A framework for practical and rigorous impact monitoring by field managers of marine protected areas

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Abstract Monitoring is a crucial component of conservation in marine protected areas (MPAs) as it allows managers to detect changes to biodiversity and to infer cause of change. However, the complexities of sampling designs and associated statistical analyses can impede implementation of monitoring by managers. Two monitoring frameworks commonly used in marine environments are statistical testing and parameter estimation. For many managers these two approaches fail to help them detect change and infer causation for one or more reasons: the complexity of the statistical test, no decision-making structure and a sampling design that is suboptimal. In collaboration with marine park rangers in Egypt, we instigated a monitoring framework to detect impacts by snorkelers in a pragmatic but scientifically rigorous way. First, we used a literature review to define causal criteria to facilitate inference. This was essential because our sampling design was suboptimal due to a lack of baseline data and there was only one impact site. Second, we established a threshold level of coral damage that if exceeded would trigger management to reduce the impact of snorkelers. This provided a clear decision-making structure. Third, we estimated effect sizes with confidence intervals to detect change. For the field managers, this approach to detection was easier to understand than assessing a null hypothesis and provided critical information for decision making. At no stage during the short study period did snorkelers cause damage that exceeded the threshold and thus mitigation was not required. In situations of technical and financial constraints this framework will increase the implementation of effective impact monitoring for many activities in MPAs and enhance management of marine biodiversity.

Keywords Effect size · Levels-of-evidence · Marine protected areas · Monitoring framework · Null hypothesis testing · Parameter estimation · Sampling design
Introduction

Background

The majority of nations are signatories to the Convention of Biological Diversity and its Work Program on Protected Areas, which requires governments to take action to conserve biodiversity, improve fish yields, support tourism and protect cultural values (De Fontaubert et al. 1996). Field managers of Marine Protected Areas (MPAs) can protect species and habitats by introducing fishing gear restrictions, excluding damaging activities from sensitive areas, restricting visitor numbers and modifying visitor behaviour (Hawkins and Roberts 1994; Marion and Rogers 1994; Salm and Clark 2000). Increasingly, government and funding agencies are demanding that managers demonstrate they are meeting their management objective in relation to biodiversity conservation (Hocking et al. 2000). Monitoring can help managers achieve this objective by detecting change in biodiversity and to identify cause of change (Fabricius and De’ath 2004; Underwood 1989). Only with this information can managers act decisively to prevent negative impacts, such as a decline in habitat area, or reliably conclude management is having a positive impact on, for example, abundances of exploited species.

Unfortunately, detecting and inferring cause of change to biodiversity in MPAs is not simple. Many potentially destructive human activities are legally permitted in some MPAs (Day 2002; Preen 1998) and it is not always clear how biodiversity responds to these activities (Hatcher et al. 1989). Human impact to marine biodiversity is rarely diagnostic because it cannot always be distinguished from impact caused by natural agents of disturbance (Riegl and Velimirov 1991). In addition, populations of species and distribution of habitats are naturally variable (Connell and Sousa 1983; Connell et al. 1997; Hatcher et al. 1989). Consequently, separating the effects of humans to biodiversity from natural variability is not straightforward (Green 1979; Osenberg and Schmitt 1996; Underwood 1996). Indicator variables have been promoted as a pragmatic approach for dealing with these challenges in MPAs (Pomeroy et al. 2005, 2007). Pomeroy et al. (2007) defined an indicator as “a unit of information measured over time that allows you to document changes in specific attributes of your MPA”. Used in isolation, however, indicator variables have major limitations to interpretation (Hatcher et al. 1989; Rouphael and Hanafy 2007; Underwood and Chapman 1999). Foremost are the unlikely assumptions that ecological variables are invariant prior to disturbances and change predictably in response to human activity (Marsh 1995; Oliver 1995). Hence, simply measuring an indicator variable is unlikely to allow managers to determine with confidence the cause of change.

A more scientifically robust approach to detect change in biodiversity and to infer causation is the use of formal scientific frameworks (Fabricius and De’ath 2004; Underwood 2000). There are two frameworks commonly used to monitor biodiversity in marine environments (Benedetti-Cecchi 2001). The first is point-source null hypothesis testing (hereafter significance testing) combined with a before/after, control/impact (BACI) sampling design (Green 1979; Underwood 2000). Under more controlled situations, a true experimental design involving random assignment of treatments to replicate experimental units might be available (Manly 2001). With this framework, detection of change is based on a probabilistic test used to falsify a null hypothesis. Interpretation is based on how a response variable at impact locations changed from before to after the start of a disturbance, and in relation to control locations. Within the second framework, detection is based on estimating the difference in a response variable between impact and control locations with a measure of uncertainty such as a confidence interval (CI) (Beyers 1998; Fabricius and De’ath 2004; Suter 1996). Within this framework (hereafter parameter estimation), the difference between locations can be assessed irrespective of statistical significance. Proponents of this framework recommend that the cause of impact be inferred using multiple lines-of-evidence (Beyers 1998; Fabricius and De’ath 2004; Suter 1996), which is a process of making a conclusion based on several pieces of circumstantial evidence.

In this paper, we begin by comparing the needs of MPA managers in regards to biodiversity