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Evaluation of coral reef management effectiveness using conventional versus resilience-based metrics

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ABSTRACT

With increasing stressors to coral reefs, defining tools that evaluate their dynamics and resilience is important to interpret system trajectories and direct conservation efforts. In this context, surveys must go beyond conventional monitoring approaches that focus on abundance and biomass of key groups and quantify metrics that better assess ecological processes and ecosystem trajectories. By measuring a variety of conventional (e.g. proportional cover of broad benthic groups, biomass of herbivorous fish) and complementary resilience-based metrics (e.g. algal turf height, coral recruitment rates, juvenile coral densities, herbivorous fish grazing rates), this study evaluated the ecosystem responses to community-based management in Fiji. The study was conducted across three paired *tabu* areas (periodically closed to fishing) and adjacent fished sites. Conventional metrics reflected no management effect on benthic or herbivorous fish assemblages. In contrast, the complementary metrics generally indicated positive effects of management, particularly within the benthos. Significant differences were observed for turf height (33% lower), coral recruitment rate (159% higher) and juvenile coral density (42% higher) within areas closed to fishing compared to adjacent open reefs. In addition, turf height was inversely related to coral recruitment and juvenile coral density, and longer turfs (≥5 mm) were more competitive in interaction with corals. These results emphasise that conventional metrics may overlook benefits of local management to inshore reefs, and that incorporating complementary resilience-based metrics such as turf height into reef survey protocols will strengthen their capacity to predict the plausible future condition of reefs and their responses to disturbances.

1. Introduction

The status of ecosystems over space and time has long been used as criterion for prioritisation and decision-making in conservation planning. Historically, ecosystem assessments have typically focused on quantifying common status metrics such as biomass and abundance of target groups, as well as species diversity (e.g. Yoccoz et al., 2001). Although such assessments offer the advantage of relying on generally fast and relatively simple estimation methods, their capacity to convey quantitative information on ecosystem function is limited (Wright et al., 2006). It is thus important to identify indicators of dynamic processes to capture a further facet that may help to anticipate the likely trajectory of ecosystems over time and in response to disturbances (Glaser et al., 2012). If such indicators can be practically and cost-effectively integrated into ecosystem assessments, there is scope for (i) evaluating the effectiveness of conservation tools (e.g. marine reserves) more thoroughly, (ii) better understanding the impact of disturbances, and (iii) supporting managers in decision-making (high vs. low-risk conservation investments).

Anticipating trajectories of complex and diverse ecosystems such as

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coral reefs is particularly challenging due to the large number of species fulfilling various functions and responding differently to a changing environment (Pandolfi, 2015). Conventional coral reef monitoring protocols focus on measuring cover of broad benthic groups, as well as fish biomass along replicate transects. Percent cover of benthic organisms fails to provide information on important ecosystem functions for a variety of reasons. First, high live coral cover is generally interpreted as a sign of ecosystem health, and the contrary is assumed of high algal cover. Healthy reefs may however display variable levels of hard coral and fleshy algal cover depending on their location (Johannes et al., 1983; Kleypas et al., 1999; Couce et al., 2012). Just as low coral cover does not necessarily reflect unhealthy reefs, reefs dominated by live corals must not be unequivocally considered healthy and/or resilient (Mumby et al., 2014; Anthony et al., 2015). Second, the resolution at which benthic groups are defined differs strongly among studies. While a coarse resolution may suffice for an immediate broad diagnosis of benthic status and ecosystem service provision, it may impair the detection of relationships between particular benthic attributes and fish communities or behaviours (Mumby et al., 2013). Conventional assessments cannot, for instance, provide information on the colonisation processes of newly opened space. This space is usually recorded ambiguously as dead coral, bare rock, pavement or rubble (Harris, 2015), yet the settlement dynamics of coral larvae or algal propagules (among others) on available substrate determine the success of critical reef recovery processes. There are also limitations to how informative fish abundances are of the ecosystem functions that fishes sustain. Tidal changes, time of day, turbidity and variability among surveyors can lead to variations in the perceived fish abundance (Thompson and Mapstone, 2002; McClanahan et al., 2007), and some important species can be wary of divers and thus not encountered in fish censuses (Kulbicki, 1998). Stationary video cameras have consequently illuminated the previously unknown, yet crucial functional roles of species that tend to be rare in visual surveys (Hoey and Bellwood, 2009; Plass-Johnson et al., 2015). Conventional reef status assessments thus risk providing a superficial level of information that does not convey functionality and ecosystem robustness, and hence may not provide enough support for adaptive management decisions. Essentially, although conventional measures of abundance can provide an idea of the system's current state, they do not consider whether the system is most likely to improve or deteriorate over time and overlook important components of system resilience.

The likelihood of coral reefs changing over time and in response to disturbances is a product of many factors. In an attempt to improve predictions of these complex systems, several important ecological processes have been identified and alternative monitoring tools proposed (e.g. McClanahan et al., 2012). Benthic assessments are increasingly encouraged to consider more dynamic indicators that respond quickly to changes and drive system resilience, such as coral recruitment success, turf height and coral-algal interactions (Anthony et al., 2015; Flower et al., 2017). Furthermore, conventional benthic monitoring often applies broad categories such as 'dead coral' or 'rock' to describe seemingly 'free space' in the reef available for colonisation, while in reality very little space is actually free of benthic organisms. Rather, such substrate tends to be overgrown by a diverse assortment of early colonisers such as turf algae, benthic cyanobacteria or crustose coralline algae, which differ in their suitability for stony coral larvae to settle and survive, but are often not adequately captured in monitoring. To evaluate settlement dynamics on free space, hereon referred to as biotic substrate colonisation, surveys would benefit from refining the level of detail in which different benthic categories (e.g. algal turfs, crustose coralline algae, cyanobacterial mats) are recorded. One of the fastest colonisers of available substrates are algal turfs (Diaz-Pulido and McCook, 2002), yet their cover and intrinsic properties are often neglected in surveys (Harris, 2015; Flower et al., 2017). While algal turf cover itself may not be very informative, it can be a strong predictor of coral recruitment and subsequent development when combined with turf height (Birrell et al., 2005; Mumby et al., 2013). For coral reef fish communities, efforts are increasingly invested towards monitoring key functional groups separately (Green and Bellwood, 2009) and quantifying herbivory (Fox and Bellwood, 2008; Rasher et al., 2013). Spatial, temporal and surveyor-related discrepancies, as well as differential species wariness (Kulbicki, 1998), imply that visual fish biomass surveys should be supported by: (i) remote video surveys, and (ii) parameters that reflect longer-term fish functions. The latter can include algal traits and prey behaviours in response to predatory fish (e.g. Vermeij et al., 2015).

Here we evaluate the effectiveness of local management using conventional reef status metrics in combination with a set of complementary metrics that have implications for system resilience. Conventional (e.g. percent cover of benthic groups, herbivorous fish biomass) and complementary resilience-based (e.g. algal turf height, coral recruitment, juvenile coral density, herbivorous fish grazing rates) metrics were quantified in paired inshore reefs open and closed to fishing within three locally managed marine areas (LMMAs) in Fiji. We hypothesised that a substantial discrepancy would be found when interpreting the level of effectiveness from these two different types of metrics, driven primarily by the limited resolution of conventional metrics. By quantifying the nature and magnitude of this discrepancy, we provide a more nuanced approach to evaluate the success of management. We also evaluate the informative value of measuring turf height in an inshore Pacific island reef setting by investigating its relationship with ecological processes that are critical for system resilience.

2. Material and methods

2.1. Study area

This study focused on three inshore reef sites within traditional fishing grounds (*qoliqoli*), namely Dakuibeqa (Beqa, Rewa Province), Nasinu (Ovalau, Lomaiviti Province) and Navakavu (Suva, Rewa Province; Fig. 1). Each *qoliqoli* contained a locally managed *tabu* area (periodically closed to fishing) that had been established for at least eight years. These locations were selected based on the premise that Fijian LMMAs represent a good example of effective community-based management (Techera, 2010; Weeks and Jupiter, 2013). All sites displayed similar characteristics regarding reef orientation (i.e. south-east facing) and topography. At paired reefs within and adjacent to each *tabu* area, surveys took place on both reef platforms (1–2 m depth) and lagoonal slopes (4–6 m depth), covering both inshore reef habitat types encompassed within all *tabu* areas. Surveys were carried out between September 2015 and February 2016.

2.2. Field surveys

2.2.1. Conventional reef status metrics

Conventional metrics of benthic and fish communities were quantified along transects at all survey sites (Table 1). Benthic surveys were carried out along three 30 m transects within each of the *tabu* and open areas, and in both reef habitats, at all sites. Benthic community structure was assessed using the line-point-transect method (English et al., 1997), with benthic cover recorded at 50 cm intervals, yielding a total of 60 points per transect. Fine-scale rugosity was quantified using the chain-and-tape method (Risk, 1972) with a small link chain (5 mm). Three replicate rugosity measurements were made along each transect (averaged per transect), with each measurement covering 5 m linear distance. Herbivorous fish biomass was quantified at all sites using underwater visual censuses (UVC) carried out along eight 30×5 m belt transects by a single surveyor (Dickens et al., 2011). The surveyor recorded the largest and wariest species during a first pass of the transect, and more site-attached territorial species (e.g. *Stegastes* spp.) in the second pass. Individual fishes were identified to the species level