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Comparison of Image-Acquisition Technologies Used for Benthic Habitat Monitoring

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Abstract. Video or photographic transects are commonly employed by coral reef monitoring programs as a quick and efficient method of surveying benthic habitats. Due to recent advances in technology, several large-scale monitoring programs have switched from using standard-definition video to using high-definition video or digital point-and-shoot cameras to conduct benthic surveys. In this study we assessed and compared the efficacy of high-definition video with that of digital still images to determine which method would be the most appropriate replacement for standard-definition video for the Coral Reef Evaluation and Monitoring Project in Florida. Transects from nine sites, spanning three reef types, were surveyed using all three methods. A mixed model ANOVA was used to determine whether significant differences existed in percent cover estimates provided by the three technologies. No significant differences ($p > 0.05$) in cover were detected for any benthic group between the three camera types, supporting the notion that either high-definition video or still images provided a suitable replacement for standard-definition video. Although both technologies improved image resolution and agreement between observers in the identification of benthic fauna, still images offered additional advantages over high-definition video, including increased consistency in the number of frames acquired per transect, decreased costs, and reduced processing time. In light of the parameters of our monitoring program and the demonstrated efficacy of using still cameras to survey underwater transects, we found digital point-and-shoot cameras to be the preferred technology for future surveys.

Key words: Coral reef monitoring, CREMP, Percent cover, Video transect, Still-image transect, Technology.

Introduction

Video or photographic surveys have proven to be an effective and cost-efficient method for monitoring benthic communities (Aronson et al. 1994; Jokiel 2005; Leujak and Ormond 2007). These methods provide advantages over *in situ* surveys because the speed of data collection reduces the time required underwater, images offer a permanent historical record, and observer agreement can be maximized through training and calibration in the lab (Cabaitan et al. 2006; Hill and Wilkinson 2004; Jokiel 2005). Video or photographic transects provide highly comparable estimates of “true” coral cover (Jokiel 2005; Leujak and Ormond 2007) and, when used with appropriate experimental design, have a high degree of statistical power to detect temporal changes in coral cover (Brown et al. 2004).

Since its inception in 1996, the Coral Reef Evaluation and Monitoring Project (CREMP) has used video transects to quantify benthic cover in the Florida Keys (Porter et al. 2002). Until 1999 a Hi8 camcorder was used to capture transect images, and from 2000 to 2010 CREMP used a MiniDV digital camcorder. Improvements in video and digital still-image technology in the last decade have produced attractive new options for replacing standard-definition video. Several large-scale coral reef monitoring programs are already using high-definition video or digital still cameras (Coral Reef Assessment and Monitoring Program 2008; Jonker et al. 2008; National Park Service 2011; T. Smith, University of the Virgin Islands, pers. comm.), yet few data are available directly comparing these technologies that would indicate which is more suitable for coral reef monitoring.

The current study was undertaken to assess the efficacy of replacing standard-definition video with either high-definition video or digital still images for quantifying benthic cover. The goals of the study were to ensure that image acquisition and analysis were consistent with previous methods and to determine which of the new technologies offered the greatest suite of logistical advantages. A comparison of costs and time required in the field and lab is outlined, and several statistical appraisals were performed to elucidate differences between the three technologies. The findings presented here summarize the justification for adopting a newer image-acquisition technology and are provided as a reference for other monitoring programs when determining which technology to use to survey transects.

Materials and Methods

The Coral Reef Evaluation and Monitoring Project has used an established protocol to monitor benthic cover at fixed sites throughout the Florida Keys since 1996 (Porter et al. 2002; Ruzicka et al. 2010). For the present assessment, three CREMP sites were randomly selected from each habitat type (patch reef, deep forereef, and shallow forereef), for a total of nine sites. One 22-meter transect was surveyed at each site. Transects were prepared by securing a fiberglass tape taut between two permanent stakes and then laying a plastic chain along the substratum, directly underneath the tape, to mark the transect center. Transects were surveyed using three methods of image acquisition: standard-definition video (DV), high-definition video (HDV), and digital still images (stills). Digital video was recorded onto mini-DV tapes with a Sony Handycam DCR-TRV900; HDV was recorded onto an external hard drive with a Sony HVR-V1U HDV camcorder; still images were recorded onto a High-Capacity Secure Digital (SDHC) memory card with a Canon PowerShot SD1100 IS. To help maintain a constant height above the substratum and minimize variation in transect width, convergent lasers were attached to video camera housings and an aluminum bar was mounted to the bottom of the still camera housing. Using the plastic chain to guide the lasers (video) or aluminum bar (stills), video/still images were captured for the entire length of the transect. For video transects, a steady swim speed was maintained (~4–6 minutes per transect for DV and ~7–9 minutes per transect for HDV). For still-image transects, images were captured while the camera was stationary, using visual reference points to progress along the transect and ensure minimal overlap between images.

Video processing and image preparation varied across technologies. Whereas abutting images were produced directly with the still camera, it was necessary to extract frames from video transects prior to analysis. RavenView™, an automated image-processing program, was used to extract abutting frames from DV transects. Non-overlapping frames were manually extracted from HDV using Sony Vegas™ Movie Studio Platinum 9.0. Extracted video frames and still images were overlaid with 15 random points per image. Images acquired from all three technologies were analyzed using a custom software package, PointCount'99, to estimate percent benthic cover. Because the amount of reef area recorded in each image varied between the three technologies, the placement of points on the images could not be standardized. Therefore, to avoid Type I errors and ensure that differences in percent cover estimates were not due to point placement, three sets of random points were applied to the images collected for every transect. In all, 81 sets of random points were analyzed (nine sites × three technologies × three sets of random points for each transect). To minimize bias during identification, lower-resolution images (i.e., DV) were analyzed first, followed by HDV, and then stills.

For the image analysis, differences in the percent cover (mean ± SE) of scleractinian corals, octocorals, macroalgae, sponges, and bare substrate were determined using a generalized linear mixed model ANOVA with habitat, technology, and their interaction as fixed effects in SAS® v9.2. Percent cover data were pooled for each set of random points and arcsine square-root transformed. Although the analysis focused on differences between technology types, habitat was included as a fixed effect to understand whether differences in community structure between the three habitat types affected percent cover estimates provided by the different technologies. Sets of points were treated as a random variable in the model to account for their unique placement in each set analyzed.

Prior to image analysis, a single transect for each technology was analyzed by all observers to ensure at least 95% agreement in the identification of benthic taxa. A Bray-Curtis Similarity Index on arcsine square-root transformed data was used to compare agreement between observers for each technology. Similarity matrices and an nMDS plot were created using PRIMER 6 software to evaluate the effect of increased image resolution on inter-observer agreement.

An additional analysis was conducted for DV and still images using a subset of CREMP stations (N = 103) to compare the consistency in the number of images acquired per transect between the technologies. The number of images per transect collected with DV in 2010 was compared with the number of still images acquired during the 2011 field season. A Wilcoxon Signed Rank Test was used to determine whether the mean (± SE) number of images per transect was significantly different between the technologies. HDV was not included in this analysis because this technology was not used to complete an entire CREMP field season.

Differences in costs and time required in the field and lab, as well as other logistical considerations, were evaluated for the three technologies.

Results

No significant differences in the percent cover of the four benthic taxa groups or bare substrate were detected between the three technology types (Table 1; Fig. 1). A significant difference in the percent cover of the benthic taxa groups and bare substrate across habitat types was detected, but this was expected because of differences in community structure. No interaction effects between habitat and technology were found for any of the benthic categories, indicating that all significant differences in percent cover were due solely to habitat and not technology. The only discernible difference between technologies was a relatively higher estimate of macroalgae and a comparable decrease in bare substrate in HDV and stills compared with DV; however the differences were not significant (Fig. 1).

	Stony corals	
	F	**P**
Habitat	19.42	<.0001
Technology	0.03	0.9747
Habitat*Tech	0.01	0.9996
	Octocorals	
	F	**P**
Habitat	17.22	<.0001
Technology	0.06	0.9419
Habitat*Tech	0.03	0.9977
	Macroalgae	
	F	**P**
Habitat	53.24	<.0001
Technology	0.86	0.4295
Habitat*Tech	0.06	0.9923
	Porifera	
	F	**P**
Habitat	31.78	<.0001
Technology	0.52	0.5950
Habitat*Tech	0.26	0.9014
	Substrate	
	F	**P**
Habitat	7.39	0.0012
Technology	0.16	0.8526
Habitat*Tech	0.00	1.0000

Table 1: F statistics and P values from the mixed model ANOVA test for five benthic categories (Habitat and Technology *dfnum* = 2, *dfden* = 72; Habitat*Technology *dfnum* = 4, *dfden* = 72). Mean ± SE values for each benthic category for each habitat are reported in Fig. 1. *N* = 81 sets of points.

A greater level of agreement between observers was found for stills than for HDV and DV transects (Fig. 2). Overall similarity, averaged across all observers, was greater for stills (96.3%) and HDV (96.0%) than for DV (94.6%).

The number of images acquired per transect was more consistent for stills than for DV (Fig. 3). The range for stills was much smaller (50–73 images per transect) than for DV (52–98 images per transect), and 81% of still-image transects were between 60 and 70 images, whereas only 57% were for DV (Fig. 3). There was a significant difference in the average number of images per transect between DV and stills (Wilcoxon Signed Rank Test, W = − 3555.000, $p < 0.001$). The mean number of images per transect acquired through DV in 2010 (68.8 ± 0.84) was significantly greater than that through stills in 2011 (63.2 ± 0.37). Though a full field season was not completed using HDV, based upon the subset of stations used in this study, HDV would have added another 15 to 20 images per transect, on average. This is due to the difference in the aspect ratio of HDV (16:9) compared with DV and stills (4:3).

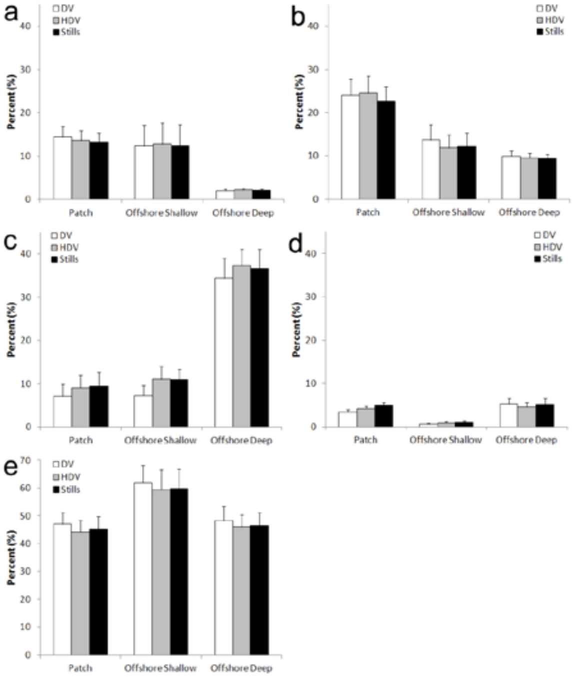

Figure 1: Percent cover estimates (mean ± SE) for **a** stony corals, **b** octocorals, **c** macroalgae, **d** sponges, and **e** bare substrate acquired through DV, HDV, and stills, grouped by habitat. For each bar, *N* = 9 sets of random points. Scale on y-axis is different for bare substrate. F statistics and P values listed in Table 1.

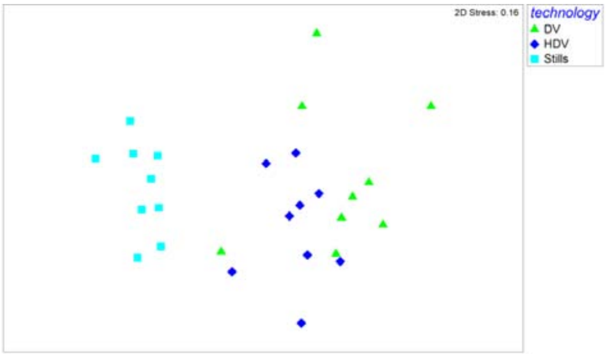

Figure 2: Non-metric multidimensional scaling (nMDS) ordination plot of observer similarities for each technology. Points reflect the level of agreement between observers (*N* = 9) for percent cover estimates pooled for all benthic taxa groups identified.

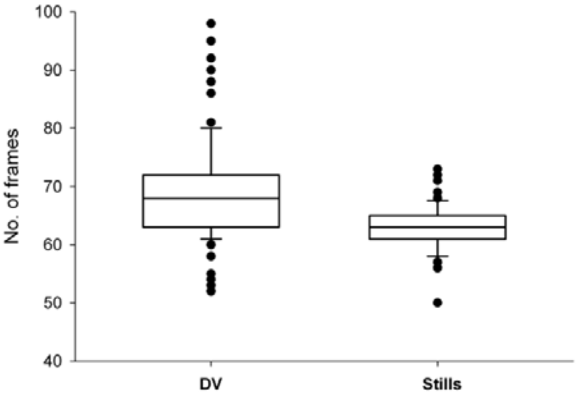

Figure 3: Boxplot showing the number of images acquired per transect (N = 103) using DV in 2010 and still images in 2011. Lower boundary and error bar of the box represent 25th and 10th percentile of the data, respectively. The solid black bar within each box indicates the median. Upper boundary and error bar of the box represent the 75th and 90th percentile of the data, respectively.

In the field, DV transects took the least amount of time to record (~4–6 minutes) compared with HDV (~7–9 minutes) and still-image transects (~9–12 minutes). HDV necessitated a slower swim speed to prevent motion blur, and stills required that the camera be stationary when images were captured. However, both DV and HDV transects required more processing time in the lab than did stills (Table 2). Whereas HDV and still-image files could be transferred directly to the computer from their respective digital storage devices, DV files required additional time to manually capture onto the computer from videotapes. Time spent on the point-count analysis was comparable for DV and still-image files but was longer for HDV files because of the increased number of frames per transect (Table 2).

	Field Survey	**Frame Extraction**	**Point Count***	**Total Time**
Digital Video	5	30	130	165
HD Video	8	20	164	192
Still Images	11	0	128	139

Table 2: Estimated field and lab time (minutes/transect) required for each technology. *Point count times calculated based on the average number of images per transect × 2 minutes per image (approximation).

Discussion

Numerous studies have demonstrated the value of using photographic or video techniques to evaluate coral reef condition (Aronson et al. 1994; Leujak and Ormond 2007). Several large-scale monitoring programs have already incorporated HDV or digital still cameras for image acquisition (Coral Reef Assessment and Monitoring Program 2008; Jonker et al. 2008; National Park Service 2011; T. Smith, University of the Virgin Islands, pers. comm.). However, none of these programs has published a rigorous comparison of all three technologies. We found no significant differences in benthic cover estimates between standard-definition video, high-definition video, and still images, instilling confidence that data collected in future surveys would be comparable to previous datasets, regardless of which technology was chosen to replace DV. Since HDV and stills both provided a suitable alternative to DV, we considered several other differences, which guided us in the selection of an appropriate technology to conduct future benthic habitat surveys.

Both HDV (1920 × 1080 pixels) and stills (up to 3264 × 2448 pixels with the Canon PowerShot SD1100 IS) offered a substantial increase in image resolution compared with DV images (720 × 480 pixels). The higher resolution of HDV and stills resulted in a greater level of agreement among observers (Fig. 2). Improved image clarity also facilitated the identification of organisms and benthic taxa that had been difficult to distinguish in lower-resolution images. This may also explain the slightly higher percent cover estimates of macroalgae and the corresponding decrease in bare substrate observed in HDV and stills compared with DV (Fig. 1). Higher-resolution images, especially stills, may also allow for other types of analyses to be conducted (e.g., juvenile coral density).

Another factor we considered was the number of images collected per transect. There was less variation in the number of frames collected per transect with stills than for DV (Fig. 3). The number of images per transect using stills never exceeded 75, while the 90th percentile corresponded to 80 images per transect using DV (Fig. 3). While convergent lasers help maintain a consistent distance above the substratum, the height of the camera can still vary along the length of the transect. This results in some variability in the area of substrate covered by each image and therefore a more variable number of images per transect. There is less variation in stills, partly because the aluminum bar fixes the distance above the substratum for each image. This is an important consideration for programs that analyze an entire transect rather than a subset of images per transect. The number of frames analyzed affects the number of points included in the analysis, which ultimately influences the power to detect change (Brown et al. 2004; Pante and Dustan 2012). The variance associated with the number of frames collected per transect for DV would likely be similar for HDV.

Technologies examined differed in terms of the time required and associated costs. Consistent with findings from Jokiel et al. (2005), video transects required less time in the field, but this benefit was offset by the time required to process images in the lab (Table 2). In our study, the difference was mostly due to frame extraction. HDV images had to be extracted manually, and though automated software was used to extract frames from DV, additional steps were applied for quality control, leading to even longer processing times. Although frame extraction times might seem insignificant for a single transect, a difference of 20 (HDV) to 30 (DV) minutes per transect can equate to hundreds of additional hours spent converting video to still images.

Equipment costs for both HDV and DV are substantially greater than for a point-and-shoot camera. Digital cameras and housings can be purchased for a few hundred dollars each, but professional HDV cameras and housings (such as those currently being used by some monitoring programs and the camera tested in this study) can each cost more than $5,000 (R. Waara, National Park Service, pers. comm.; T. Smith, University of the Virgin Islands, pers. comm.). This is a significant investment for any monitoring project, especially considering the rate at which camera technologies are advancing and the risk of flooding cameras underwater. Because the costs associated with purchasing a point-and-shoot camera are less, more than one camera can be purchased so that multiple transects can be photographed simultaneously. This can offset the increased time per transect and thus decrease the total time in the field.

Point-and-shoot cameras also offer a variety of qualitative benefits, including simplicity of use, decreased bulk, and the ability to control image size. Compared with HDV or DV, the frequency of motion blur in still images is greatly diminished (especially in low light) because the camera is stationary when the images are captured. In addition, images can be reviewed immediately underwater and recaptured if necessary, an advantage not shared with video because images are extracted at a later time. Stills also require considerably less digital storage capacity than DV and HDV. Based on the total number of transects surveyed in a typical CREMP field season (N = 225), still images require less than a quarter of the storage space (~50 GB) required for DV (~225 GB) and less than a sixth of that required for HDV files (~325 GB).

Based on the factors discussed above, digital point-and-shoot cameras were selected as the most suitable technology. While HDV offered higher-resolution images than DV, stills provided both quantitative and qualitative advantages over HDV. Many aspects of a monitoring program (such as overall budget, experimental design, history of data collection, and personnel) must be considered, but the findings presented here outline the rationale behind our program's decision to conduct future surveys using digital still cameras.

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