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Original research article

The impacts of short-term temporal factors on the magnitude and direction of marine protected area effects detected in reef fish monitoring

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ABSTRACT

Marine protected areas (MPA) and in particular no-take marine reserves have been identified as important tools for the conservation of reef fish and habitats. A significant challenge of reef fish monitoring is to determine the influence of temporal factors on fish counts. Fish assemblages are dynamic and changes in activity patterns throughout the day can influence the results of surveys. While many monitoring programs account for the impacts of spatial heterogeneity on fish assemblages the effects of short-term temporal variation are less well known. In the present study, we analysed data from 197 video drops inside and outside New Caledonian MPAs and examined temporal variations in various metrics commonly used to monitor marine reserves. In addition to describing short-term temporal patterns related to time of day, tide height and state, and lunar cycle; we also examined the influence of these temporal factors on the size and direction of any MPA effects detected. Fewer Serranidae were observed at full moon than the rest of the lunar cycle and there were negative correlations between Chaetodontidae and Acanthuridae abundance and tide height. We did not find any consistent effects of time of day. Generally, variation in short term temporal factors did not affect the direction MPA effects detected but did affect the size of the effects for some metrics. For both small fish abundance and species richness, bigger differences between protected and unprotected sites were detected at high tide than low tide. These results highlight how survey results can vary with timing of sampling and have implications for developing optimal monitoring programs.

1. Introduction

Coral reefs are highly biodiverse ecosystems that provide numerous ecosystem services such as coastal protection, food for coastal communities and income from tourism (Moberg and Folke, 1999). However, many reefs are threatened by overexploitation, disease, increased sedimentation and nutrient levels, and the impacts of climate change (McCook, 1999; Fabricius, 2005; Aeby et al., 2011; Hoegh-Guldberg, 2011; Kennedy et al., 2013). Overfishing has been identified as one of the most widespread threats to reefs with direct effects through the removal of species but also indirect effects through the removal of top predators (Burke et al., 2011). Marine protected areas (MPA) and in particular no-take marine reserves (NTMR) have been identified as important tools for the conservation of reef fish and habitats (Bellwood et al., 2004; Pandolfi

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et al., 2005; Allen, 2008) with reported effects including increases in density and biomass especially for commercial species and increases in body size (McClanahan and Arthur, 2001; Friedlander et al., 2003; Unsworth et al., 2007; Russ and Alcala, 1996). However, without effective management MPAs are likely to fail to meet conservation goals (Fox et al., 2014).

An important component of effective management is precise and accurate monitoring data. Good monitoring programs provide information on changes that are occurring within MPAs and also on how well the MPAs are meeting management objectives (Pelletier et al., 2005). One of the challenges of MPA monitoring is that the effects of protection on fish assemblages can be obscured by natural variation (Kulbicki et al., 2007). The strong relationship between the abundance of coral reef fish and habitat is well known (Friedlander and Parrish, 1998) and the need to account for habitat heterogeneity in MPA studies is well established (Garcia Charton et al., 2000). Many MPA studies currently employ methods to partition reserve and habitat effects (Miller and Russ, 2014). In contrast, it is less often acknowledged that short-term temporal variation in fish assemblages due to factors such as time of day, tidal state or lunar phase also has the potential to affect the outcome of monitoring studies (Bijoux et al., 2013).

The primary aim of monitoring programs is to measure real changes in fish abundance and assemblage composition over time so that the effects of protection can be assessed. However, short-term changes in fish behaviour can affect the outcome of monitoring fish counts. Diurnal variability can be caused by changes in the local abundance of species as a result of daily movement patterns (e.g. between different feeding habitats) or by fish being more or less visible to observers as a result of behavioural changes (e.g. water column feeding vs predator avoidance) (Thompson and Mapstone, 2002). A number of studies have found distinct diurnal patterns in local fish abundance (Colton and Alevizon, 1981; Galzin, 1987). This short-term temporal variation has the potential to affect fish monitoring counts in a number of ways. For example, logistical constraints sometimes mean that fish counts from a particular survey site are carried out on the same day or time of day. As a result, differences in time of day when surveys are carried out could confound among location comparisons (e.g. MPA and control sites). In addition, this temporal variation could increase within treatment variability, reducing statistical power to detect protection effects. Alternatively, if counts are always carried out at the same time, variation in fish counts due to temporal variation may be reduced, increasing the accuracy of monitoring counts. However, results could still be biased if there is systematic temporal variation in fish abundances or assemblage composition. For example, if the local abundance of a species decreases during the day and surveys are carried out in the afternoon, monitoring counts are likely to underestimate the abundance of this species.

In addition to time of day, there are a number of other factors that operate over relatively short times scales (hours to months), such as the phases of the lunar cycle and tidal state, that have been associated with changes in fish behaviour and could potentially influence fish counts (Curtis-Quick et al., 2012; Zeller, 1998; Starr et al., 2007). Changes in the lunar cycle have been associated with the timing of spawning of a number of fish species (Samoilys, 1997; Hoque et al., 1999). Migrations of individuals to spawning sites could affect local fish abundance and consequently monitoring fish counts. Another temporal factor associated with short term changes in fish behaviour is tidal state. For instance, daytime spawning peaks of fishes at Johnson Atoll in the Central Pacific were shown to be correlated with local changes in current direction (Sancho et al., 2000). Tidal state can also potentially influence fish feeding behaviour as individuals take advantage of differences in the resources available to them (Curtis-Quick et al., 2012). Differences in fish abundance observed at particular tidal states could be related to changes in activities making them more or less visible to observers. For instance, depending on which monitoring method is being used, a fish feeding on plankton in the water column on a flood tide might be more visible than an individual foraging near the substrate.

Although many studies have highlighted the potential of temporal variability in fish assemblages to influence the outcome of monitoring surveys (Colton and Alevizon, 1981; Thompson and Mapstone, 2002; Willis et al., 2006), in practice, quantifying and accounting for these effects presents a number of difficulties. Characterizing short term variability in fish assemblages requires the collection of high-frequency data across relevant time scales, which can be expensive, time consuming and potentially beyond the scope of most monitoring programs. However, potential benefits include more effective monitoring with increased power to detect protection effects.

Underwater video methods have been used for marine ecological studies since the 1950s, and more recently for monitoring marine biodiversity (see Mallet and Pelletier, 2014 for a review). Video methods have a number of advantages over conventional underwater visual census and fishing based methods for monitoring fish populations including their non-destructive nature, the fact that they cause minimal disturbance to marine life and their potential for high spatial and temporal replication. A rotating, unbaited camera system, STAVIRO (**STA**tion**Vi**deo**RO**tative, in French), has been used since 2007 to survey a number of reefs in close proximity to Nouméa, New Caledonia (Pelletier et al., 2012). The resulting dataset includes fish count data for a wide range of species collected across a range of short-term temporal factors (tide height, time of day, tidal state, lunar cycle) and provides an opportunity to investigate the potential effects of temporal variables on monitoring fish counts. Our primary aim was to use this monitoring data to investigate the influence of temporal factors on metrics commonly used to monitor MPAs. We also investigate whether any MPA effects detected (size and direction) vary with temporal factors. Finally, we discuss the implications of these findings for the design of effective monitoring programs and the reporting of MPA effects.