VIEWPOINT

Improving assessments of marine protected areas

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ABSTRACT

1. The use of experimental design and statistical analysis to evaluate the effects of marine protected areas (MPAs) is increasingly popular throughout the world.

2. However, in looking at historical approaches to MPA evaluations, flaws were identified in the execution of theoretically correct designs, as well as disconnects between the stated objectives of MPAs and those of assessment studies.

3. MPA assessments can be improved by: (1) considering the enforcement/compliance level; (2) linking explicitly the choice of indicator(s) to the MPA objectives; (3) accounting for habitat structure; (4) taking into account the age and size of the MPA; and (5) quantifying the fishing pressure outside the MPA (including possible displacement effects).

4. Neglecting social factors, using inappropriate indicators, and/or ignoring relevant covariates, carries the risk of having MPAs dismissed as an effective management tool. Societal expectations are strong that MPAs will confer benefits, and thus assessment studies need to be progressively improved using new methodologies and the best available scientific evidence. Copyright © 2009 John Wiley & Sons, Ltd.

INTRODUCTION

Marine protected areas (MPAs) are spatially explicit tools widely used for ecosystem-based management (Agardy *et al.*, 2003). They are mainly aimed at reconciling consumptive or non-consumptive human uses with conservation needs, possibly producing ecological, socio-economical and cultural benefits (Badalamenti *et al.*, 2000; Klein *et al.*, 2008; White *et al.*, 2008). A large number of MPAs have been established so far worldwide, and assessed for their effectiveness (Lubchenco *et al.*, 2007). Due to the continuous advances in ecological science and assessment methods, it is timely to consider some options to improve the evaluation of ecological effects of MPAs.

THE NEED FOR A HISTORICAL STANDPOINT

To provide a quantitative idea of the historical development of the approaches used to assess protection effects, we searched the peer-reviewed literature on empirical fish assessments of MPAs using *Web of Science*. The search string was '('marine protected area' OR 'marine reserve') AND Mediterranean AND fish'. In order to gain a proper historical perspective it was necessary to search back beyond the 1990s, thus additional information sources such as personal archives and libraries were exploited. The search focused on the Mediterranean basin, as an illustrative example: 51 peer reviewed papers were found (see Appendix). The publication rate on MPA assessment studies in the Mediterranean has progressively increased up to the present, as has the establishment of new MPAs in the basin.

Port-Cros (France) was the first Mediterranean MPA, established in 1963, for which few years after its establishment, pioneer surveys on fish (Harmelin-Vivien, 1982) provided important early data on protection effects and highlighted critical technical aspects (e.g. the novel use, at that time, of non-destructive underwater visual census). However, conclusions were not robust, due to the qualitative-observational nature of

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data collected and the use of poorly replicated sampling designs (i.e. no controls were sampled to allow comparison with the protected condition), and/or inappropriate methods of statistical analysis. This would represent a serious 'fault' undermining the validity of any investigation now, but, at that time, there was no tradition, nor solid scientific consensus, for the use of appropriate sampling designs in MPA studies (see Guidetti, 2002 and references therein).

During the 1980s, all papers ($n = 7$; see Appendix) were still observational or used inappropriate experimental designs (Figure 1). In the 1990s, about 50% of the studies ($n = 8$) used appropriate experimental designs with replicated controls to assess protection effects on fish in space and/or time (Figure 1). From 2002 to present, the number of observational studies or investigations with poor experimental designs (i.e. with unreplicated controls) represented less than 15% of the published papers ($n = 4$), with 40% of the studies ($n = 11$) adopting correctly replicated experimental designs. Around 45% of the studies ($n = 12$) used correct experimental design and additionally accounted for covariates that could potentially confound with the effects of protection (Figure 1). These assessment studies were first published in regional journals, with low or no impact factors. Over time, some studies were published in international journals, covering a broader range of impact factors. The identified progress towards improved studies could therefore have been driven by both the continuous advances in ecological science leading to improved assessments and the increased rigour in reviews and publication standards.

Published studies that contrasted one protected with a single fished (control) location, or one location for each level of full, partial or null protection were common ($n = 11$), across all years examined. These represent typical cases of pseudoreplication (Hurlbert, 1984), where the effects of protection cannot be logically separated from other sources of variability. A technical definition of an MPA could be 'one or more locations protected by a set of regulations based on a goal or goals to induce expected changes in some variable(s) (e.g. increased mean abundance and/or size of fish) from before to after their enforcement, in comparison with a number of unprotected locations (used as multiple controls)'. Based on the experimental design theory aimed at assessing human impacts (Underwood, 1993), the ideal sampling design for MPA assessments should thus include temporal replication before and after its establishment and spatial replication within and outside (i.e. before-after-control-impact [BACI] design).

Scientists are not often in the position to use the ideal design (e.g. when the MPA is already established, or when funds are limited to allow temporal and/or intense spatial replication). Nevertheless, there is the chance to use progressively deconstructed sampling designs with at least replicated controls, such as after-control-impact (ACI) designs, with temporal and spatial comparisons after the MPA establishment, or control-impact (CI) designs, with only spatial comparisons (Osenberg et al., 2006).

An increasing proportion of papers in the last decade adopted appropriate designs (Figure 1). However, their use alone does not insure against the wrong conclusions being drawn about the effects of MPAs, possibly leading to inappropriate management measures. Besides this increased attention to formal experimental designs and related statistical analyses, other substantial issues, which are equally important to obtain reliable outcomes on the effects of protection, received little attention. Such issues include: (1) accounting for the socio-cultural context; (2) paying better attention to the choice of appropriate indicators; and (3) adapting sampling and analytical designs to the MPA context. These are developed and discussed in the next section.

Owing to the large number of studies on MPAs and to the need to search within libraries and personal archives, the historical analysis developed above was focused on the Mediterranean Sea. However, the way research is conducted within the Mediterranean is not historically different from MPA evaluations in other regions. In the 1980s, the situation was almost the same in relation to coral reefs (Russ, 1985), and then gaps were progressively identified regarding social considerations (Christie et al., 2003), indicators identification (Pelletier et al., 2005) and sampling design and statistical issues (Osenberg et al., 2006). Thus the historical trends and
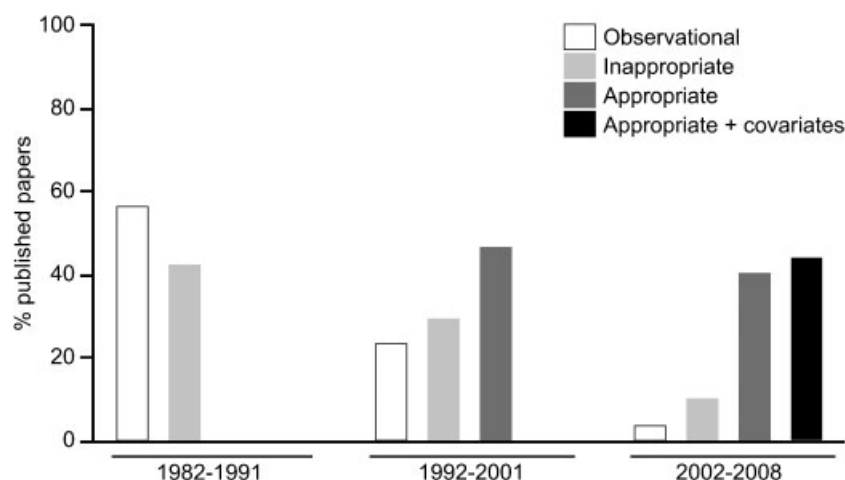

Figure 1. Percentage of Mediterranean MPA assessment studies published from the 1980s to present. Studies were categorized into four groups according to the methods used and/or the nature of the data collected: (1) observational, where data were not collected according to any experimental design; (2) inappropriate, where data were collected using an unreplicated experimental design; (3) appropriate, where a correctly replicated experimental design was used; and (4) appropriate with covariates, same as (3) in addition considering covariates.

associated gaps identified here for the Mediterranean are likely to be transferable to other regions of the globe.

CRITICAL GAPS IN MPA ASSESSMENT STUDIES

First, the social factors are seldom explicitly considered or quantitatively evaluated (Lundquist and Granek, 2005). In a recent, well-designed study, where no significant effects of protection were found, the authors recognized that protection was not enforced and fishing continued to occur within the MPA (Lipej *et al.*, 2003). Without enforcement and compliance, an MPA is just a paper park and no protection effects should be expected. Actual enforcement and compliance, and not the formal MPA establishment, must be considered as the true starting point of protection (Guidetti *et al.*, 2008). Besides, poor MPA site selection and design or lack of community involvement undermine public support for MPAs and create a false sense of security that conservation is actually being achieved (Agardy *et al.*, 2003; Christie *et al.*, 2009; Mascia and Claus, 2009).

Second, the choice of the indicators should be clearly linked to the MPA goal(s), the hypothesis tested and the pre-existing knowledge (Niemi and McDonald, 2004). For example, species richness, which seldom responds to protection (Pelletier *et al.*, 2005), should be used only when the specific MPA goal is to enhance biodiversity. On the other hand, indicators that perform well in responding to cessation of fishing (e.g. density and size of commercial fish; Russ, 2002) should only be used when the specific MPA goal is the recovery of target populations.

Third, habitat structure (both heterogeneity and complexity) affects indicators of the response to protection (García-Charton and Pérez-Ruzafa, 1999). Since MPAs are often established in complex and heterogeneous habitats (García-Charton *et al.*, 2004), we need to distill the effects of protection from those attributable to habitat features. Experimental designs with multiple controls are partly used to partition the natural variability (due in part to habitat) from the variability due to protection measures. However, even with replicated designs, assessing if a positive response is related to protection or to an intrinsic structural feature of the protected area can be significantly improved by measurements of habitat covariates.

Fourth, MPA size and age may exert a strong influence on the fish response to protection. A strong cumulative response to protection can only be expected for long established MPAs (Micheli *et al.*, 2004; Claudet *et al.*, 2008), suggesting that the evaluation of MPA effectiveness in re-stocking exploited populations or preserving biodiversity should be framed in a temporal context. In addition, MPA size-dependency (Claudet *et al.*, 2008) should also be taken into account in the evaluation process as MPA effectiveness is increased with increased size of the no-take zone and decreased size of the buffer zone. Assessments should thus take into account the sizes of these two zones.

Fifth, within-MPA conditions are generally much better quantified than conditions at control locations, usually summarily described as 'fished'. Yet, the effectiveness of an MPA is assessed relative to external controls. Any conclusion drawn about the effectiveness of an MPA depends on the state of the population in the control locations. When looking only at relative differences between control and protected locations, one MPA could appear more effective than another simply because its surrounding fishing grounds are more intensively fished. Quantifying the actual fishing pressure occurring outside an MPA, the potential spillover across MPA boundaries, as well as human behaviour in control areas (e.g. displacement effects) is therefore essential for an appropriate assessment of MPA effectiveness (Castilla, 1999; Stelzenmüller *et al.*, 2008; Mascia and Claus, 2009).

In conclusion, even when using appropriately replicated sampling designs, failing to properly assess effects of protection due to neglecting social factors, using inappropriate indicators, or ignoring relevant covariates, carries the risk of having MPAs dismissed as an effective management tool. Decision makers, in fact, would be misled to believe that the price paid in terms of restrictions to human uses is not equal to or higher than the ecological and socio-economical benefits realized (Fisher *et al.*, 2008). Societal expectations are strong that MPAs will confer benefits, and thus assessment studies need to be progressively improved using new methodologies and the best available scientific evidence.

REFERENCES

Agardy T, Bridgewater P, Crosby MP, Day J, Dayton PK, Kenchington R, Laffoley D, McConney P, Murray PA, Parks JE, Peau L. 2003. Dangerous targets? Unresolved issues and ideological clashes around marine protected areas. *Aquatic Conservation: Marine and Freshwater Ecosystems* **13**: 353–367.

Badalamenti F, Ramos AA, Voultsiadou E, Sánchez-Lizaso JL, D'Anna G, Pipitone C, Mas J, Ruiz-Fernandez J, Whitmarsh D, Riggio D. 2000. Cultural and socio-economic impacts of Mediterranean marine protected areas. *Environmental Conservation* **27**: 110–120.

Castilla JC. 1999. Coastal marine communities: trends and perspectives from human-exclusion experiments. *Trends in Ecology & Evolution* **14**: 280–283.

Christie P, McCay BJ, Miller ML, Lowe C, White AT, Stoffle R, Fluharty DL, Talaue McManus L, Chuenpagdee R, Pomeroy C, Suman DO, *et al.* 2003. Toward developing a complete understanding: A social science research agenda for marine protected areas. *Fisheries* **28**: 22–26.

Christie P, Pollnac R, Oracion E, Sabonsolin A, Diaz R, Pietri D. 2009. Back to basics: an empirical study demonstrating the importance of local-level dynamics for the success of tropical marine ecosystem-based management. *Coastal Management* **37**: 349–373.

Claudet J, Osenberg CW, Benedetti-Cecchi L, Domenici P, García-Charton J-A, Pérez-Ruzafa Á, Badalamenti F, Bayle-Sempere J, Brito A, Bulleri F, *et al.* 2008. Marine reserves: size and age do matter. *Ecology Letters* **11**: 481–489.

Fisher B, Turner K, Zylstra M, Brouwer R, Groot R, Farber S, Ferraro P, Green R, Hadley D, Harlow J, *et al.* 2008.

Ecosystem services and economic theory: integration for policy-relevant research. *Ecological Applications* **18**: 2050–2067.

García-Charton J-A, Pérez-Ruzafa Á. 1999. Ecological heterogeneity and the evaluation of the effects of marine reserves. *Fisheries Research* **42**: 1–20.

García-Charton J-A, Pérez-Ruzafa Á, Sánchez-Jerez P, Bayle-Sempere J, Reñones O, Moreno D. 2004. Multi-scale spatial heterogeneity, habitat structure, and the effect of marine reserves on Western Mediterranean rocky reef fish assemblages. *Marine Biology* **144**: 161–182.

Guidetti P. 2002. The importance of experimental design in detecting the effects of protection measures on fish in Mediterranean MPAs. *Aquatic Conservation: Marine and Freshwater Ecosystems* **12**: 619–634.

Guidetti P, Milazzo M, Bussotti S, Molinari A, Murenu M, Pais A, Spano N, Balzano R, Agardy T, Boero F, *et al.* 2008. Italian marine reserve effectiveness: does enforcement matter? *Biological Conservation* **141**: 699–709.

Harmelin-Vivien M. 1982. Ichtyofaune des herbiers de posidonies du parc national de Port-Cros. I: composition et variations spatio-temporelles. *Travaux Scientifiques du Parce de Port-Cros* **8**: 69–92.

Hurlbert SH. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* **54**: 187–211.

Klein CJ, Chan A, Kircher L, Cundiff AJ, Gardner N, Hrovat Y, Scholz A, Kendall BE, Airame S. 2008. Striking a balance between biodiversity conservation and socioeconomic viability in the design of Marine Protected Areas. *Conservation Biology* **22**: 691–700.

Lipej L, Bonaca MO, Siskko M. 2003. Coastal fish diversity in three marine protected areas and one unprotected area in the gulf of Trieste (northern Adriatic). *Marine Ecology* **24**: 259–273.

Lubchenco J, Gaines S, Grorud-Colvert K, Airamé S, Palumbi S, Warner R, Simler Smith B, Alcala A, Branch G, Brumbaugh D, *et al.* 2007. *The Science of Marine Reserves*, 2nd edn, International Version. PSCO: Corvallis, OR. http://www.piscoweb.org.

Lundquist CJ, Granek EF. 2005. Strategies for successful marine conservation: integrating socioeconomic, political, and scientific factors. *Conservation Biology* **19**: 1771–1778.

Mascia MB, Claus CA. 2009. A property rights approach to understanding human displacement from protected areas: the case of marine protected areas. *Conservation Biology* **23**: 16–23.

Micheli F, Halpern BS, Botsford LW, Warner RR. 2004. Trajectories and correlates of community change in no-take marine reserves. *Ecological Applications* **14**: 1709–1723.

Niemi GJ, McDonald ME. 2004. Application of ecological indicators. *Annual Review of Ecology, Evolution, and Systematics* **35**: 89–111.

Osenberg CW, Bolker BM, White J-SS, St. Mary CM, Shima JS. 2006. Statistical issues and study design in ecological restorations: lessons learned from marine reserves. In *Foundations of Restoration Ecology*, Falk D, Palmer N, Zedler J (eds). Ecological Restoration International; 280–302.

Pelletier D, García-Charton J-A, Ferraris J, David G, Thébaud O, Letourneur Y, Claudet J, Amand M, Kulbicki M, Galzin R. 2005. Designing indicators for assessing the effects of marine protected areas on coral reef ecosystems: a multidisciplinary standpoint. *Aquatic Living Resources* **18**: 15–33.

Russ GR. 1985. Effects of protective management on coral reef fishes in the central Philippines. In *Proceedings of the Fifth International Coral Reef Congress*, Tahiti, 27 May – 1 June 1985, Gabrie C, Salvat B (eds). Vol. 4, Symposia and Seminars (B); 219–224.

Russ GR. 2002. Marine reserve as reef fishery management tools: yet another review. In *Coral Reef Fishes: Dynamics and Diversity in a Complex Ecosystem*, Sale PF (ed.). Academic Press; 421–443.

Stelzenmüller V, Maynou F, Bernard G, Cadiou G, Camilleri M, Crec'hriou R, Criquet G, Dimech M, Esparza O, Higgins R, *et al.* 2008. Spatial assessment of fishing effort around European marine reserves: implications for successful fisheries management. *Marine Pollution Bulletin* **56**: 2018–2026.

Underwood AJ. 1993. The mechanics of spatially replicated sampling programmes to detect environmental impacts in a variable world. *Australian Journal of Ecology* **18**: 99–116.

White C, Kendall BE, Gaines S, Siegel DA, Costello C. 2008. Marine reserve effects on fishery profit. *Ecology Letters* **11**: 370–379.

APPENDIX

Supplementary data associated with this article can be found in the online version of this article