of these analysis methods, which could be limited through training and regular inter-observer comparison. One of the benefits of capturing digital imagery is that there is a permanent record of the benthic community. As a result, any concerns associated with method or inter-observer differences can be overcome through reanalysis of the imagery using a single method by a single observer.

Conclusion

Digital imagery is increasingly being used as a tool to monitor the condition of benthic habitats on coral reefs using cameras in situ (Dalton & Smith 2006), and to validate broad-scale assessments of habitat collected remotely from aircraft (e.g. Mumby et al. 2001). It is therefore imperative that the methods of analysis of digital images are effective for the assessment of threats such as coral bleaching. Moreover, bleaching and other disturbances often occur over large spatial scales across the jurisdiction of different management agencies within and between countries. To obtain a comprehensive account of these large-scale events it is often necessary that data be compiled from sources that use different methods and techniques for capturing and processing data. Here we have demonstrated that the techniques commonly used by Western Australian agencies to assess coral cover and bleaching from benthic images are compatible within the bounds of the taxonomic level investigated. Consequently information collected using these techniques may be combined and analysed for broad-scale assessments of bleaching and monitoring of coral reef health.

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