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Periodically harvested closures require full protection of vulnerable species and longer closure periods

Jordan Goetze [a,b,c,*], Tim Langlois [a,b], Joachim Claudet [d,e], Fraser Januchowski-Hartley [f,g], Stacy D. Jupiter [h]

[a] The UWA Oceans Institute, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia
[b] School of Plant and Animal Biology, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia
[c] Department of Environment and Agriculture, Curtin University, Bentley Campus, WA 6485, Australia
[d] National Center for Scientific Research, CRIOBE, USR 3278 CNRS-EPHE-UPVD, 66860 Perpignan, France
[e] Laboratoire d'Excellence CORAIL, France
[f] Department of Geography, College of Life and Environmental Sciences, University of Exeter, UK
[g] UMR 248 MARBEC/UMR250 ENTROPIE, UM2-CNRS-IRD-IFREMER-UM1, Université Montpellier 2, Montpellier, France
[h] Wildlife Conservation Society, Melanesia Program, Suva, Fiji

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ABSTRACT

Periodically harvested closures (PHCs) are small fisheries closures with objectives such as sustaining fisheries and conserving biodiversity and have become one of the most common forms of nearshore marine management in the Western Pacific. Although PHCs can provide both short-term conservation and fisheries benefits, their potential as a long-term management strategy remains unclear. Through empirical assessment of a single harvest event in each of five PHCs, we determined whether targeted fishes that differ in their vulnerability to fishing recovered to pre-harvest conditions (the state prior to last harvest) and demonstrated post-harvest recovery benefits after 1 year of re-closure. For low and moderately vulnerable species, two PHCs provided significant pre-harvest benefits and one provided significant post-harvest recovery benefits, suggesting a contribution to longer-term sustainability. PHCs with a combination of high compliance and longer closing times are more likely to provide fisheries benefits and recover from harvest events, however, no benefits were observed across any PHCs for highly vulnerable species. We recommend PHCs have longer closure periods before being harvested and species that are highly vulnerable to fishing (e.g. large species of; grouper, wrasse and parrotfish) are avoided during harvests to avoid overexploitation and increase the sustainability of small-scale fisheries.

1. Introduction

In an attempt to recover fisheries resources and provide food security to communities in the Western Pacific, locally-managed marine areas have been widely promoted (Govan, 2009; Jupiter et al., 2014). Periodically harvested closures (PHCs) have become one of the most common forms of fisheries management used in locally-managed marine areas, with over 1000 closures estimated across the Western Pacific (H. Govan, pers. comm.). PHCs are generally small fisheries closures (e.g., median area of 1 km^2 in Melanesia; Govan et al., 2009), with periodic harvest regimes that make them functionally similar to rotational closures (Cohen and Foale, 2013). Historically they have been applied in Pacific coastal communities to increase catch efficiency and provide for socioeconomic and cultural needs, while objectives such as sustaining small-scale fisheries and conservation of biodiversity have been proposed more recently (Cohen and Foale, 2013; Jupiter et al., 2014, 2012). The widespread use of PHCs in a region where small-scale fisheries are essential for food security (Bell et al., 2009), highlights the importance of understanding the best practice and trade-offs of PHCs for fisheries management and conservation strategies.

PHCs vary markedly in the way they are managed, in particular the time they are closed versus open to fishing, which has resulted in variation in their ability to increase the abundance, size or biomass of targeted species (Bartlett et al., 2009; Cinner et al., 2006; Goetze et al., 2015; Jupiter et al., 2012). However, a recent meta-analysis found that PHCs across Melanesia were capable of providing pre-harvest protection benefits through increased abundance and biomass of targeted species, which translated into harvest benefits when opened to fishing (Goetze, 2016). The meta-analysis found that these benefits are greater in PHCs that are large, have high compliance and are closed to fishing for long periods. However, variation in these factors within Fijian PHCs has resulted in inconsistent outcomes for the abundance, size and biomass

* Corresponding author at: The UWA Oceans Institute, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia.
E-mail addresses: gertza@gmail.com (J. Goetze), timothy.langlois@uwa.edu.au (T. Langlois), joachim.claudet@gmail.com (J. Claudet), f.a.hartley@gmail.com (F. Januchowski-Hartley), sjupiter@wcs.org (S.D. Jupiter).

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of targeted species (Goetze et al., in review). While there is some evidence for well-managed and designed PHCs providing short-term fisheries benefits prior to harvesting, a large proportion of the biomass of targeted species is usually removed during harvest events (Goetze, 2016). The ability of PHCs to recover from high levels of harvesting and their role in sustaining fisheries has not been explored empirically.

Similar to no-take marine reserves (hereafter referred to as marine reserves), recovery of targeted biomass within a PHC is expected to occur through multiple mechanisms, the importance of which will vary depending on the length of time that the area is protected (Russ and Alcala, 2003). Recruitment, the addition of juveniles, growth of the existing population and migration/movement across PHC boundaries are some of these mechanisms. The rapid changes in fishing pressure associated with opening and closing PHCs makes it particularly important to account for migration/movement across PHC boundaries. For example, "spill-in" of targeted species into protected areas can occur when fishing pressure outside is high (Eggleston and Parsons, 2008) or a "bail-out" effect can occur when there is a sudden increase in fishing pressure within PHC boundaries (Jupiter et al., 2012). This highlights the importance of monitoring both PHCs and sites open to fishing across the entire harvesting regime when investigating recovery dynamics.

Assessing the implications of PHCs for long-term fisheries management and conservation requires understanding how species that vary in their vulnerability to fishing are affected by harvest regimes. Long term studies using marine reserves have been used to assess how coral reef fish recover from the effects of fishing and suggest that decadal time scales may be required for the full recovery of fish assemblages in heavily fished areas (McClanahan et al., 2007; McClanahan and Graham, 2015; Russ and Alcala, 2004). In addition, coral reef fishes have a broad range of life history traits that influence their vulnerability to overfishing including: maximum size; growth rate; maximum age; age of sexual maturity; and rates of mortality (Abesamis et al., 2014; Cheung et al., 2005; Jennings et al., 1999; Russ and Alcala, 1998). Recovery trajectories will thus not only depend on the local fishing intensity, but also on the life history traits and vulnerabilities of targeted fish species, with higher vulnerabilities generally resulting in slower recovery (Abesamis et al., 2014; Claudet et al., 2010; McClanahan and Humphries, 2012). For example, Abesamis et al. (2014) use marine reserves to show that the full recovery of large predators in overfished regions may take between 20 and 40 years, while smaller-bodied herbivores may recover within 10 years.

The recovery trajectories of coral reef fishes observed in marine reserves is applicable to PHCs during the no-take closure periods. Abesamis et al. (2014) related the recovery trajectories observed in marine reserves to the management of PHCs and estimated that a 10% removal of stock will require several years of recovery for less vulnerable species (e.g., small parrotfish), while moderately to highly vulnerable species (e.g., large groupers) may take more than a decade. This suggests that certain species will be better suited to the strategy of periodic harvesting and collecting data on the recovery trajectories of target species across different levels of vulnerability will be essential to ensure the long-term sustainability of the harvesting regime within PHCs. We estimated the biomass of targeted species immediately (1–2 days) before, after and 1 year after a harvest event, inside and outside of five PHCs across Fiji with varying management strategies. We aimed to determine if targeted fish biomass within PHCs would recover to pre-harvest conditions and provide post-harvest protection benefits after 1 year of re-closure, a common closure time across Melanesia (Goetze, 2016). Additionally, we assessed how targeted species with low, moderate and high vulnerabilities to fishing were impacted and whether they recovered from harvest events. We hypothesised that species with high vulnerability were likely to benefit least from PHCs, and that magnitude of recovery would decrease with increasing vulnerability.

2. Methods

2.1. Study area

Surveys were carried out on reefs adjacent to five villages on Koro (Nakodu, Tuatua), Ovalau (Nauouo, Natokalau) and Vanua Levu (Kiobo) islands in Fiji in 2013 and 2014 (Appendix A). PHCs had been established for 3–8 years prior to surveys, though the frequency at which they had been previously harvested and level of compliance with management varied (Table 1). Each PHC was established by the local community in conjunction with a non-government organization. Surveys were carried out 1–2 days before, 1–2 days after and approximately 1 year after harvests, which lasted between 1 and 7 days and involved line fishing, spear fishing and/or fish drives into gill nets. Key informants reported that historical harvest events were of similar intensity to those presented here, although this could not be verified empirically. For clarity we refer to the PHCs by their associated village (Nakodu, Tuatua, Natokalau, Nauouo and Kiobo; Table 1, Appendix A).

2.2. PHC and harvest information

Most PHCs were relatively large (0.73–3.14 km^2) compared to the median for Melanesia (1 km^2; Govan et al., 2009) and varied in habitat and depth (Table 1). No significant differences in the benthic strata (measured through underwater visual census) were observed between PHC and open areas (Jupiter et al., in review). Compliance levels were based on surveys with village spokespersons, who were asked to rate compliance as low (frequent breaches of management rules), moderate (occasional breaches of management rules) or high (infrequent offenses of management rules), based on their direct observations within each village. To estimate fishing pressure during harvest events (harvest intensity), we recorded the gear, area, time, number of fishers and their catch (species, abundance and length) during the harvest of each PHC. Harvest intensity was then calculated as the total number of fisher hours per km^2 of PHC.

2.3. Sampling design

We sampled between 2 and 5 sites inside each of the five PHCs (depending on PHC size), and 4 to 6 sites outside PHCs in areas open to regular fishing (depending on comparable available habitat; Appendix A). Sites open to regular fishing were distributed on either side of each PHC in areas within the local community's fishing ground. At each site, the fish community was sampled by conducting stereo diver operated video (stereo-DOV) surveys along six replicate 5 × 50 m transects separated by 10 m, following Shedrawi et al. (2014). Sampling was conducted 1–2 days before the opening of each PHC, 1–2 days after the harvest and approximately 1 year after the harvest. All five PHCs were closed to fishing for the entire year following the monitored harvest.

2.4. Sampling technique and video analysis

Stereo-DOVs can provide highly accurate estimates of fish length and position relative to the camera system (Harvey et al., 2004) and are one of the most effective methods for detecting harvest impacts on targeted species within PHCs (Goetze et al., 2015). Stereo-DOVs were used to collect length estimates and biomass was calculated using the standard length-weight equations and values from FishBase (Froese and Pauly, 2015), preferentially selected from sites closest to Fiji (Jupiter and Egli, 2011). System design and procedures for video analysis followed Goetze et al. (2015), and data were extracted from EventMeasure software and checked following Langlois et al. (2015).