

The Science of Marine Reserves: A Synthetic Analysis of Global Effects and a New Communication Tool for Latin America and the Caribbean

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ABSTRACT

Marine reserves are an increasingly popular tool to achieve a variety of marine conservation goals. Scientific studies of marine reserves are accumulating rapidly, providing data on the biological impacts of reserve protection for a wide variety of geographic locations and organisms. By conducting a comprehensive survey of peer-reviewed scientific literature, we compiled a global database of studies documenting biological effects (density, biomass, individual size, or species diversity) from fully protected marine reserves. Our meta-analysis demonstrates that marine reserves have strong, positive effects on the density and biomass of organisms, the mean size of many species, and the community diversity within reserve borders. Trophic level and commercial importance also influence the strength of these effects. We show that marine reserves have similar positive impacts in both temperate and tropical ecosystems. A new educational booklet, *The Science of Marine Reserves*, incorporates this and other recent scientific findings about marine reserves into an easily understood format for the general public. The Latin American and Caribbean version of the booklet uses examples from the region and from around the globe to demonstrate key concepts about marine reserves. Important topics include the results of the global meta-analysis, demonstrating positive effects inside reserves, as well as effects outside reserves and considerations for marine reserve design. This booklet is intended to facilitate communication about the biological impacts of marine reserves among scientists, interest groups, NGOs, academic institutions, and management agencies. The booklet is now freely available. For more information, please visit: <http://www.piscoweb.org/outreach/pubs/reserves>

KEY WORDS: Marine reserve, meta-analysis, marine protected area

La Ciencia de las Reservas Marinas: Una Síntesis de Sus Efectos Globales y una Nueva Herramienta para su Divulgación en Latinoamérica y el Caribe

El uso de reservas marinas, como herramienta de gestión para conseguir distintos objetivos en el manejo y conservación de los recursos marinos, se ha incrementado en los últimos años. Los estudios científicos se están acumulando rápidamente, proporcionando datos sobre los impactos biológicos de la protección mediante reservas para una gran variedad de lugares geográficos y organismos. A través de una búsqueda exhaustiva en la literatura científica 'peer-reviewed' compilamos una base de datos global de estudios que documentan los efectos biológicos (densidad, biomasa, tamaño individual, o diversidad de especies) de reservas marinas completamente protegidas. Este 'meta-análisis' demuestra que las reservas marinas tienen efectos fuertes y positivos en la densidad y biomasa de organismos, el tamaño promedio de varias especies, y la diversidad de la comunidad dentro de las reservas. El nivel trófico y la importancia económica también influyen en la magnitud de estos efectos. Demostramos también que los efectos de las reservas marinas son similares tanto en ecosistemas templados como tropicales. Una nueva herramienta educativa, la libreta *La Ciencia de las Reservas Marinas*, resume éstas y otras conclusiones científicas sobre las reservas marinas en lenguaje y formato sencillo para el público en general. Como temas importantes se incluyen los resultados del meta-análisis global, demostrando los efectos positivos tanto dentro de las reservas como fuera de sus límites, y consideraciones para el diseño de reservas marinas. La libreta servirá para facilitar la comunicación sobre los impactos biológicos de las reservas marinas entre científicos, ONGs, instituciones académicas, agencias de manejo de recursos naturales y grupos de interés. La libreta estará disponible de forma gratuita en los primeros meses de 2008. Para más información, por favor visitar: <http://www.piscoweb.org/outreach/pubs/reserves>.

PALABRAS CLAVES: Reservas marinas, meta-análisis, área protegida marina

INTRODUCTION

In recent years, marine reserves have become a major research focus of marine ecology, fisheries science, and conservation biology. Part of this interest results from the growing evidence that many traditional methods of marine resource management (i.e. maximum sustained yield, single species management, etc.) have resulted in the collapse of many stocks of key commercial species (Roughgarden and Smith 1996, Myers *et al.* 1997, Myers and Worm 2003, Essington *et al.* 2006). Managers have therefore increasingly turned to marine reserves, defined here as fully protected, no-take zones, to address a variety of management goals, such as stock enhancement or

biodiversity conservation (Allison *et al.* 1998, Russ 2002, Gaylord *et al.* 2005). It is generally assumed that marine reserves have a number of effects on biological communities living inside of them. In a review of the marine reserve literature through 1999, Halpern (2003) demonstrated that marine reserves have a positive effect on a number of biological parameters, including increases in density, size, and biodiversity. Despite this thorough analysis, there is still some disagreement about the strength and the generality of the impact of marine reserves. Some of this skepticism may be justified since the original analysis was somewhat limited by the number of published studies on marine reserves at the time. Since 1999, there

have been over 85 studies published on the empirical effects of marine reserves on some aspect of the biology of organisms living within reserves, in addition to a variety of reviews of more specific aspects of marine reserves (e.g. Russ 2002, Micheli *et al.* 2004, Claudet *et al.* 2008). In this paper, we use an updated synthesis (Lester *et al.* in review), which includes all works published through 2006 to investigate a broader range of research questions about the effects of marine reserves.

We can address a number of questions about marine reserves. These include the strength of effects of marine reserves on species-level attributes, such as density and biomass, and how these effects vary for different taxonomic, trophic, and functional groups, and intensity of exploitation. We summarize much of this and other relevant information on marine reserves in a new educational booklet, *The Science of Marine Reserves*, designed for scientists, interest groups, NGOs, academic institutions, and management agencies. The Latin American and Caribbean version has been published in both Spanish and English and uses case studies and examples from that region and worldwide to demonstrate key concepts about marine reserves in clear, concise language, and with simple and informative graphics. The booklet is freely available as a downloadable pdf or in hard copy. For more information, please visit: <http://www.piscoweb.org/outreach/pubs/reserves>

METHODS

For the analyses presented here, we used the data from a recent meta-analysis conducted by Lester *et al.* (in review), which examined the overall responses of four biological measures (density, biomass, mean size, and diversity) in temperate and tropical ecosystems. In this paper, we focus on the effects of trophic group (herbivore, filter-feeder, invertebrate-feeder, and piscivore) and fishery importance (none, aquarium trade, minor commercial, and major commercial) on changes in density for fishes and invertebrates.

The Lester *et al.* (in review) dataset included only studies published in peer-reviewed, scientific journals, and was compiled according to the following methods. Because the review of Halpern (2003) included most studies published before 1999, we searched the online database “Web of Science” (<http://portal.isiknowledge.com>) for the term “marine reserve.” This search returned over 300 citations. From this list, we included only those studies that examined fully protected marine reserves (e.g. no-take zones) and excluded studies that examined marine protected areas that only included partial protection or protection of some species. In addition, we only included studies that compared a reserve to a non-reserve, such as a similar control site or the same area sampled before and after protection. Finally, we only used studies that empirically and quantitatively measured

some aspect of the main biological responses of interest (density, biomass, mean size of individual species, or diversity) in the both in the reserve site and in the comparison site. This procedure generated a list of over 85 additional studies and around 300 additional unique species-site combinations.

For each data point (either a species or a community response), we calculated the proportional change by dividing the non-reserve response by the reserve response, and converted this to a percentage by subtracting 1. For example, a species whose density was 20 in a control site and 50 in a reserve site yield a proportional increase of 2.5 and a percentage increase of 150 %. For overall measurements, we calculated the mean for each biological response across all species (when species-level data were given) for a given study in a given reserve and then calculated the mean for each response in a given reserve in those cases where a reserve was studied in multiple publications. For species-level responses, we calculated the mean response for an individual species when that species was examined in multiple reserves or multiple studies. We assigned each species to specific taxonomic groups, trophic groups, functional groups, and fishery importance based on information from the literature, from guidebooks, and scientific databases (e.g. Fishbase; www.fishbase.org). We then computed means for each biological response, using data from individual reserves as replicates.

RESULTS AND DISCUSSION

Using this dataset, other work found strong positive effects of marine reserve protection on density, biomass, size and diversity of marine organisms (PISCO 2008, Lester *et al.* in review). Our more detailed analysis of these data revealed similar strong positive effects on density for different taxa, different trophic levels, and different levels of exploitation between reserve and non-reserve areas. In general, higher predators (e.g. piscivores and invertebrate feeders) responded more strongly to reserve protection, showing increases in density between 400 % and 1000 %, while lower trophic groups increased between 20 % and 200 % (Figure 1). However, because of the large variance in each group, none of the differences among groups were significant for either fishes or invertebrates. When grouping species by fishing intensity, some differences in groups emerge. Not surprisingly, species of major commercial importance showed dramatic increases in density (around 600 %) in reserves for both fishes and invertebrates, while those species that are unfished showed increases in density of only around 50 % in reserves. These differences in groups were significant for fishes (ANOVA, $df = 3,73$, $F = 3.92$, $p = 0.01$) and trending positive but non-significant for invertebrates (ANOVA, $df = 2, 38$, $F = 2.17$, $p = 0.10$).

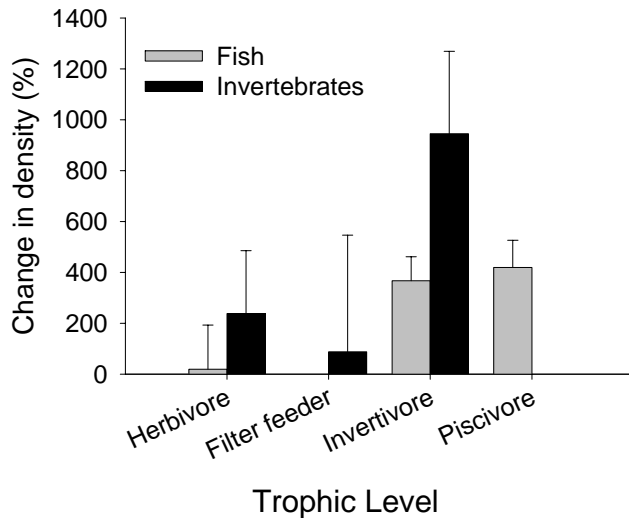


Figure 1. Changes in density (%) of taxa from different trophic levels in response to marine reserve protection.

Our results demonstrate that marine reserves worldwide have strong, positive effects on a wide variety of biological response measures relative to non-reserve areas. These increases are found in a variety of geographical locations and climatological regions worldwide. We found that changes in density varied with taxonomic group, trophic level, and importance to fisheries. Species at the highest trophic levels and species most important to commercial fisheries also responded better to marine reserve protection. We would expect that the most heavily fished species might respond best to reserve protection, but some of these highly commercial species as well as top predators tend to be longer lived (Figure 2).

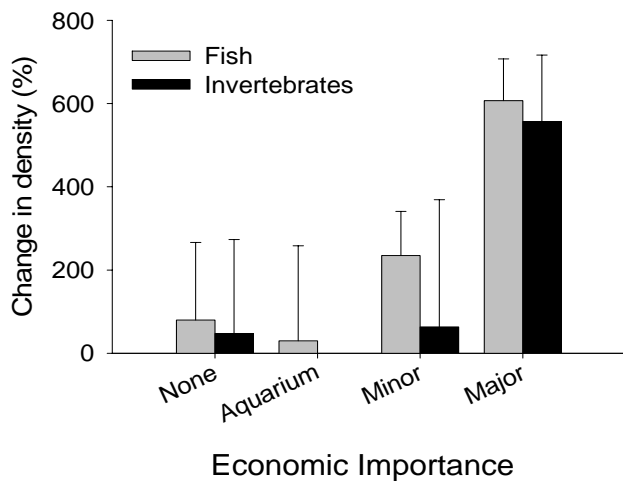


Figure 2. Changes in density (%) of fish and invertebrate species in response to marine reserve protection based upon their economic importance.

Our findings clearly support the often-made assertions that marine reserves “work” when goals of marine reserves include increasing a number of biological responses in those reserves. Marine reserves are extremely effective in increasing density, biomass, and average size of a variety of species with different life histories. Reserves also appear to increase local species richness (Lester *et al.* in review).

These main findings, as well as additional information on marine reserve science, has been synthesized in a series of new booklets entitled “The Science of Marine Reserves” (PISCO 2008). These booklets are designed to convey the science of marine reserves, including the positive effects inside and outside reserves, and considerations for designing and implementing marine reserves in clear and concise language using simple but informative graphics. The Latin American and Caribbean version of the booklet, published in English and Spanish, uses examples and case studies both from the region and worldwide to illustrate key concepts about marine reserves. The booklets are designed to facilitate discussion about marine reserves among scientists, policy makers, managers, NGOs and the general public. The booklets are now freely available. For more information, please visit: <http://www.piscoweb.org/outreach/pubs/reserves>

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