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Diver operated video most accurately detects the impacts of fishing within periodically harvested closures

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ABSTRACT

Periodically harvested closures (PHCs) have become the most common form of spatial management in Melanesia. Despite their popularity, their effectiveness to sustain local fish stocks remains largely unknown. Here we test the ability of non-destructive sampling techniques to detect the impacts of fishing in a PHC where harvest catch data provide an impact of known magnitude. We compared the ability of three commonly used techniques (underwater visual census, UVC; diver operated stereo-video, stereo-DOV; and baited remote underwater stereo-video, stereo-BRUV) to detect the impact of a harvest on fish assemblages within a PHC in Fiji. The technique stereo-DOV recorded a significant decrease in harvested individuals at both the assemblage and species level (primarily herbivorous species). The technique stereo-BRUV also recorded an impact at the assemblage level, but only for carnivorous fishes, which were less numerous in the catch. UVC did not detect an impact of the harvest at the assemblage or species level. We conclude that stereo-DOV is the most suitable technique for detecting the impacts of harvests and monitoring the effectiveness of PHCs as a fisheries management strategy, especially in areas where herbivorous fish are targeted. However, stereo-BRUV may be more appropriate where strong gradients in the abundance of carnivorous species or behavioural responses to divers are expected.

1. Introduction

Small scale or artisanal fisheries are essential to the livelihood and food security of millions of people worldwide (Bene et al., 2010), yet the resources supporting these fisheries are in decline (Worm et al., 2009). Periodically harvested closures (herein referred to as PHCs) have emerged as the most common form of spatial management in Melanesia where they are used to meet multiple objectives, including sustaining small scale fisheries and the conservation of biodiversity (Cohen and Foale, 2013; Crawford et al., 2006; Foale and Manele, 2004). PHCs are typically small in size (e.g. median area 1 km^2 in Melanesia and 0.02 km^2 in Fiji) and vary markedly in the proportion of time that they are open to fishing (Cohen and Foale, 2013; Govan et al., 2009). Here we focus on a common form of PHC that is closed for the majority of the year and harvested during a short, pulse event lasting less than 10 days. Despite the popularity of this strategy, there is only limited evidence to suggest this management technique can sustain local fish stocks (e.g. Bartlett et al., 2009b; Cinner et al., 2005). To assess the effectiveness of PHCs as a fisheries management tool, information must be collected across a broader range of fishing intensities, using non-destructive methods to estimate fish abundance before and after each harvest. Changes in abundance can then be compared to catch data to assess how well a method detects the impact of fishing.

The most common non-destructive method for assessing the abundance of fish assemblages is underwater visual census (UVC), where a diver identifies and counts fishes within a predefined area. All studies that have examined the effectiveness of PHCs to sustain targeted fish stocks have used some form of UVC (Bartlett et al., 2009a, 2009b; Cinner et al., 2005; Jupiter and Egli, 2011; Jupiter et al., 2012) as the method is logistically simple and cost effective (English et al., 1997). However, biases associated with UVC include: variation in the behavioural response of fish to divers (Chapman et al., 1974; Watson and Harvey, 2007); inter-observer variability (Thompson and Mapstone, 1997); and inaccuracies in estimating sampling area boundaries (Harvey et al., 2004).

Diver operated stereo-video (stereo-DOV; herein referred to as DOV) relies on the use of video cameras to record belt transects, while identification and abundance measurements are made on a computer after the field work is completed rather than *in situ*. This technique can overcome some of the biases involved with UVC such as inter-observer variability and inaccuracies in the estimation of sampling

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area boundaries (Harvey et al., 2001, 2004; Watson et al., 2005). As the imagery from transects is recorded in a digital format, it can be paused during analysis, allowing references and expert help to assist with identification. Conversely, the reduced clarity of video images and the restricted field of view in comparison to the human eye may make it difficult to identify some individuals (Holmes et al., 2013).

Both UVC and DOV surveys can be biased by problems associated with behavioural responses of fish to divers, especially in areas where spearfishing is common (Bartlett et al., 2009b; Feary et al., 2011; Lindfield et al., in press). Employing a remote sensing technique, baited remote underwater stereo-video (stereo-BRUV; herein referred to as BRUV), can overcome the biases associated with divers influencing fish behaviour. BRUV uses bait to attract fishes, which makes the technique particularly suited to sampling large carnivorous species often targeted by fisheries (Cappo et al., 2003; Langlois et al., 2012; Watson et al., 2010), without precluding estimates of herbivorous species (Harvey et al., 2007). Like DOV, the use of stereo facilitates accurate measurements of the sampling area (Harvey et al., 2004). However, variation in the distance a bait plume travels makes it difficult to determine the extent of the area sampled by BRUV (Ellis and DeMartini, 1995; Priede and Merrett, 1998; Willis and Babcock, 2000).

Comparisons between techniques aim to determine the optimal method for detecting change and have highlighted how inherent biases influence assessments of fish assemblages (see Supplement 1 for a summary). However, without knowing the “true” composition of fish within an area, it is not possible to determine which technique is the most accurate. As a result, some studies use gradients in fishing pressure (such as that found inside and outside of a marine reserve) to determine which techniques best detect differences (Langlois et al., 2006; Pelletier et al., 2011; Tessier et al., 2013). Again, without knowing the “true” gradient or difference they cannot conclude which technique is the most accurate. Intensive harvests that can occur during the opening of a PHC (e.g. Jupiter et al., 2012) provide a unique opportunity to compare the ability of each technique to document the effects of fishing. This can be achieved by comparing changes in fish abundance (from the catch data of a harvest) to the change observed with each technique. We aimed to compare the ability of the three techniques, UVC, DOV and BRUV, to record the change in relative fish abundance before and after a moderately intense, week-long harvest event inside a PHC in Fiji.

2. Methods

2.1. Study area and harvest data

Comparisons among methods were carried out in the Kubulau *qoliqoli* (traditional fishing ground), Vanua Levu, Fiji, from the 15th of October to the 1st of November 2012. The total area of Kubulau's qoliqoli is 262 km^2 and contains a network of 21 PHCs and three permanent no-take marine reserves, totalling approximately 120 km^2, or 44% of the qoliqoli (Fig. 1; Weeks and Jupiter, 2013). We sampled inside and adjacent to the Cakau Naitaga PHC (2.07 km^2), which was established as a 5 year closure in early 2009, with the stipulation that it may only be harvested for major church gatherings with the consent of the district high chief (WCS, 2009). However, in practice, Cakau Naitaga has been harvested once per year since its creation in 2009, with local fishermen reporting that historical harvests were similar in intensity to the harvest presented here. The Cakau Naitaga PHC was opened to fishers from the villages Kiobo and Navatu (Fig. 1) for a period of 7 days (24th–30th October 2012). The catch (mainly from spearguns and handlines) was landed in Kiobo village, identified to species level and counted. The

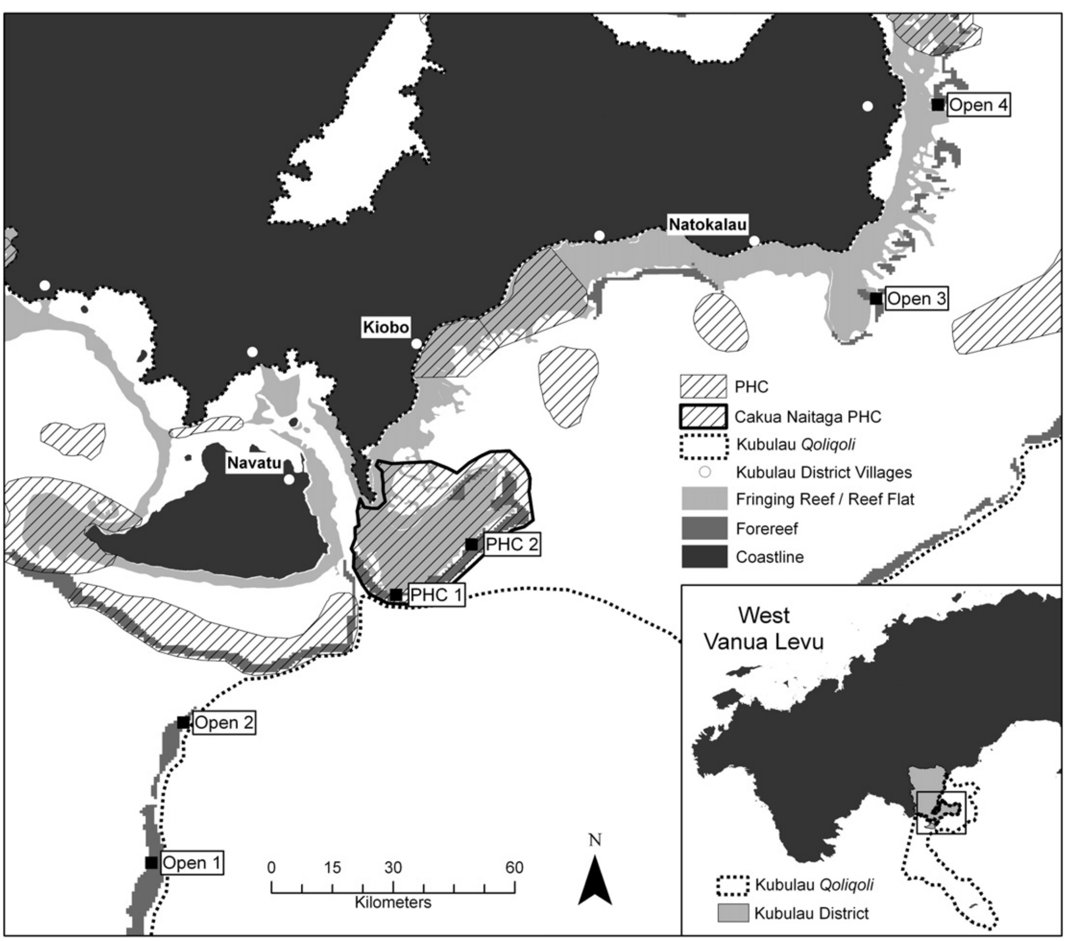

Fig. 1. Map of survey locations within the central portion of the Kubulau District qoliqoli, Vanua Levu, Fiji.