Marine protected areas:

a global exploration of their quantity and quality

by

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Abstract

Expansion in the number and extent of marine protected areas (MPAs) has been dramatic during the past century, but coverage remains limited and there are concerns that many MPAs are failing to meet their objectives. After updating the global database of MPAs maintained by the *Sea Around Us*, new estimates of global marine protected area were calculated and revealed a degree of progress towards protecting at least 10% of the global ocean by 2020. It is estimated that more than 6,000 MPAs covering 3.27% of the world's oceans (~11.9 million km^2) have been designated to date. The protection these MPAs offer is generally weak with about one-fifth (~2.2 million km^2) of their combined area designated as no-take (i.e., where fishing and other extractive activities are prohibited). Additional large tracts of ocean will need to be protected to reach the 10% target, and hypothetical scenarios for such expansion were investigated. To improve understanding of the likely conservation effectiveness of MPAs, trends in their management effectiveness were explored. Results from a self-administered survey questionnaire, distributed to managers and other experts associated with a random sample of MPAs from around the world, revealed a wide range of MPA management effectiveness across different socioeconomic contexts. The results were intended to inform a model of MPA management effectiveness based on socioeconomic, governance and other contextual variables, but no clear relationships between contextual variables and MPA management effectiveness were identified. Overall, the survey findings confirmed results of other studies: while some MPAs are well supported with funding, staff and equipment, others lack even basic management elements. Additional research is essential to understanding the issues preventing MPAs from meeting their objectives, including effectively contributing to biodiversity conservation.

Preface

The research question and methodological design for this thesis were developed collaboratively by my supervisor, Dr Daniel Pauly, and me. I collected most of the data for this thesis, although some of the updates to the MPA database were contributed by other researchers at the *Sea Around Us*. I also carried out the data analysis for this thesis, with the exception of the calculation of MPA coverage for the US and Australia (Chapter 2), and the distance of each respondent MPA from the coast (Chapter 3), which Chris Hoornaert assisted with.

The survey reported in Chapter 3 was approved by the UBC Behavioural Research Ethics Board (certificate number H13-00472, project title “Global trends in marine protected area effectiveness”).

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AIC	Akaike information criterion
AICc	Second-order Akaike information criterion
CBD	Convention on Biological Diversity
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
EPI	Environmental Performance Index
EEZ	Exclusive economic zone
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
HDI	Human Development Index
IUCN	International Union for Conservation of Nature
NOAA	National Oceanic and Atmospheric Administration
NGO	Non-governmental organization
MDS	Multiple-dimensional scaling
METT	Management Effectiveness Tracking Tool
MPA	Marine protected area
MPACS	Marine Protected Area Classification System
UNESCO	United Nations Educational, Scientific and Cultural Organization
UK	United Kingdom
UN	United Nations
US	United States
WCPA	World Commission on Protected Areas

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Chapter 1: Introduction

1.1 Status of MPAs globally

Human activities have had – and continue to have – deep, far-reaching and compounding impacts on marine ecosystems, transforming marine populations and habitats, and producing fundamental changes to ecosystem structure and function (e.g., Pauly *et al.* 1998; Jackson *et al.* 2001; Halpern *et al.* 2008). In response, various management and protection strategies have been used to mitigate these effects, including input and output controls on extractive activities, regulations for non-extractive activities, active restoration efforts and integrated coastal management. Among them are marine protected areas (MPAs), considered a key tool for marine conservation (Pauly *et al.* 2002; Fox *et al.* 2012).

An MPA can be broadly defined as any area of ocean that is more protected than the surrounding marine environment. Recently, there has been more emphasis and research focus on MPAs with strict, no-take[1] protection, prohibiting all extractive activities, including but not limited to fishing (Jones 2014). The most widely applied definition of MPA, developed by the International Union for Conservation of Nature (IUCN), lies somewhere in between: "Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Kelleher 1999). Although this definition has been superseded by a new one encompassing all protected areas[2] (Dudley 2008), it retains its utility due to its specific recognition of the marine environment.

Within this general definition lies a great variety of types of MPAs in terms of their objectives and the strictness of their protection. It is incorrect to assume, as some people do, for example, that all MPAs prohibit fishing. This is not the case; some MPAs protect only single species and others have regulations concerning primarily only oil and gas development. What exactly is included and excluded by MPA

[1] No-take MPAs are also referred to as marine reserves.

[2] "A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley 2008).

definitions is the subject of continual debate and discussion (Dudley 2008; Day *et al.* 2012; Eddy 2013; Spalding *et al.* 2013).

The variety of MPAs is further illustrated by the "plethora of terms" used to label and describe them (Jones 2002), without much consistency at the international level. One system for classifying MPAs according to a standard set of criteria, the IUCN Protected Area Categories, has had limited success in the marine environment – they have been misapplied for an estimated 50% of MPAs (Day *et al.* 2012). To assist in their correct application, new guidelines aiming to clarify their use in the marine environment have recently been released (Day *et al.* 2012). However, as the IUCN categories are designed to be applied according to the objectives of the protected area, rather than the regulations in place (or indeed the regulations that are enforced), there remains a disconnect between management intentions and actions, and hence the categories cannot be used reliably as a proxy for strictness of protection (e.g., Guarderas *et al.* 2008; Fitzsimons 2011; Robb *et al.* 2011; Marinesque *et al.* 2012). For example, MPAs (correctly) classified as category I are considered to be incompatible with extractive activities, although the presence or absence of extractive activities should not be a priority when assigning a management category (Day *et al.* 2012). (Strict protection as a management action should then follow from this stated objective.) A new classification system, the Marine Protected Area Classification System (MPACS), has been proposed as a way to classify levels of biodiversity protection in MPAs (Al-Abdulrazzak and Trombulak 2012). MPACS takes into consideration seven criteria, including the MPA's stated purpose, protection level, effect on ecological communities and connection to human communities.

Regardless of their diversity (or because of it) MPAs are seen as a valuable tool for conserving marine ecosystems. And while protected areas alone are not adequate for nature conservation, they are a cornerstone of international conservation strategies. One of the first global targets for MPAs was defined at the 2002 World Summit on Sustainable Development where a commitment was made to establishing a representative network of MPAs by 2012 (United Nations 2002). In 2003, at the IUCN World Parks Congress, countries committed to protecting 20-30% of each marine and coastal habitat type by 2012 (IUCN 2003). More recently, the Conference of the Parties to the Convention on Biological Diversity (CBD) adopted the Aichi Targets. Target 11 commits countries to the following:

> "By 2020, at least 17 per cent of terrestrial and inland water areas, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are

conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes." (CBD 2010)

Progress towards meeting these targets has been slow. Mostly the goals have not been met and the deadlines have been extended (Wood et al. 2008; Toropova et al. 2010; Wood 2011; Veitch et al. 2012). For example, the Aichi Target 11 for 10% MPA coverage adopted in 2010 remained largely unchanged from the coverage target adopted in 2006 – although there is a new emphasis in wording and focus (TNC 2012).

Estimates taken from Spalding *et al.* (2013) indicate that MPAs cover more than 8 million km^2, extending over 2.3% of the world's oceans and 5.5% of the area within exclusive economic zones (EEZs). This coverage is highly uneven and driven by a small number of very large MPAs (each bigger than 100,000 km^2), most of which have been designated during the past five years, far away from human population centres. MPA coverage is greater in EEZs than the high seas (Spalding *et al.* 2013) and in more economically developed countries' waters than in less economically developed countries' waters (Marinesque *et al.* 2012). In 2008, only 0.08% of the global ocean area was estimated to be within no-take MPAs (Wood *et al.* 2008).

Yet simply looking at the numbers and extent of MPAs is misleading in terms of assessing conservation effectiveness, as these results do not provide insights into what is happening on the water in terms of MPA protection levels and management effectiveness. To get an indication of the protection levels being realized, Marinesque *et al*. (2012) assessed levels of MPA protection according to IUCN management categories (which are unreliably applied, as noted above). The authors found that most MPAs do not have an assigned IUCN management category and that the four categories (of six) that offer the highest levels of protection were largely under-utilized and never accounted for more than 10% of the area protected.

Simple metrics, such as MPA coverage and IUCN management categories, can mask the influence of variable protection levels and management effectiveness, which might mean that even less than the 2.3% of the oceans that lie within MPAs are being effectively protected or realizing conservation outcomes. As Wood *et al.* (2008) pointed out in their assessment of progress towards global marine protection targets, their coverage estimates represent "best case scenarios" and "it should not be assumed that (1) the process that created these marine protected areas also provided mechanisms for regulating human activities in the area, (2) where regulatory mechanisms are in place they are all being implemented, or (3) they are implemented effectively."

1.2 Assessing protected area effectiveness

The effectiveness of protected areas, marine and terrestrial, can be described and assessed in different ways, leading to confusion and lack of comparability among studies. In order to understand the different approaches, they can be grouped into three general types focusing on the effectiveness of different parts of the protected area implementation process: (1) designation, (2) management, and ultimately, (3) conservation outcomes (Figure .1.1). Within each of these three groups, assessments differ in their methodology, geographic scale, topical scope and level of detail, with concomitant trade-offs in resource-requirements.

1.2.1 Designation

At their broadest level, protected area effectiveness assessments consider metrics such as the global extent of protected area. In this context, protected area coverage is not simply a conservation goal, but a metric for conservation success too. Indicators include spatial coverage and representativeness of protected areas (in capturing endangered species and different ecosystems or habitat types, for example), and related statistics, which in the case of MPAs include connectivity and proportion of EEZ protected (e.g., Chape *et al.* 2005; Wood *et al.* 2008; Spalding *et al.* 2013). One can think of the assessments in this group as measuring the effectiveness of protected area *designation*. This is because they generally do not take into account the degree of protection these protected areas aim to afford the natural values within their bounds; nor do they consider the outcomes of protected areas in terms of conservation and restoration of biodiversity.

Yet the data for even these relatively superficial metrics of MPA coverage have their problems. The number and extent of designated protected areas is in a constant state of flux with new ones continually being created (thousands per year; IUCN and UNEP-WCMC 2012) as well as degazetted, downsized and downgraded (Mascia and Pailler 2011). And depending on how (marine) protected area is defined, coverage statistics can change drastically. Simply including the Southern Ocean area (35 million km^2)

managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) in calculations of global MPA coverage, for example, would instantly expand global marine protected area to beyond the 10% target.[3]

1.2.2 Management

Protected area management effectiveness evaluation considers protected area effectiveness in terms of the actions of management authorities in implementing protected areas and achieving their objectives. Generally, these types of assessments aim to evaluate "how well [a] protected area is being managed – primarily the extent to which it is protecting values and achieving goals and objectives" (Hockings *et al.* 2006). They are usually conducted at the site level, but also at the network or regional level. Depending on their scope, such assessments can go beyond telling us whether protected areas are being managed effectively or not; they can identify failures, successes and why they happen, and how management can be improved.

Many methodologies for assessing protected area management effectiveness have been developed. They range from rapid, scorecard-type, qualitative systems to detailed, lengthy evaluations involving stakeholder group discussions and collection of monitoring data. The Management Effectiveness Evaluation Framework developed by the IUCN and its World Commission on Protected Areas (WCPA; Hockings *et al.* 2000; Hockings *et al.* 2006) provides the basis for many of these methodologies. This framework, which is not itself a management assessment methodology, but rather a framework for developing such assessment systems, breaks up the management process into six sections each of which is considered part of successful protected area management (Hockings *et al.* 2006). The six elements are

- Context: status of the protected area and its environment, including values, threats, opportunities and other external influences (e.g., the political and socioeconomic context);
- Planning: process of planning and designing the protected area to conserve values and mitigate threats (e.g., protected area size and shape, and management planning);
- Inputs: allocation of resources needed to conduct management (e.g., availability and application of staff, funding and equipment);

[3] The CCAMLR area is considered a category IV protected area (Day *et al.* 2012).

- Process: the way in which management is conducted (e.g., enforcement, staff training, maintenance);
- Outputs: delivery of goods and services (e.g., work output and achievement of management plan);
- Outcomes: achievement of protected area objectives (e.g., recovery of species; accrual of socio-economic benefits; integrity of cultural sites) – the ultimate measure of management effectiveness in this context (Hockings *et al.* 2006).

The effectiveness of protected area management rests with the achievement of that protected area's specific objectives, whatever they might be. Although one should be aware that using such a metric could lead to the situation of rewarding protected areas with modest goals (Jones 2002). Therefore, if the goal is to evaluate progress towards conservation outcomes, assessments of management effectiveness should be combined with some measure of the area's conservation objectives, such as its IUCN management category.

Closely related to the assessment of management effectiveness is the concept of assessing MPA governance, which includes management policies but goes further to also consider government institutions and context (Rossiter and Levine 2014). Jones and colleagues have developed a framework for systematically assessing and comparing governance of individual MPAs, which has been applied to 20 case studies around the world (Jones *et al.* 2011; Jones *et al.* 2013a). Through the analysis of these case studies, they have been able to identify different approaches to MPA governance with common strengths and weaknesses (Jones *et al.* 2013b).

1.2.3 Conservation outcomes

These assessments concentrate on the maintenance and recovery of protected area values on the ground (or 'in the water'). Such metrics include the health of animal and plant populations, and habitat and ecological processes, as well as threat reduction. Assessments of conservation outcomes can range in scale from measuring the genetic diversity of a single population to gauging ecosystem service delivery. These measures of conservation outcomes, while more resource-intensive to assess than implementation (design and management) activities, provide the ultimate test of protected area conservation effectiveness. Often the links between protected area implementation (design and management) and conservation outcomes are assumed (Kapos *et al.* 2008). This is generally because it is easier to assess implementation activities than it is to assess conservation outcomes (Carter *et al.* 2011).

Protected area outcomes are not limited to conservation benefits; there are also economic and social benefits that can be assessed (Pollnac *et al.* 2001; Christie 2004). Conservation of nature is, however, a defining objective of all protected areas (Dudley 2008). As Gaston *et al.* (2008) note, “Literature on management of protected areas tends to focus on performance against the original justifications for the designation of a site as protected, whereas the conservation biology literature at large tends to take a broader perspective, asking how well protected areas perform in attaining conservation goals regardless of the grounds for their establishment.” When an assessment of outcomes reveals that an MPA is failing to meet its objectives or broad conservation goals, this could indicate a failing of MPA design or management, or the influence of external threats (Figure 1.1).

While the above three groupings – designation, management and conservation outcomes – allow us to think systematically about the different ways of assessing protected area effectiveness, they are not absolute or mutually exclusive. Rather, they are complementary. Data on protected area extent, for example, can be combined with measures of conservation outcomes for large-scale environmental impacts, such as those measurable by remote-sensing technology. And management effectiveness evaluations are greatly enhanced by incorporating outcomes assessment, as outlined in the Management Effectiveness Evaluation Framework (Hockings *et al.* 2006). Researchers can also consider aspects of all three groupings together. In a recent landmark study of MPA conservation outcomes, Edgar *et al.* (2014) investigated the combined effects of five MPA design and management features on conservation outcomes. Their results indicate that the realization of conservation benefits required the presence of at least three out of the five MPA features they investigated – isolated location, large size (>100 km^2), prohibition of extractive activities, good compliance and old age (>10 years old). This underlines the proposition that for the best chance of a protected area to realize conservation outcomes, all aspects of the implementation process need to be effective (Figure 1.1).

But effective protected area design and management may not be sufficient for realizing conservation outcomes, as even a well-designed and -managed protected area can be scuppered by external threats (Figure 1.1; Jameson *et al.* 2002). And on the other hand, in certain contexts, poorly designed and managed protected areas might still maintain their values (if they are remote and far away from human pressures, for example; Hockings *et al.* 2006).

1.3 MPA management effectiveness

There is concern that many MPAs represent nothing more than paper parks. That is, they exist only on paper, without adequate management actions on the water to provide effective protection. These MPAs can give the "illusion" of protection (Agardy *et al.* 2011), particularly when one considers only MPA extent. Given the weight placed on MPAs as a key marine conservation tool, the growing number of MPAs being designated and the associated resources invested, it is critical to understand whether MPAs are meeting their objectives.

During the past 15 years increasing emphasis has been placed on ensuring the management effectiveness – not simply growing coverage – of protected areas. In 2004, Parties to the CBD committed to creating a comprehensive, ecologically representative and *effectively managed* system of protected areas that conserve at least 10% of all ecoregions (CBD 2004a). This commitment was renewed with the Aichi Biodiversity Targets (CBD 2010), the 11th one stipulating that protected areas – both marine and terrestrial – should be "effectively and equitably managed." Other related decisions have outlined that CBD Parties need to assess the management effectiveness of at least 60% of protected areas by 2015 (Woodley *et al.* 2012).

The issue of protected area management effectiveness is not a new one, though. In 1984, the IUCN evaluated threats to protected areas, and the most commonly reported threat was inadequate resources for management (Hockings 2003). A summary of the findings of past global studies of protected area management effectiveness is included in Table 1.1.

In their meta-analysis of protected area management effectiveness evaluations, Leverington *et al.* (2010) identified more than 40 management evaluation tools differing in their methodology, scope, scale and level of detail. To combine the different types of data generated by these disparate tools, Leverington *et al.* (2010) used a method of cross-analysis, which had two components: "'matching' the topic of each indicator to a common 'headline indicator', and establishing a 'translation' system so that the different scoring systems are incorporated in a consistent way." Their results, which represent information available for both marine and terrestrial protected areas, show that protected area management effectiveness was mediocre overall. The average site-level score was 0.53 on a scale of zero to one. Some 13% of protected areas fell into the study's least effective category (according to the authors' threshold of <0.33; Table 1.1) and probably represent nothing more than paper parks. Indicators with the poorest scores included factors related to inputs (such as adequacy and security of funding, and staff numbers) and the management processes (such as community assistance programs and management evaluation). In a related study, Vonk (2010) found that the average score for the management effectiveness of only the marine sites in the same dataset was 0.51 – a figure comparable to that calculated for terrestrial and marine protected areas combined (0.53). The poorest scoring indicators at the marine sites overlapped with those identified in the Global Study: indicators relating to adequacy of funding and staff, and community assistance programs.

While this research shows that management effectiveness of protected areas is likely to be generally poor around the world and that sites do not have the resources to meet basic management needs, these results should not be considered representative of all protected areas, as they do not cover a probability-based sample. Rather, the results represent sites for which management effectiveness assessments had already been conducted and were available for inclusion in the analyses. Both Leverington *et al.* (2010) and Vonk (2010) suggest that their results could be negatively biased by the fact that many management effectiveness evaluations have been conducted by non-governmental organizations (NGOs) at sites already deemed to be vulnerable. It is also possible that evaluations are more readily available for regions and protected areas with more resources for conservation and evaluation, and therefore, the results could overestimate protected area management effectiveness globally.

Other large-scale studies on the management effectiveness of MPAs have produced even more pessimistic results. In their report on the status of coral reef MPAs globally, Burke *et al.* (2011) undertook a rapid, superficial review of MPA effectiveness at minimizing one threat: overfishing. The authors used expert input and a literature review to score as many sites as possible according to a three-point scale of effective, partially effective or ineffective. Of the sites they could obtain scores for (43%; 1,147 of 2,679), 47% were rated as ineffective at reducing the threat of overfishing, 38% were considered partially effective and just 15% were considered effective. Mora *et al.* (2006) conducted an area-based assessment of the effectiveness of coral reef MPAs, and found that less than 0.1% of coral reef area lies within MPAs managed in a way that would prevent extractive activities (i.e., no-take MPAs with no poaching).

The lack of knowledge of MPA management effectiveness at a global scale is a matter of concern. For most of the studies discussed here, more than half of the existing sites could be considered 'data deficient' with regards to their management effectiveness (the notable exception being Mora *et al.* (2006)). In their global review of MPAs, Kelleher *et al.* (1995) gauged the management effectiveness of 383 MPAs, representing 29% of the total at the time, and they remarked that the data were "sketchy." Even so, more than 70% of MPAs (923) in the Kelleher *et al.* (1995) study lacked sufficient information to be assessed according to the broad, three-point scale of (low, moderate, high) management effectiveness. As Jones (2002) points out, this dearth of information could indicate poor management at these sites and that if one were to interpret the results of Kelleher *et al.* (1995) assuming a worst-case scenario, i.e., assuming the 923 data-deficient sites have "low" effectiveness, only 9% of the world's MPAs would be classed as highly effective (Jones 2002). But even if these data-deficient sites were not biased and indeed representative of MPAs at the time, it would mean that less than a third of MPAs (31%) were achieving their management objectives.

1.4 Research aims

This research aims to assess effectiveness of MPAs globally using two metrics: (1) the quantitative growth in MPA coverage in relation to global targets and (2) the quality of MPA management. Assessing the achievement of global MPA coverage targets will involve estimating the current extent of MPAs globally and exploring possible future progress towards achieving 10% global ocean coverage, as defined by Aichi Target 11 (CBD 2010). This will provide a snapshot of the current status of marine protected area on a global scale and a foundation for the second part of the research, which aims to advance on the widely applied metric of MPA coverage and assess effectiveness in more depth. This will be done using a survey questionnaire to gather information on the state of management at a randomly selected sample of MPAs around the world. The aim of the survey will be to acquire a measure of management effectiveness for a representative group of MPAs that can be combined with contextual indicators to explore, model and predict the likely management effectiveness of the global complement of MPAs. Developing such a model of MPA management effectiveness would facilitate a more detailed investigation of MPA effectiveness than areal statistics allow.

Table 1.1 Summarized results of previous global assessments of protected area management effectiveness presented under generalized labels of not effective, partially effective and effective. Each of these studies uses different assessment methods, which limits their comparability.

	Management effectiveness (% of sites)				
Scope	**Effective**	**Partially effective**	**Not effective**	**Number of sites assessed (% of total)**	**Source**
Coral reef MPAs	15	38	47	1,147 (43%)	Burke *et al.* (2011)[1]
Global protected areas (marine and terrestrial)	24	62	13	4,151 (4%*)	Leverington *et al.* (2010)[2]
Global MPAs	20	64	16	355 (6%†)	Vonk (2010)[2]
Coral reef MPAs	9	--	--	980 (100%††)	Mora *et al.* (2006)[3]
Tropical MPAs	43	--	35	90 (<9%†††)	Alder (1996)[4]
Global MPAs	31	40	29	383 (29%)	Kelleher *et al.* (1995)[5]

[1] Three-level scale: effective, partially effective, ineffective at reducing the threat of overfishing

[2] Scale of zero to one: <0.33, clearly inadequate; 0.33-0.67, basic management; >0.67, sound management

[3] Assessed according to levels of poaching within the MPA; 9% represents the percentage of coral reef MPAs that prevent poaching activities; other values not available

[4] Perceived success according to managers (20% were unable to judge the MPA's success)

[5] Management level classified as high, moderate, low

* Based on a total number of 100,000 protected areas globally at the time (2010)

† Based on a total number of 5,850 MPAs globally at the time (from Toropova *et al.* 2010)

†† C. Mora, pers. comm., University of Hawaii

††† based on an estimate of 950 MPAs globally at the time

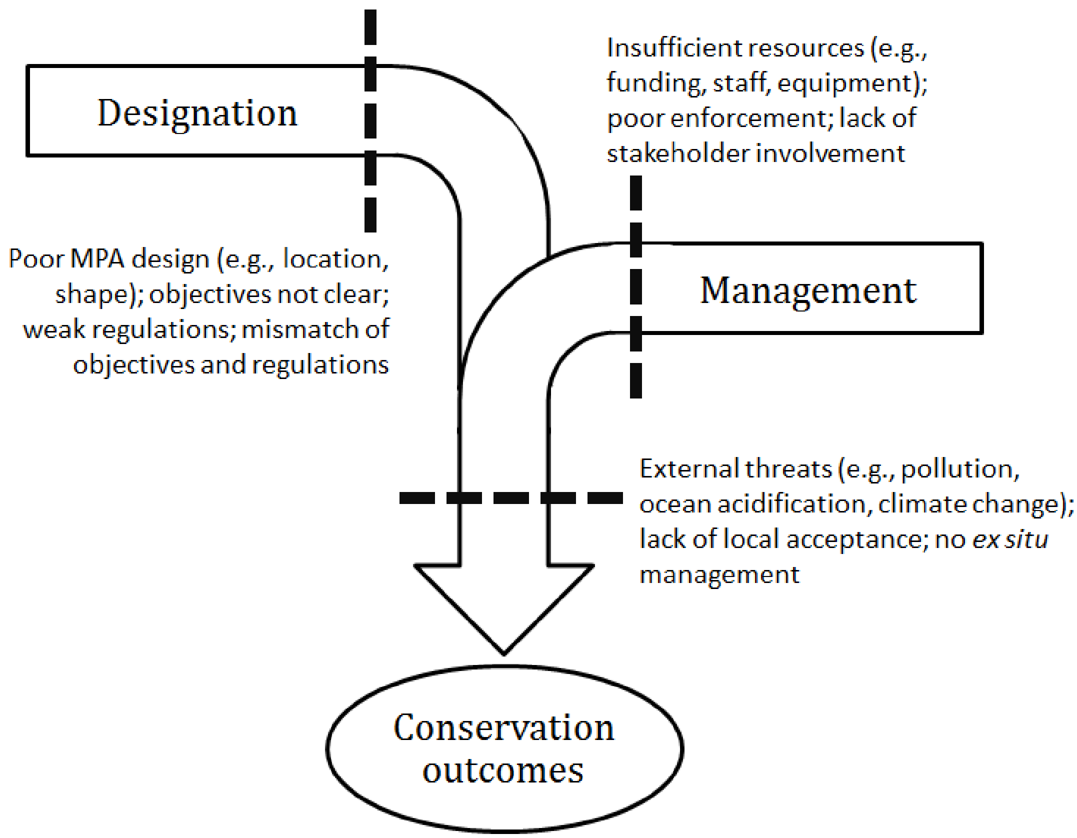


Figure 1.1 Elements of MPA implementation that contribute to effective attainment of conservation outcomes. These elements plus conservation outcomes also provide a convenient, three-part framework for understanding the varied ways of assessing protected area effectiveness.

Chapter 2: An updated assessment of progress towards global MPA coverage targets

2.1 Introduction

Marine protected areas (MPAs) are a valuable tool, among many, for protecting the marine environment. As such, a number of international targets have been set to encourage MPA establishment. One of the first was defined at the 2002 World Summit on Sustainable Development where a commitment was made to establish a representative network of MPAs by 2012 (United Nations 2002). More recently, Parties to the Convention on Biological Diversity (CBD) adopted the Aichi Targets. Target 11 commits participating countries to conserving at least 10% of coastal and marine areas by 2020 "through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures … integrated into the wider landscapes and seascapes" (CBD 2010).

Overall, progress towards meeting international targets has been slow, however, and they have not been met (Wood *et al.* 2008; Toropova *et al.* 2010; Wood 2011; Veitch *et al.* 2012). Wood *et al.* (2008) estimated that if the expansion of marine protected area continued at the prevailing rate, the target for 10% marine protection within areas under national jurisdiction would not be achieved until 2047. As for realizing 10% of the global ocean as protected, the authors predicted that would not be realized until two decades later.

In recent years, there has been a dramatic increase in the protection of very large areas of ocean, which could strongly influence trends in growth. During 2013, Australia established the 990,000-km^2 Coral Sea Commonwealth Marine Reserve, and South African legally designated the Prince Edward Islands Marine Protected Area, adding 180,000 km^2 to global coverage. The 1,070,000-km^2 South Georgia and South Sandwich Islands Marine Protected Area was established during the previous year. Additional very large MPAs are in the planning stages and due to be designated within the next few years (Table 2.1).

The most recent, comprehensive assessment of MPA coverage shows an optimistic increase to 2.3% of the global ocean in 2012 (Spalding *et al.* 2013) up from 0.65% in 2006 (Wood *et al.* 2008). As for the amount of protected area within exclusive economic zones (EEZ), this grew from 1.6% (Wood *et al.*

2008) to 5.5% (Spalding *et al.* 2013) between 2006 and 2012. To what extent coverage of MPAs with strict levels of protection, namely no-take MPAs, has increased is unclear; Wood *et al*.'s (2008) study offers an estimate of 0.08% of the global ocean in 2006. It is clear that significant expansion in marine protected area is still required to see the 10% coverage target met by 2020.

The utility of global percentage targets has been questioned in a number of ways (e.g., Margules and Pressey 2000; Agardy *et al.* 2003; Wells *et al.* 2007; Wood 2011; De Santo 2013). Although MPA designation is not sufficient to ensure effective conservation, it is a first step, and protected area extent remains a comprehensible and quantifiable metric that has been chosen by the international community to encourage conservation action. Therefore, the objectives of this research are to investigate the quantitative extent of MPAs by (1) providing an updated estimate of global marine protected area, both total and no-take; and (2) assessing the feasibility of protecting 10% of global marine areas by 2020.

2.2 Methods

The methods used in this research are largely based on those of Wood *et al.* (2008).

2.2.1 Database

The global database of MPAs originally developed by Wood *et al.* (2008) and maintained by the *Sea Around Us* was updated and expanded using a variety of data sources, including national inventories, additional protected area databases, legislation, management plans, peer reviewed and non-peer reviewed literature, and direct communication with local experts. Some 600 sites were deleted as non-qualifying MPAs, >700 site details were updated and >2,500 records were added.[4]

The criterion originally used for inclusion of MPAs in the database (Wood *et al.* 2008) was based on the 1999 IUCN protected area definition: "Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Kelleher 1999). This definition has since been superseded by a new protected area definition from the IUCN: "A clearly

[4] These updates are currently (May 2014) not available on the *Sea Around Us* website (www.seaaroundus.org), but they should be later in 2014 or in early 2015.

defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley 2008). This new definition no longer refers to the marine environment specifically. Therefore, while the updated definition was relied upon to differentiate between protected areas and areas declared for extractive uses (Dudley 2008), the 1999 definition specifies the criterion for what is a marine rather than a terrestrial protected area. As per Wood *et al.* (2008), this definition was applied by reviewing whether the legal boundary of the site extended seaward of the mean high-water mark. Other criteria for inclusion in the database are outlined in Wood *et al.* (2008).

The information provided by original data sources was used to determine what was included or excluded from the database based on the above criteria, and to provide supplementary information such as designation date, IUCN management category, no-take area, etc. The definitions employed by the source material were reviewed to ensure concurrence with the definitions outlined here. However, as definitions used by individual organizations and nations can differ from those employed by the IUCN, there are likely to be some inconsistencies.

2.2.2 MPA coverage

Global marine protected area was estimated for all MPAs in the database designated up to the end of 2013. Although the database is not yet a fully comprehensive record of MPAs established up to that date, ensuring inclusion of all of the largest MPAs (some of which were designated in 2013) was a priority. These very large MPAs represent a disproportionately large percentage of global coverage.

Due to the lack of spatial data for many MPAs in the database, coverage was calculated by summing their marine areas with the exception of three countries' MPAs, which are known to have significant overlapping areas and have comprehensive spatial data available. UNESCO World Heritage sites, UNESCO Man and the Biosphere Reserves, and Ramsar sites (wetlands of international importance) were excluded because of their near-complete overlap with nationally designated sites. This decision is in-line with other global MPA studies (e.g., Wood *et al.* 2008; Toropova *et al.* 2010). When the marine area of an MPA was not known, its total area was prorated according to the median proportion of marine area (relative to total area) for those MPAs for which this quantity was known in that country. Thus it was assumed that MPAs within a country were similar with regards to their marine and terrestrial proportions. MPAs without any areal information (~5%) were excluded from coverage statistics.

For Australia, the United States and the United Kingdom, all of which have large areas of overlapping MPA designations, alternative sources of comprehensive spatial information were used. For Australia, 2012 spatial data were downloaded from the Collaborative Australian Protected Areas Database (CAPAD)[5] and used as is. For the United States, spatial data current as of March 2013 were accessed from the National Oceanic and Atmospheric Administration's (NOAA) MPA inventory[6]. Some amendments were made to the US dataset: (1) protected areas in the Great Lakes were excluded, and (2) temporally dynamic sites and those with sustainable production as their primary conservation focus were excluded as they do not meet the IUCN definition of a protected area, which stipulates that protected areas should be "long-term" and have the primary objective of nature conservation (Day *et al.* 2012; NOAA 2013). Despite these exclusions, some US sites remain in the database that are not clearly MPAs as defined by the IUCN, namely, fisheries management areas that offer limited protection. To calculate total marine protected area and its annual growth for Australia and the US, all overlapping areas were removed using the ArcGIS Symmetrical Difference tool in each year to avoid double-counting. For the United Kingdom, data for annual, cumulative marine protected area coverage were taken from the UK Biodiversity Indicators in Your Pocket 2013 report (indicator C1) current to June 2013 (DEFRA and JNCC 2013). Although some overlap likely remained for the MPAs in other countries, this was considered negligible relative to total marine protected area.

2.2.3 No-take coverage

In this research, no-take MPAs or zones were considered to be "marine areas in which the extraction of living and non-living resources is permanently prohibited, except as necessary for monitoring or research to evaluate effectiveness" (Jones 2007). However, for most countries, the definition used by national data sources for no-take coverage was relied upon, which potentially introduced inconsistencies with regard to this definition. For example, Papahānaumokuākea Marine National

[5] http://www.environment.gov.au/topics/land/nrs/science-maps-and-data/capad

[6] http://marineprotectedareas.noaa.gov/dataanalysis/mpainventory/

Monument is listed as "no take" by NOAA, although it allows some subsistence fishing by permit (NOAA 2011).

For the US and Australia, total no-take area was calculated using spatial datasets (detailed above) and the associated metadata. For the US, all MPAs designated as "no take," "no access" and "no impact" in the NOAA MPA inventory were included in calculations of no-take area. This criterion provides an imperfect delineation between no-take and other MPAs as it includes some MPAs allowing limited extractive uses and it excludes others with zoned no-take areas.

For Australia, IUCN management categories Ia, Ib and II were used as a proxy for the presence of no-take regulations. Although IUCN management categories have generally been inconsistently applied, Australia has implemented a national initiative to align its protected area designations with the IUCN management categories. Again, however, this does not provide a clear criterion. While categories Ia, Ib and II are considered to be largely incompatible with extractive uses (except some traditional use in Ib and II protected areas), in practice, IUCN management categories are applied according to management objectives not management actions (Day *et al.* 2012); thus, there can be inconsistencies with regards to allowable activities (Fitzsimons 2011). Despite this uncertainty, using the IUCN management categories as a proxy for no-take area in this country was considered the most suitable option, as it provided a trade-off between excluding Australian MPAs from these calculations and detailed investigation of each MPA's management plan. The only amendment was to exclude the Coral Sea Commonwealth Marine Reserve from no-take area calculations as the management plan for this site, which would have designated approximately half of the area as no-take, has been dropped and will be re-drafted (MPA News 2013).

Information on no-take area was available for most MPAs (~67%). An additional ~1% of MPAs were known to be partly no-take, although the exact no-take area was unknown. The total marine area of these MPAs was prorated using the median proportion of no-take area (relative to total marine area) for those MPAs for which this quantity was known globally. Thus it was assumed that zoned MPAs were similar with regards to the proportion of their area designated no-take. MPAs without any information on no-take extent were excluded from no-take coverage calculations.

The assumptions that were made to enable calculation of the marine and no-take area of MPAs for which this information was not available introduced error into these estimates. This error is likely small compared to the cumulative global marine protected area.

2.2.4 Growth in MPA coverage

Year of MPA designation was used to calculate cumulative marine protected area over time since 1950. These data were available for ~93% of MPAs representing ~98% of the total global coverage. Where significant inconsistencies between original year of designation and the area declared were known, this information was updated to reflect growth in coverage as accurately as possible. For example, the waters surrounding the Galapagos Islands were first protected in 1986 as a Marine Resource Reserve Area, and although there have been subsequent changes in designation type (Jones 2013), in this analysis, the area was considered protected from 1986 onwards. However, the MPA's no-take areas were zoned during 2000, therefore those areas were considered as designated during that year.

In accordance with the methods of Wood *et al.* (2008), the remaining protected area (~2% of global coverage without information for year of designation) was distributed across all years according to the proportion of the total marine protected area designated in that year.

2.2.5 Proposed MPAs

Additional very large MPAs have been proposed for establishment and could be designated in the next few years (Table 2.1). Online resources and communication with experts were used to estimate the likely size of these MPAs, many of which are proposed to cover entire EEZs. The areas used in this research do not represent the final sizes of these MPAs, which are still in the consultation and planning stages, but rather a possible scenario for future growth in MPA coverage. If designated, not all of the proposed MPAs will add to quantitative measures of global coverage, as some areas are already designated as MPAs, generally with less strict protection levels than will be enabled by the proposed designations. Therefore, before incorporating these areas into projections for possible future MPA growth, the area of MPAs already established within each one's proposed limits was subtracted from the estimated area. The combined area of the proposed MPAs (Table 2.1) was distributed evenly across years from 2014 to 2020 to represent a hypothetical scenario for future MPA expansion. Linear regression of the logged hypothetical increase in cumulative global protected area from 2014 to 2020 (based on the proposed MPAs) was used to estimate a hypothetical annual growth rate.

Other possible future scenarios for growth in MPA coverage were considered for MPAs that could be established in the Sargasso Sea (Laffoley *et al.* 2011), the Arctic high seas (Galloway 2014) and the global high seas (Sumaila *et al.* 2007), as well as a scenario treating the Southern Ocean area managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) area as an MPA.

2.3 Results

2.3.1 Global network of MPAs

According to the database used in this research, 6,186 MPAs covering ~11.9 million km^2 were designated by the end of 2013. This represents 3.27% of the world's oceans. Of that protected area, 19% is within no-take MPAs, covering 2.2 million km^2 or 0.63% of the global ocean. Of the ocean area within EEZs, 8% (~11.3 million km^2) is designated as protected. In the high seas, ~0.5 million km^2 (0.2% of the high seas area) is protected.

The mean and median size of MPAs globally is approximately 2,430 km^2 and 3.3 km^2, respectively. The substantial difference between the mean and median size is due to the existence of a small number of very large MPAs that dominate areal statistics (Figure 2.1). While the smallest MPA covers a fraction of a hectare (<0.001 km^2), the largest extends across more than 1 million km^2 (South Georgia and South Sandwich Islands MPA). The combined area of the 23 MPAs that are greater than 100,000 km^2 is more than 7.5 million km^2, representing 64% of global marine protected area. Twelve of these were designated subsequent to 2006.

2.3.2 Attainment of global coverage targets

Cumulative global marine protected area grew steadily, but slowly, from the mid-1970s to 2006, apart from a few sharp increases due to the establishment of very large MPAs (Figure 2.2). This overall trend is similar to that described in Wood *et al.* (2008). Figure 2.2 indicates that there were sudden increases in the extent of no-take protected area in 2006 and 2010. These jumps were largely due to the establishment of Papahānaumokuākea Marine National Monument (2006) and the Chagos Marine Reserve (2010).

Almost all of the world's MPAs have been designated within EEZs. A handful of MPAs have been designated in the high seas in recent years, but they represent a small fraction of the total global marine protected area, just 4.4% (~530,000 km^2). Thus the annual rate of growth in cumulative EEZ protected area is virtually indistinguishable from the rate of growth of global marine protected area.

Figure 2.3 shows growth in the cumulative logged marine protected area since 1960 under different scenarios. The first panel (Figure 2.3A) is a reproduction of Wood *et al.*'s (2008) data showing the observed growth and a future projection of the annual rate of increase in global marine area protected (based on observed data for 1984-2006; 4.6%, $r^2 = 0.96$). The second panel (Figure 2.3B) shows the observed trend derived from data used in this research and a future projection based on the proposed MPAs in Table 2.1 (2014-2020; 4.7%, $r^2 = 0.99$). Comparison of Figures 2.3A and B reveals a difference in the trends. The discrepancy is primarily due to the addition of several large US MPAs to the current database. These MPAs were established prior to 2006, but had not previously been considered MPAs. They are permanent fisheries management measures established with the primary aim of protecting natural heritage, however, their inclusion in such calculations of MPA coverage is debatable (Spalding *et al.* 2013).

Figure 2.3B also presents a possible scenario for future growth in MPA coverage between 2014 and 2020. This is based on the establishment of eight very large, proposed MPAs to be located within EEZs (Table 2.1). If all of these MPAs were to be successfully designated, protected area coverage within EEZs would increase from 11.3 million km^2 to 16.6 million km^2, exceeding 10% coverage within areas under national jurisdiction and reaching approximately 4.6% global ocean protection. A regression calculated for this time period provides an estimate of 4.7% annual growth ($r^2 = 0.99$). The remaining panels (C-E) in Figure 2.3 show how the addition of hypothetical MPAs to statistics of global marine protected area would influence such estimates and progress towards the 10% target.

2.4 Discussion

Designation of an MPA is one step to seeing an area effectively protected; it is not sufficient for conservation outcomes (Figure 1.1). Marine protected area provides a simple metric that is communicable and quantifiable, and has been chosen by the international community as an indicator of conservation progress. However, the simplicity of this indicator can mask failures and successes in other aspects of protected area implementation. It is worth noting that Aichi Target 11 calls for more than 10% protection; it requires that protected areas be effectively and equitably managed, ecologically representative, well-connected and integrated into the wider landscape or seascape (CBD 2010).

The results presented here show an improvement in progress towards meeting the 10% coverage target of Aichi Target 11. Compared to the results of Wood *et al.* (2008), cumulative global marine protected area has grown from 2.35 million km^2 in 2006 to 11.9 million km^2 in 2013 representing a five-fold increase in global ocean protected area. This progress is due to both the establishment of new MPAs – in particular, a handful of very large sites – and the addition of previously unaccounted MPAs. The results for total protected area presented here are similar to the cumulative coverage estimates of Spalding *et al.* (2013),[7] although larger (11.9 million km^2 rather than 8.3 million km^2) due to the inclusion of extensive Australian MPAs designated during November 2012 and the US fisheries management areas already mentioned.

There has also been concomitant growth in no-take area during the same time period, from 0.08% (Wood *et al.* 2008) to 0.63% of the global ocean. This no-take coverage represents about one-fifth of the area within MPAs (2.2 million km^2), ~30% of which is contained within one very large MPA, the Chagos Marine Reserve. The remainder of the global marine protected area varies greatly in type and level of protection. To give a some examples, mussel dredging – a destructive fishing technique – is allowed in Danish marine Natura 2000 sites,[8] and Brazil includes among its protected areas so-called "extractive reserves" (*reserva extrativista*) intended for sustainable use, which provide fishing communities with exclusive use rights and encourage permanent occupation by traditional populations (Kalikoski and Vasconcellos 2011). Other MPAs are intended to protect only certain or single species, such as genetic reserves in Chile (Fernandez and Castilla 2005).

Growth in MPA coverage is largely due to the establishment of a small number of very large MPAs, which tend to dominate such areal statistics. Additional large MPAs are slated for designation in coming years (Table 2.1). In 2012, the Cook Islands and New Caledonia announced their intentions to create,

[7] The estimates of Spalding *et al.* (2013) are based on data from the World Database of Protected Areas (http://www.protectedplanet.net/) up to 2012 but excluding the Coral Sea Commonwealth Marine Reserve and other MPAs designated in Australia during November 2012.

[8] http://www.worldfishing.net/news101/industry-news/oceana-questions-eus-wrong-decision

within 2-3 years, what could be the biggest MPAs designated yet at 1.1 million and 1.3 million km^2 respectively (Table 2.1; MPA News 2012a). Furthermore, the Global Ocean Legacy campaign aims to establish a suite of very large, strictly protected MPAs in pristine and remote parts of the ocean, some of which have already been successfully designated, such as Papahānaumokuākea Marine National Monument and the Chagos Marine Reserve (Nelson and Bradner 2010). If designated, the proposed sites – all within EEZs – would add around 4.7 million km^2 to the 11.9 million km^2 that is already protected globally, thereby exceeding 10% MPA coverage within EEZs. Distributing this area evenly across years from 2014 to 2020, equates to a growth rate of about 4.7% annually, which is very similar to the rate of 4.6% calculated by Wood *et al.* (2008) for 1984 to 2006.

Toonen *et al.* (2013) reported an annual rate of increase in marine protected area of 2.8% between 2006 and 2012 – significantly slower than both the rates calculated here for proposed MPA growth (2014-2020) and by Wood *et al.* (2008) for an earlier time period (1984-2006). The authors' prediction for attaining 10% protection of the global ocean is 2025, which is much earlier than predicted here, although discordant with the growth rate they report.

Taking into account MPAs established subsequent to 2006 and MPAs proposed for establishment in the next few years, it is possible that 10% of areas under national jurisdiction could be protected by 2020. Yet protecting 10% of the global ocean remains out of reach. Assuming an annual growth rate of 4.7% could be maintained beyond 2020 (Figure 2.3B), the 10% global protection target would be reached around 2037. This shows that although recent expansion in marine protected area has drawn the date of attainment closer compared to the 2067 prediction of Wood *et al.* (2008), it is still unlikely to be realized by 2020. What is striking is the extent to which marine protected area needs to expand to accommodate such a target. The future hypothetical scenarios presented in Figure 2.3 (C-D) suggest that vast areas of ocean will need to be protected to advance significantly towards 10% global coverage. Furthermore, how long the current growth rate can be sustained remains to be seen; we might expect to see a declining trend in the rate of MPA establishment as marine areas residual to extractive uses and not already protected become rarer (Mora and Sale 2011; Devillers *et al.* 2014).

From the results presented here (Figure 2.3), we see that only by protecting additional vast areas of ocean, largely available beyond EEZ limits, can we expect to see 10% of the ocean protected. Up to now, the biggest MPA to be established and widely counted in calculations of global coverage is the South Georgia and South Sandwich Islands MPA, covering 1,070,000 km^2. Yet, establishment of an MPA that could be nearly four times that size, a Sargasso Sea MPA – in addition to the seven proposed MPAs within EEZs listed in Table 2.1 – would see just 5.7% of the global ocean protected. Adding the 2.5 million km^2 Arctic high seas area would push global coverage only 0.7% higher to 6.4%. On the other hand, adding the 35-million km^2 Southern Ocean area managed by CCAMLR to calculations of global MPA coverage would instantly expand global marine protected area to beyond the 10% target. The CCAMLR area is already considered an IUCN category IV protected area (Day *et al.* 2012), therefore such a scenario would require no change to on-the-water management.

While it is clear that the designation of a handful of very large MPAs has had a significant impact on the quantitative extent of MPAs globally, concerns have been raised about potential negative implications of their designation over the longer-term. As with smaller MPAs, there is concern that these protected areas could amount to no more than paper parks, offering little – if any – protection in the water. Monitoring and enforcement pose a significant challenge, which is inherently more difficult on such vast scales and on the high seas (Cressey 2011; McCauley *et al.* 2013; Pala 2013). Instituting sustainable financing mechanisms, and technology and logistical partnerships will help to ensure conservation measures are effectively enforced (De Santo 2013). The designation of very large, strictly protected MPAs has also spurred debate about social justice, equity and "fortress" conservation (e.g., De Santo *et al.* 2011; Anonymous 2013; De Santo 2013). It has been suggested that the ecological benefits of establishing very large MPAs could be realized through the establishment of networks of smaller MPAs and broad-scale marine spatial planning (e.g., Agardy *et al.* 2011; De Santo 2013).

It has also been argued that creating MPAs in areas facing little threat "are not true to the cause of marine conservation" (Agardy *et al.* 2011), as they divert resources away from proximate areas facing significant threats, where management is often more difficult (Craigie *et al.* 2014). Devillers *et al.* (2014) have shown – although it had been assumed before – that MPAs are biased towards places that are undesirable for extractive activities, and the designation of large, remote protected areas will exacerbate the imbalance. Protecting large, unspoiled areas before they are degraded and claimed for other uses, is the aim of some of these large-scale MPAs, however (Nelson and Bradner 2010; Toonen *et al.* 2013).

The question of whether to prioritize protection of remote, uncontested, intact or non-remote, exploited, imminently threatened locations has no immediate, science-based resolution. While it seems logical that both types of protection are necessary, the resource-limited nature of protected area implementation means we need to think about where the balance should fall. The answer appears to hinge on the issue of value for money: which approach will conserve more biodiversity (over what time span), given the limited resources available? There are different opinions, but no science to tell us which areas are more deserving of protection (McCauley *et al.* 2013). Despite differences in opinion, a key principle can be agreed upon: siting and design of protected areas should prioritize ecological goals over political ones (Craigie *et al.* 2014; McCauley *et al.* 2014). Gains should be measured by avoided biodiversity loss, not square kilometers (Craigie *et al.* 2014).

Inevitably, there are limitations to consider when interpreting the findings presented here. These limitations are broadly: the reliability of the data and the simplicity of marine protected area as a metric for biodiversity conservation (already mentioned). First, the quality of the global MPA dataset used here (and indeed, all large-scale protected area datasets) is influenced by the dynamic nature of protected areas themselves (which are constantly being designated and degazetted; Mascia and Pailler 2011); ambiguity concerning inclusion and exclusion criteria; and the consistency and completeness of national and other data sources. It could be argued that some areas included in these calculations should have been excluded and other areas that were excluded should not have been. For example, certain fisheries management areas that provide only limited protection have been included (see Methods). On the other hand, managed marine areas designated for purposes other than conservation (considered "ancillary" areas by the CBD; CBD 2004b), such as the Chilean Management and Exploitation Areas for Benthic Resources (Gelcich *et al.* 2008), have not been included. It is worth noting that the issue of what 'counts' when quantifying marine protected area has been debated and there have been efforts by the IUCN to clarify the criteria (Dudley 2008; Day *et al.* 2012; Eddy 2013; Spalding *et al.* 2013). Aichi Target 11 also begs a clear definition of "other effective area-based conservation measures" (TNC 2012; Woodley *et al.* 2012), in addition to protected areas. This term offers room for interpretation, but in order for these areas to contribute effectively to measures of conservation progress, a definition needs to be developed that does not dilute the intentions of the target.

To elaborate on the second limitation: MPA coverage is a simplified indicator of conservation success that is able to tell us little – if anything – about conservation outcomes (Gaston *et al.* 2008). Looking simply at the extent of protected areas can be misleading as it masks uneven protection levels (e.g., Marinesque *et al.* 2012), distribution (e.g., Chape *et al.* 2005; Wood *et al.* 2008), management effectiveness (e.g., Mora *et al.* 2006; Leverington *et al.* 2010), and ultimately, conservation outcomes (e.g., Edgar *et al.* 2014). Coverage statistics not only mask shortcomings, but also successes, such as heightened protection levels for already-designated MPAs. At the Kermadec Islands, for example, a Benthic Protection Area designated in 2007 covers the entire EEZ, but does not protect the water column (Eddy 2013). New plans aim to strengthen the level of protection to a no-take area (Table 2.1);[9] this would not impact global MPA coverage estimates, however. There is a growing unease about simply looking at measures of MPA extent and research focus has shifted to reflect this, in-line with Aichi Target 11's additional expectations for protected areas to be effectively and equitably managed, ecologically representative, well-connected and integrated into the wider landscape or seascape (CBD 2010).

To fully understand and gauge MPA effectiveness on a global scale, we need to look beyond the number of square kilometers protected, and develop and refine methods for assessing additional aspects of MPA implementation. These are generally protection level, management activities and conservation outcomes. This will greatly contribute to understanding global progress towards meeting international targets, but more importantly, to understanding the role MPAs have in conserving biodiversity. As we gain ground in meeting the target of 10% coverage, these methods will provide a way to advance beyond quantitative goals and ensure the additional stipulations of Aichi Target 11 are met, so that what has been designated successfully contributes to conservation outcomes.

[9] The area surrounding the islands up to 12 nm from the coastline is already designated a no-take area.

Table 2.1 Very large MPAs proposed for establishment within EEZs. This table does not present confirmed or prescriptive information about these proposed MPAs, it simply outlines a possible scenario for future growth in coverage.

Location	Size (10^3 km^2)	Contribution to global coverage (10^3 km^2)	Description
Bermuda	254	254	EEZ excluding inner fishing area[1]
Cook Islands	1,065	1,065	Almost half of EEZ[2]
Easter Island	714	564	EEZ excluding an inner fishing area proposed to extend 20-60 km from shore[3, 4]
French Polynesia	700	700	Waters around Marquesas Islands[5]
Kermadec Islands	678	0	Entire EEZ, already designated a Benthic Protection Area[3]
New Caledonia	1,291	1,291	EEZ excluding provincial waters within 12 nm (22.2 km) from shore[6]
Pitcairn Island	834	834	EEZ excluding inner fishing area extending 12 nm (22.2 km) from shore[3]
South Georgia and the South Sandwich Islands	1,070	0	EEZ north of 60° latitude, already an IUCN category VI MPA[7]
Total	6,606	4,708	

[1] Estimated marine area based on the inner fishing area extending to 157 km (140 nm) representing the mid-point of three MPA design options presented by the Government of Bermuda (2013)

[2] www.bigoceanmanagers.org; MPA News (2012a)

[3] http://www.pewenvironment.org/campaigns/global-ocean-legacy/id/8589941025

[4] Estimated marine area based on the inner fishing area extending to ~45 km representing the mid-point of the proposed areas

[5] http://web.presidence.pf/index.php/mrm-filtre/630-la-polynesie-dans-le-concert-mondial-pour-la-preservation-des-aires-marines

[6] C. Fonfreyde, pers. comm., New Caledonia Maritime Affairs Office

[7] A. Gammell, pers. comm., Global Ocean Legacy

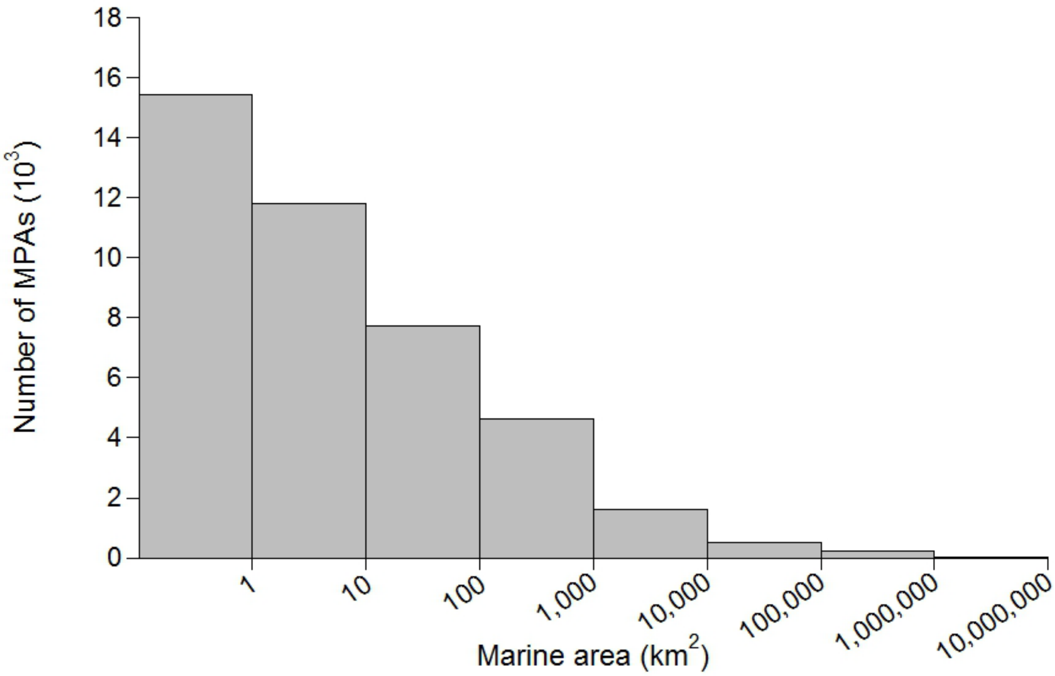


Figure 2.1 Area-frequency distribution of MPAs globally.

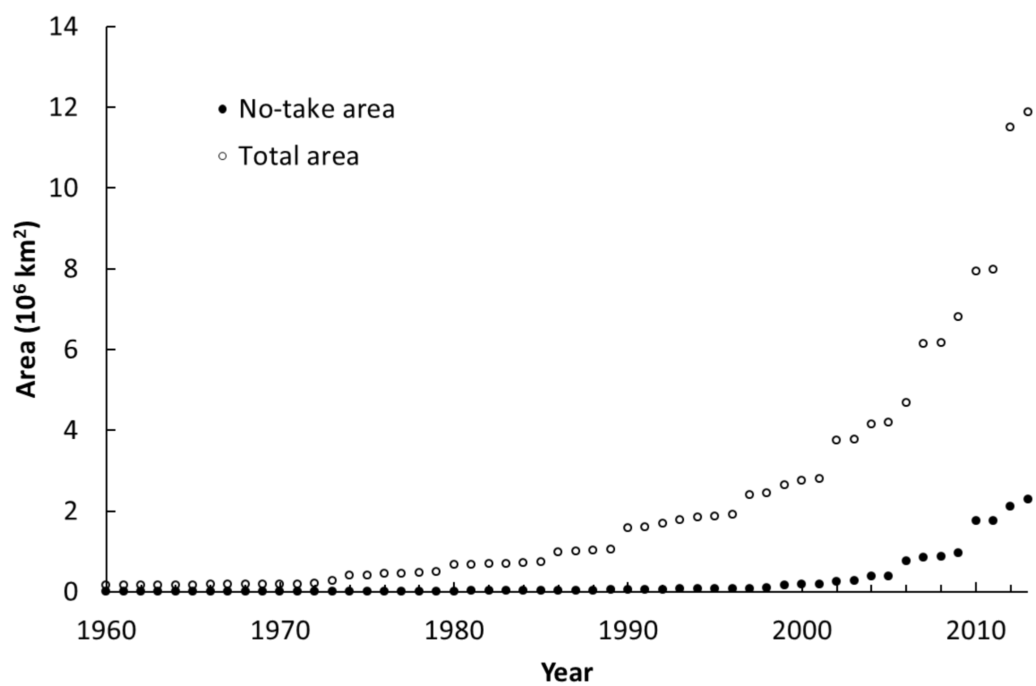
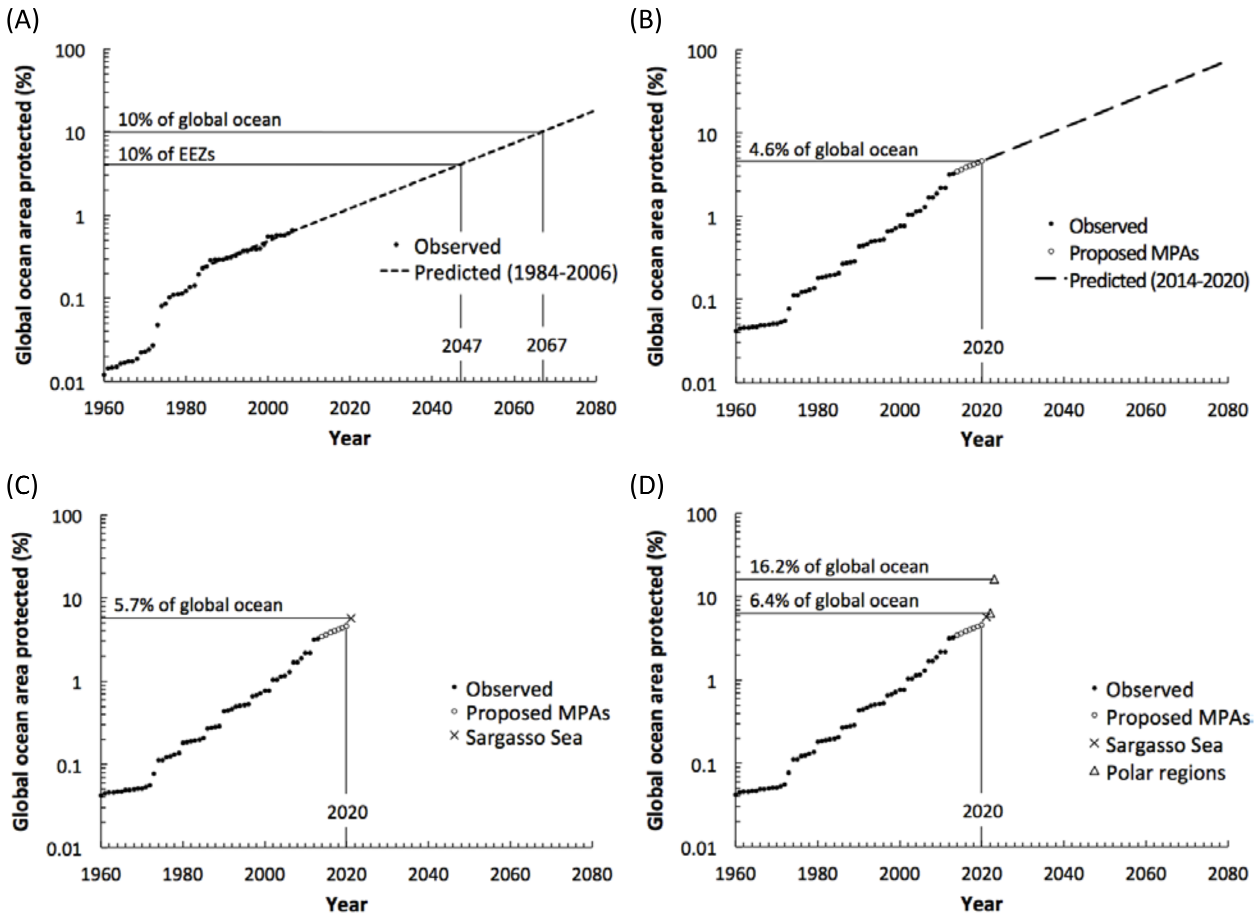


Figure 2.2 Growth in cumulative global total (open circles) and no-take (solid circles) marine protected area from 1960 to 2013.



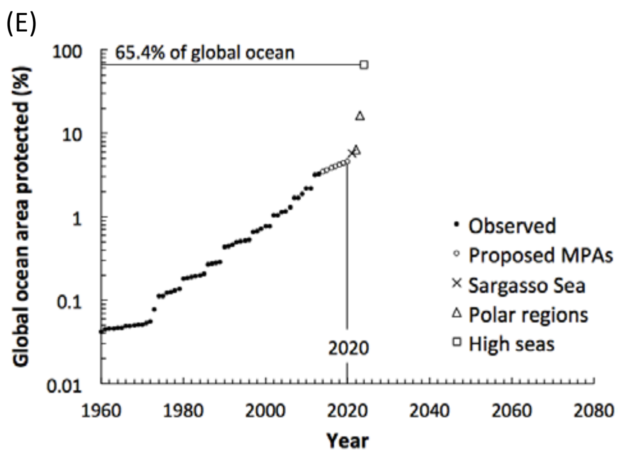


Figure 2.3 Trends in the observed and projected global coverage of MPAs. (A) Reproduction of data from Wood *et al.* (2008)[10] showing the observed (1960-2006) and projected (4.6%, $r^2 = 0.96$; based on observed data for 1984-2006) growth of global marine protected area in relation to attainment of the 10% targets. (B) Updated observed (1960-2013) and projected (4.7%, $r^2 = 0.99$; based on a hypothetical increase for 2014-2020) growth of global marine protected area. (C-D) Updated observed (1960-2013) growth of global marine protected area including the cumulative addition of hypothetical MPAs in (C) the Sargasso Sea, (D) the High Arctic and CCAMLR region, and (E) the global high seas.

[10] Oryx by Fauna & Flora International Reproduced with permission of CAMBRIDGE UNIVERSITY PRESS in the format reuse in a dissertation/thesis via Copyright Clearance Center.

Chapter 3: Exploring MPA management effectiveness on a global scale

3.1 Introduction

The number and extent of protected areas around the world, both terrestrial and marine, has grown rapidly during the past century (Toropova *et al.* 2010; IUCN and UNEP-WCMC 2012). While protected area numbers in the marine environment considerably lag those in the terrestrial realm, growth has nonetheless been dramatic, with a recent sharp increase in marine coverage primarily due to the establishment of a few very large MPAs (Chapter 2; Toropova *et al.* 2010; Spalding *et al.* 2013).

Progress in establishing protected areas arguably represents one of the greatest conservation successes of the past century (Ervin 2003), particularly as protected areas are considered a cornerstone of international conservation strategies. However, protected area designation can only be seen as a victory for conservation if the protected areas are effectively conserving the values they contain (Hockings *et al.* 2006; Leverington *et al.* 2010). Research has shown that this is not necessarily the case (e.g., Butchart *et al.* 2010; De'ath *et al.* 2012; Laurance *et al.* 2012). For example, in the marine environment, it has been found that less than 0.1% of coral reefs lie within MPAs managed to prevent extractive activities (i.e., no-take MPAs with no poaching). In a separate study, Burke *et al.* (2011) undertook a rapid review of coral reef MPA effectiveness and deduced that just 15% of sites were effective at reducing the threat of overfishing, whereas almost half (47%) were ineffective.

Despite recent increases in marine protected area, only a small fraction of the global ocean is designated as protected (3%; Chapter 1), and the international community continues to push for more MPAs in an attempt to reach the CBD's 10% target. However, a more important gap lies in our understanding of whether MPAs are achieving their conservation objectives (Jones *et al.* 2013a). There is concern that many MPAs represent nothing more than paper parks; that is, they exist only on paper, without adequate management actions on the water to provide effective protection. "Unfortunately, the commitment to setting aside land and water [in protected areas] has yet to be always matched with similar commitments of resources for management," Hockings *et al.* (2006) note, and the challenges facing MPA managers are significant. In the marine environment, protected areas receive on average half of the funding required for effective conservation (Balmford *et al.* 2004). As such, perfect management remains a laudable if elusive goal (Hockings *et al.* 2006).

Given the key role of protected areas in international and national conservation strategies, and the limited resources available to establish and maintain them, it is essential for policy-makers, conservation practitioners, funding organizations and society to understand how effective they are (Salafsky *et al.* 2002). Evaluation of MPA management effectiveness allows an assessment of the likelihood that MPA objectives will be met, based on whether the necessary resources and capacity are in place to facilitate such achievements. Such research contributes to understanding progress towards the CBD's Aichi Target 11 for protected areas, which outlines that MPAs should not only cover *at least* 10% of the global ocean by 2020, but should also be effectively and equitably managed, ecologically representative, well-connected and integrated into the wider landscape or seascape (CBD 2010). While case studies have contributed to idiosyncratic insights, their role is limited when investigating general relationships between effectiveness, management and context of MPAs on a large scale.

This research aims to offer a balance in the trade-off between the resource-intensive monitoring of MPA ecological outcomes and more superficial metrics of protection measurable at a global scale (such as those calculated in Chapter 2). The numerous methods that have been developed and applied to appraise protected area management effectiveness – that is, the extent to which protected areas are achieving their objectives (Hockings *et al.* 2006) – offer one approach for such a balance. By applying these tools at a global scale, the aim of this research is to improve understanding of the worldwide status of MPAs' management effectiveness (quality), and hence, their likely ecological outcomes.

3.2 Methods

3.2.1 Survey development

Given the global scope and aims of this research, a brief, closed-answer survey questionnaire was chosen as the most effective method for gathering a standardized set of information on a sample of MPAs. The aim was to develop a tool that was easy to use and widely applicable to different MPAs, particularly with regards to their varying objectives and governance systems.

Expert scoring has been used in numerous previous studies, particularly those conducted at the regional and global level (e.g., Mascia 1999; Bruner *et al.* 2001; Alder *et al.* 2002; Appeldoorn and Lindeman 2003; Balmford *et al.* 2004; Mora *et al.* 2006; Hargreaves-Allen *et al.* 2011; Schultz *et al.* 2011), and a number of methodologies have been developed to gather this type of information. Although expert scoring could be considered less accurate than long-term scientific monitoring, both types of data are subject to error and require judicious interpretation (Hockings 2003). While expert scoring is subjective, qualitative, and related to individual participants' ambitions and reference points, scientific monitoring data are not typically available for the majority of protected areas and datasets are not readily comparable. Expert scoring, on the other hand, is more time- and cost-effective, particularly for a large-scale study such as this. The knowledge of MPA managers can be based on years of on-the-ground experience and may better capture the realities and complexities of management (Hockings 2003; OSPAR Commission 2007).

Of the many methodologies available for evaluating protected area management, scorecard methodologies were the most informative for the purposes of this research, specifically the Management Effectiveness Tracking Tool (METT) for terrestrial areas (Stolton *et al.* 2003; Stolton *et al.* 2007) and an analogous version adapted for MPAs, the WWF-World Bank MPA scorecard (Staub and Hatziolos 2004). The "How is Your Marine Protected Area Doing?" guidebook (specifically the section on governance indicators; Pomeroy *et al.* 2004), and regional assessment methodologies developed for Indonesia (Carter *et al.* 2011) as well as the Western Indian Ocean (Wells and Mangubhai 2005), were also influential in identifying indicators and question wording. Questions and indicators were taken from these scorecards and recombined to create a new survey questionnaire designed to provide an overall measure of management effectiveness, rather than a detailed assessment of individual aspects of MPA management.

Much simpler assessments of management effectiveness have been used in the past. In their regional study of East African MPAs, Wells *et al.* (2007) use the presence/absence of five management features (staff, budget, management plan, active enforcement and external project support) to score management effectiveness of MPAs on a scale of zero to five. Here, the aim was to choose a limited set of indicators that strike a balance between detailed, resource-intensive assessments and low-resolution scales of effectiveness to maximize both the validity and quality of the management effectiveness data, as well as the survey response rate. Basing the design of the survey questionnaire on previously developed evaluations, which are themselves founded on the international standards of Hockings *et al.*'s (2006) evaluation framework, was expected to lend credibility and familiarity to the approach.

Although it is unlikely that one assessment system will be suitable for all MPA management circumstances, there are common elements and processes, or "minimum standards" (Carabias *et al.*

2004), that can form the foundation of broad-scale evaluations such as this (Hockings *et al.* 2006). The final indicators were selected based on their applicability to a wide variety of types of MPAs, their correlation with overall management effectiveness and outcomes (Leverington *et al.* 2010; Vonk 2010) and the expected ease with which managers could answer the questions and access the required information. The survey indicators covered all six stages of the management cycle, as identified in Hockings *et al.* (2006), with emphasis on inputs, processes and outputs.

When protected area management effectiveness evaluations take a scorecard approach, a scoring system is used to produce an overall estimate of management effectiveness (e.g., MBRS 2004; Staub and Hatziolos 2004; Wells and Mangubhai 2005; OSPAR Commission 2007; Stolton *et al.* 2007; Carter *et al.* 2011). Combining data for a variety of indicators necessarily results in a loss of information and potentially oversimplifies a complex concept. The survey used here aims to provide information on indicators that contribute to a single overarching concept (management effectiveness), without significant depth of information with regards to individual indicators.[11]

The questions were intended to be simple and easily understood by MPA professionals with a limited understanding of English. The layout of the questions was modeled on those employed in other scorecard methodologies, but adjusted to facilitate ease of answering. Open-ended questions were used as little as possible to aid in comparison.

The questions were arranged in sections that covered the following 12 management areas: MPA boundary, staff, facilities and equipment, current funding, management objectives, management plan, resource use rules, enforcement, education and awareness program, stakeholder involvement, monitoring and evaluation, and condition of natural features. There were also questions to acquire basic descriptive information about the MPA (full name, management authority, size, no-take area) and the participant's association with the MPA. At the end of the questionnaire, participants were given additional space to include any further information that they thought might be useful.

To reduce error introduced at different stages of the survey process, guidance was taken from the "Tailored design" method by Dillman *et al.* (2009), which addresses the four types of error: coverage, sampling, non-response and measurement. Non-response error, the fact that not all people approached

[11] There are more detailed management assessment tools available that address the need for in-depth management effectiveness evaluation (e.g., Pomeroy *et al.* 2004).

to complete the survey are able or willing to complete it, and measurement error, “the deviation of the answers of respondents from their true values on the measure” (Couper 2000), in particular, were addressed at this stage. The following techniques described by Dillman *et al.* (2009) and Dillman and Bowker (2001) were employed for:

- Establishing trust: personalizing the introductory letter; ensuring confidentiality and aggregation of results; and emphasizing the importance of the task.
- Increasing perceived benefits for participants: making the cover letter and questionnaire interesting and motivational; highlighting survey benefits to the MPA community; and clearly explaining the purpose of the survey.
- Decreasing the perceived costs of participation: making it convenient and quick to respond; avoiding subordinating language; carefully designing and formatting the cover letter, introductory survey page, instructions and questionnaire to be brief, and easy to understand and to complete; not requiring an answer to every question; and employing skip-logic.

Skip logic, which refers to the redirection of participants through the survey based on their answers to previous questions, served two functions: it allowed participants to skip irrelevant questions, saving time and avoiding confusion, and it simplified the scoring system.

Pre-testing was carried out with colleagues and potential participants known to the researcher in order to refine the wording, answer options and flow of the questionnaire and introductory letter. The questions were formatted in two versions: an electronic form using Microsoft Word (which could also be printed) and a web-based version using Survey Monkey (http://www.surveymonkey.com). Survey Monkey is a customizable survey tool that is easy to use, cheap and widely applied, making it potentially less threatening to participants. Survey Monkey has ways for dealing with common online survey issues, such as compatibility with different internet browsers and screen sizes, and it can facilitate skip-logic patterns. Electronic distribution was chosen as the preferable distribution mode for this survey as it allows access to a large number of MPAs around the world at low cost and in remote locations that would otherwise be impractical or unfeasible to survey given the scope of this research (Andrews *et al.* 2003). Self-administered surveys can also prevent social desirability bias. The complete questionnaire is included in Appendix A.

3.2.2 Sampling

A probability-based, stratified sampling design was used to select a representative sample of MPAs to approach for the survey. Probability-based designs permit generalizations and address sampling error, which arises from the fact that not all units in the sampling frame will be measured. Stratified sampling allows better representation of subgroups and of variation in the variable of interest (management effectiveness, in this case; Kalsbeek 2008). To apply this method required a reliable database of MPAs and definition of the sampling frame, followed by stratification and sampling.

The global database of MPAs originally developed by Wood *et al.* (2008) and maintained by the *Sea Around Us* was updated and expanded (Chapter 2) using a variety of data sources, including national inventories, additional protected area databases, legislation, management plans, peer reviewed and non-peer reviewed literature, and direct communication with regional and national experts. Some 600 sites were deleted as non-qualifying MPAs, >700 site details were updated and >2,500 records were added.[12]

For the purposes of this research, MPAs designated under international conventions (e.g., UNESCO World Heritage Convention 1972, Ramsar Convention on Wetlands 1971) were excluded from the sampling frame in order to prevent duplication of sampling units, as most internationally designated sites are also recognized nationally. MPAs around Antarctica and on the high seas were also excluded, as they are not relevant in the context of measuring associations with contextual socio-economic variables. Only MPAs established before 2009 were included in order to prevent an underestimation of effectiveness due to the inclusion of immature MPAs that had not yet had enough time to institute a comprehensive management system and make progress in meeting their management objectives.

The resultant population of MPAs (N = 6,001) was sampled using a random stratified sampling design, based on their development context and size, both of which are hypothesized to have a relationship to management effectiveness (Table 3.2). The Human Development Index (HDI; UNDP 2013), which combines measures of (1) health (life expectancy at birth), (2) education (mean years of schooling and expected years of schooling) and (3) income (gross national income per capita; UNDP 2013), was used to rank countries according to their level of development and subsequently split them into quartiles (a

[12] These updates are currently (May 2014) not available on the *Sea Around Us* website (www.seaaroundus.org), but they should be later in 2014 or in early 2015.

relative ranking system also used by the United Nations to represent low, medium, high and very high levels of development). Additional HDI values were taken from Hastings (2009) in order to fill gaps and provide HDI values for sub-national political units. Although there are problems with comparing HDI values from these two different sources and years (see Hastings 2009), it was deemed less problematic than grouping disparate economies under one HDI value.

The population was further separated into a five size strata delineated according to logistically scaled size classes (0-1 km^2; 1-10 km^2; 10-100 km^2; >100 km^2). As only total area was available for some MPAs, their marine area was prorated using the median marine proportion for other MPAs in the same country. MPAs lacking any areal data (5% of total) were excluded from the sampling frame. The MPAs were randomly and proportionally sampled from each stratum so that 6% of the sampling frame had been selected for participation in the survey (n = 360). This number provided a balance between statistical power and resources required to conduct the survey.

3.2.3 Distribution

Contact information (names and email addresses[13]) for individuals closely associated with each of the sampled MPAs were sourced from publicly available online resources (including websites, online contact forms, government directories and online reports) and personal contacts. Thus, while the sampling design was probability-based, the list of recipients was identified using nonrandom methods. Although every effort was made to ensure completeness, 42 sampled MPAs were necessarily excluded due to a lack of contact information (discussed further in Results). The resultant list of recipients included government agencies, MPA managers, academics, local and international NGOs, members of community organizations, and resort and dive operators. In many cases more than one contact was sourced for a single MPA in order to ensure as high a response rate as possible.

Each recipient was sent a personalized email and introductory letter requesting their participation, or a colleague's participation, during July 2013. The introductory letter explained the survey, its context, the response process and provided a link to the online survey. A Microsoft Word version of the survey

[13] Initially, postal addresses were also collected; however, very few direct postal addresses were identified and it was not deemed worthwhile to invest in this mode of distribution.

questions was attached to the email. Participants were asked to return the completed questionnaire, via email, online, postal mail or fax, by the end of the month (giving two to three weeks to complete the survey; however, responses were accepted into August and September). Participants were sent an email reminder one week before the deadline encouraging them to complete the survey (survey materials were included again).

3.2.4 Validation and scoring

Before scoring the responses received from the survey, each set of answers was cross-validated against the comments provided by participants in the final, open-ended part of the questionnaire, and in some cases, through supplementary communication. Additionally, certain questions in the questionnaire were designed to allow cross-validation of answers. For example, one question regarding the punishment of infractions (question *9.4* in Appendix A) gives the answer option "There are no infractions [at the MPA]." If the participant selected this option it was expected to be in agreement with their answer to a preceding question (question *8.4* in Appendix A) asking what portion of users complies with MPA legislation and rules. The information provided for the descriptive questions at the beginning of the questionnaire was compared with that in the MPA database and other reliable sources to highlight any questionable responses. These two methods for cross-validation revealed that generally the responses agreed internally, as well as with other sources.

Based on the supplementary comments received from participants, the question concerning staff numbers (question *3.2* in Appendix A) was not answered in a consistent way, with some participants interpreting it to mean on-site staff, specifically. This was not the purpose of the question; it was rather to assess the total number of staff involved in management both on- and off-site. Due to this ambiguity, the results were considered unreliable and are not reported.

To facilitate scoring of the responses, the survey was based on the design of other scorecard methodologies, questions about the same topic were grouped together and skip logic was employed. Skip logic refers to the redirection of participants through the survey based on their answers. For example, should a participant indicate that there was no funding available for management (question *7.1* in Appendix A), they would not be asked to answer any further questions regarding funding. When it came to scoring this response, the MPA would automatically be assigned the lowest possible score for the section. This was based on the assumption that having no funding indicated the poorest level of effectiveness for that indicator. The same applies for staff, facilities and equipment, management objectives, management plan, resource use rules, enforcement, stakeholder involvement and monitoring and evaluation. In the few instances where a participant indicated two responses for one question (intentionally or accidentally; only possible in the Word version), the higher score was assigned, potentially resulting in a small overestimation of effectiveness in these cases. For details on how each question and section was structured and scored, see the complete questionnaire in Appendix A.

To reduce multiple responses received from different participants for the same MPA into a single representative set of answers, responses were compared on a question-by-question basis. Where there was a discrepancy between the answers for a closed-answer question, the mean was rounded to the nearest whole number (representing the closest, viable answer option in the survey). For open-ended questions concerning staff and funding, there were very few instances of MPAs with multiple responses due to the high rates of item non-response (Table 3.3). In these instances, the mean was used.

3.2.5 Composite measures of management effectiveness

The overall aim of the survey questionnaire used in this research was to produce a single, composite measure of management effectiveness for each respondent MPA, as is done in other scorecard methodologies (e.g., MBRS 2004; Staub and Hatziolos 2004; Wells and Mangubhai 2005; OSPAR Commission 2007; Stolton *et al.* 2007; Carter *et al.* 2011). Treating qualitative data as quantitative, as in this research, where the data are generally ordinal and not necessarily interval-scaled, harnesses the ranked nature of the data, but assumes equal intervals between sequential answer options. Subsequently adding the scores together (in the absence of weighting) assumes the intervals are equal across questions. Combining scores for individual indicators involves subjective decisions about manipulating the data through summing, averaging, weighting and scaling (Vanclay 2001; Leverington and Hockings 2004; Stolton *et al.* 2007). To investigate how such methods affected composite measures of management effectiveness, different techniques were applied and compared in combination with methods for missing data imputation (Table 3.1).

To calculate a composite measure of management effectiveness for each respondent MPA required a complete dataset. Complete-case analysis would have greatly reduced the sample size (from 126 to 77). Due to the low item-response rates for the open-ended questions, these questions were excluded from the analysis (Table 3.3). The two MPAs that had answers for <50% of the questions were also excluded.

After combining multiple responses for individual MPAs and accounting for the 'missingness' (i.e., missing data) arising from skip-logic, the rate of missingness was ~3%. Missing data were imputed using six strategies: sample-, group- and case-imputation of medians and means. For sample imputation, all missing data were imputed based on all responses received. For group imputation, in the instances where it was indicated that the missed question was applicable to the MPA (by answering in the affirmative for the section's leading question) the imputed value was based on all other applicable responses (where this was not applicable, case sample-imputation was applied). For example, if the participant indicated that there were management facilities (question *4.1* in Appendix A), but failed to indicate their condition (question *4.3* in Appendix A), the answer was imputed using the mean/median for the other MPAs with management facilities. Case-imputation involved imputing the missing score based on the mean/median of the other answers for the same MPA.

A number of techniques were applied for calculating a composite measure of management effectiveness to see how different methods and combinations of methods impacted the resultant composite measures, specifically with regards to imputation, weighting, grouping and aggregation (Table 3.1). One aggregation technique used was a modified form of non-parametric multiple-dimensional scaling (MDS) as employed in RapFish (Pitcher and Preikshot 2001; Pitcher *et al.* 2013) and implemented in the R computing environment (R Core Team 2013). RapFish is a rapid appraisal tool for evaluating the sustainability of fisheries along six evaluation fields: ecological, technological, economic, social, ethical and institutional (Pitcher *et al.* 2013). It has been used to generate an overall composite measure of countries' compliance with the FAO (UN) Code of Conduct for Responsible Fisheries (Pitcher *et al.* 2009). Rapfish uses constrained MDS ordination to reduce high-dimensional datasets to two-dimensional evaluation space in which the fisheries, or other units (in this case MPAs), are located. This space can also be presented as a one-dimensional rank order. Given the similarity of RapFish objectives and methods to the purposes of this research, it was deemed a suitable potential tool.

All combinations of the methods (Table 3.1) were applied to the 124 respondent MPAs, resulting in 60 composite measures of management effectiveness for each site.[14] The scores for each of these 60 measures were strongly and significantly correlated (Pearson's r > 0.97, p < 0.01 for all pairwise comparisons). This was at least partly explained by the fact that most of the indicator scores exhibited moderate positive correlation.

Given the high similarity between the resultant composite measures calculated using these alternative methods, the composite measure derived using the simplest methods was employed in further analyses. The simplest methods were considered to be case-mean substitution, equal weighting of questions and aggregation by addition without grouping. Case substitution is based on the assumption that, within each case, the score for the missing item is closely related to the scores of the other items (Raymond 1986). This was found to be the case in this dataset, which was intended to provide a measure of an overarching concept: management effectiveness.

To further test the influence of weighting on calculations of composite measures of management effectiveness, two simplified hypothetical MPA governance scenarios were simulated by altering the section weightings of the final dataset grouped into six sections. The two scenarios were a generalized top-down governance approach, where inputs and enforcement were weighted three times more heavily than the other sections, and bottom-up governance approach, where stakeholder involvement was weighted three times more heavily than the other sections. The resultant composite measures were compared to those derived from equal weighting of sections and from a dataset without any section grouping (as for the final composite measure chosen above). The results re-confirmed that weighting had little influence on the calculations of overall MPA management effectiveness as all sets of composite measures were highly positively correlated (Figure 3.1).

Once a composite measure of MPA management effectiveness was chosen, this was used to test whether there were differences in the measures of management effectiveness with regards to mode of survey return and the participant's position in connection to the MPA. Case mean-imputation, equal weighting and addition were applied to all survey responses with <50% missingness (n = 140). This allowed composite measures of management effectiveness to be calculated for each of multiple

[14] This number is not higher because certain combinations of methods resulted in the same score and other combinations were not possible.

responses for a single MPA. Using the Kruskall-Wallis test, due to the non-normal nature of the test group distributions, the following factors were tested to determine whether they influenced the mean management effectiveness measure:

- Mode: responses received via online and email.
- Participant affiliation (question *14.1* in Appendix A): participants who reported holding a position at the MPA management authority and participants not affiliated with the MPA management authority (aggregation of other answer options due to the small sample size of each).
- Participant connection to MPA (question *14.2* in Appendix A): as some participants identified more than one connection to the MPA in question, responses were split into three groups representing (1) participants whose only connection to the MPA was via management, (2) participants with a connection to the MPA via management and via another channel (e.g., as a user, local community member, etc.), and (3) participants not involved in management. Two tests were performed, one comparing participants who identified *any* connection to the MPA via management (groups 1 and 2 combined) with participants not involved in management (group 3), and the other comparing participants whose *only* connection to the MPA was via management (group 1) with participants that were connected to the MPA via management and via another channel (group 2).

3.2.6 Contextual variables

Many factors have been suggested as having a relationship to the success of protected area management effectiveness or natural resource management generally. A literature review revealed more than 20 variables potentially related to MPA management effectiveness, and variables that could be used to approximate them on a global scale (Table 3.2). Contextual variable data were collected and collated into 'profiles' for each MPA for which a composite measure of management effectiveness had been calculated (n = 124).

In addition to the list in Table 3.2, the following variables were identified as potentially related to patterns of MPA management effectiveness and included in the profile data: latitudinal location of MPA; total number of MPAs established nationally; year first MPA was established in the country; rate of unemployment; prevalence of undernourishment; prevalence of underweight children; and national health expenditure.

Given the scope and aims of this research, it was not feasible to pursue certain sub-national, local and community-level factors potentially related to management effectiveness. For example, Pollnac *et al.* (2001) in their study on the success of community-based MPAs in the Philippines, identified that having an opening ceremony for the MPA was positively related to the presence of MPA management features, including marker buoys, a management plan and a management committee. This local factor would be prohibitively difficult to assess at a global scale. Other factors were broadly approximated with national-scale variables, such as the value for coastal resources with the Environmental Performance Index. How well these national-level measures can approximate more abstract, localized concepts, such as attitudes and values, is unclear.

HDI was chosen as the primary variable of interest as it provides a broad index of human social and economic development, which is expected to be related to effectiveness of resource management. The 2012 Environmental Performance Index (EPI) combines 22 performance indicators covering aspects of environmental public health and ecosystem vitality in order to assess countries' progress towards established environmental policy goals (Emerson *et al.* 2012). The fisheries component of the EPI, representing one of ten policy categories covered by the Index, consists of a combination of (1) fraction of EEZ with overexploited and collapsed stocks, and (2) catch from trawling and dredging gears.

Governance indices drawn from the Quality of Government Basic Dataset (Jan *et al.* 2013) were the Corruption Perceptions Index from Transparency International[15]; Control of Corruption, Rule of Law and Government Effectiveness indices from The World Bank Worldwide Governance Indicators (Kaufmann *et al.* 2009); Failed States Index from The Fund for Peace[16], which combines 12 indicators to provide a measure of countries' vulnerability to internal conflict and societal deterioration; and the Freedom House/Imputed Polity democracy index (Hadenius and Teorell 2005).

Not all the variables collected were available for all MPAs, and in many instances, variables exhibited collinearity. Of those variables that described similar concepts and were highly correlated ($r^2 > 0.7$), all

[15] http://www.transparency.org/research/cpi/overview

[16] http://ffp.statesindex.org/

were eliminated but one. The variables that were retained had lower rates of missing data. The reduced list of variables used in subsequent analyses along with a brief description and data source are included in Appendix B.

3.2.7 Exploration of global trends

The overall aim of this research was to explore relationships between contextual variables and MPA management effectiveness. By understanding these associations, the ultimate objective was to develop a predictive model to be able to estimate the likely management effectiveness of MPAs for which there was no such direct measurement.

Cluster analysis was attempted as an exploratory technique to investigate potential patterns within the 34 survey questions, specifically whether similarities existed among the respondent MPAs' management status that could be related to contextual variables. Partitioning around medoids (PAM; Kaufman and Rousseeuw 1990), an iterative, divisive, non-hierarchical method for identifying clusters, was implemented using the "cluster" package (Maechler *et al.* 2013) in R (R Core Team 2013). This tool was chosen as it identifies general relationships that allow data reduction, it is more robust than k-means cluster analysis and allows the interpretation of cluster solutions using the silhouette criterion (Rousseeuw 1987; Borcard *et al.* 2011; Maechler *et al.* 2013). Silhouette width can provide an evaluation of clustering validity and can be used to select an appropriate number of clusters (Rousseeuw 1987).

After initial data exploration (Zuur *et al.* 2010), scatter plots of all predictor variables against MPA management effectiveness (calculated using case mean-imputation, equal weighting and addition; Table 3.1) were generated, along with a linear regression line and 95% confidence intervals to aid visual interpretation. For certain predictor variables, the data were lumped together but extended over a large scale; therefore, to visualize the data more clearly, they were graphed in two ways based on (1) untransformed data and (2) log-transformed data, although this did not reveal different patterns. Due to bias in the spread of the data, national-averaged measures of MPA management effectiveness were also calculated to avoid well-represented countries unduly influencing the results of correlations.

Bivariate relationships between the predictor variables and the composite measure of MPA success were investigated using Spearman's rank correlation due to the non-normal distribution of many of the predictor variables. Spearman's rank correlation is also able to detect curved (monotonic increasing or decreasing) relationships. Exact p-values are reported except in cases with tied ranks, where approximate p-values are reported (Whitlock and Schluter 2009). Due to the exploratory nature of this research unadjusted p-values are reported. However, as the number of tests increases in this kind of 'data dredging' analysis, there is an increased probability of type I error (rejecting the null hypothesis of no relationship when it is true; Whitlock and Schluter 2009). Therefore, for added interpretation, the adjusted p-values were calculated using Holm's procedure to account for multiple comparisons (Holm 1979).

Due to the limited *a priori* knowledge of predictor variables associated with MPA management effectiveness on a global scale, hypothesis testing was challenging. Rather than testing a set of competing models, which arguably would have been arbitrarily chosen, data dredge statistics were applied to assess the support for all combinations of contextual predictor variables using the MuMIn (Barton 2013) package in R (R Core Team 2013). The limitations of such data dredging techniques are acknowledged (Burnham and Anderson 2002), and the results have not been used to develop a predictive model but rather to identify variables that are useful candidates for further exploration. The second-order Akaike information criterion (AICc), rather than AIC, was used to rank models, as recommended when the ratio between sample size and the number of estimated parameters is less than 40 (Burnham and Anderson 2002). Relative variable importance was calculated as the sum of Akaike weights over all models that include a given variable (Burnham and Anderson 2002).

In all analyses, MPAs or countries with missing values for the particular predictor variable(s) being tested were excluded. An analysis of individual country- and MPA-level results is not presented here to avoid making comparisons that could be considered criticisms of particular MPAs or management agencies.

3.3 Results

3.3.1 Distribution and response rates

Of the 360 MPAs selected for participation in this research, contact information could not be sourced for 42 of them. A disproportionately large number of these were small, community-managed MPAs in the Philippines, which did not have readily identifiable contact information. This introduced non-response error. Requests for participation were sent to more than 600 email addresses associated with 318 MPAs.

However, it is likely that the survey materials were forwarded to additional recipients as requested in the introductory letter. Of the emails sent directly, around 10% were returned undelivered. A small proportion of emails (about 4%) received automatic out-of-office replies (mostly from participants in northern Europe), although many of these participants or their colleagues responded later.

Certain responses were deleted as they were either incomplete (did not reach the end of the survey) or referred to a site beyond the sampling frame, for example, a different (overlapping) designation, an MPA established less than five less years ago or a terrestrial site. A small number of additional participants replied that the MPA specified in the introductory letter was not an appropriate candidate for the survey, as it was not, in fact, an MPA. After investigating the above sites in more detail, 15 MPAs were excluded from the original sample.

In total, 144 valid responses for 126 MPAs in 36 countries were received, equating to 37% of the sampled MPAs (excluding sites subsequently revealed to be non-applicable). Half were received via email and half were completed online (one participant responded via telephone). One participant responded via both postal mail and electronic return; no-one opted to send their response via only postal mail or via fax. Together the MPAs that responded covered 950,000 km^2 of ocean, or ~8% of global MPA coverage. There was no significant difference between the mean MPA management effectiveness measure of email and online responses (Kruskal-Wallis $\chi^2 < 0.01$, df = 1, p-value = 0.95), indicating that the mode of survey completion and return had no effect on the composite measure of management effectiveness.

A response rate of 37% is comparable to or better than response rates reported in other research administering similar surveys to investigate protected area management. For example, Schultz *et al.* (2011) report a response rate of 27% for their global, self-administered survey questionnaire of Biosphere Reserves, and Alder (1996) report a response rate of 30% for their postal mail survey of tropical MPAs. Other similar studies are often unable to report response rates and assess bias, due to the non-random nature of survey sampling and distribution. Although there is no minimum response rate above which survey results are certain to be reliable (Groves 2006), any amount of non-response can lead to bias; the higher the response rate, the more likely non-response error will be small (Dillman and Bowker 2001).

After taking into account the missingness derived from the skip-logic design of the survey, response rates for individual questions (item response rates) varied greatly for open-ended and closed-answer questions (Table 3.3). Response rates for open-ended questions do not include “N/A” responses, which could mean no staff/funding, the question is not applicable or the participant does not know. For questions where closed-answer options were provided, all had item response rates exceeding 90%. By comparison, the two open-ended questions concerning the number of staff and amount of funding received (both management activities, rather than descriptive characteristics of the site) had much lower response rates: 65% and 14%, respectively. In their analysis of survey data (gathered using the Management Effectiveness Tracking Tool), Dudley *et al.* (2007) describe a similar problem of data gaps in reported staff numbers.

Rates of missingness were variable across the 144 responses, with ~3% reporting answers for less than 50% of the questions, although the majority (~83%) answered >90% of the questions. A complete record of question-by-question response frequencies for all 144 responses received (including multiple responses for certain MPAs) is given in Appendix C. Multiple responses for the same MPA (a situation that occurred for 17 MPAs) agreed on approximately half (48%) of their answers for closed-answer questions, and where they disagreed, the answers were similar (on average, the participants provided answers for adjacent, ranked options). There was very little or no difference between open-ended answers for MPA descriptive characteristics.

3.3.2 Respondent MPA characteristics

The resultant sample of 126 MPAs (hereafter referred to as the respondent MPAs) was broadly similar to the global database of MPAs from which they were drawn (excluding sites subsequently revealed to be non-applicable) with respect to age ($\chi^2 = 9.9$, df = 6, p = 0.13), geographical distribution (by latitude; $\chi^2 = 10.01$, df = 7, p = 0.19) and size ($\chi^2 = 1.9$, df = 4, p = 0.76). However, they differed significantly in terms of the development status of the countries where they were located ($p < 0.01$; Figure 3.2). More of the respondent MPAs were located in very high and high development countries than would be expected from frequencies in the global MPA database. And they were located in medium development countries less frequently. Therefore, overall the respondent MPAs represented MPAs from countries with higher levels of human development than is the case globally. (See Appendix D1 for a detailed comparison of the respondent MPA and database characteristics.)

3.3.3 Survey responses

Overall the respondent MPAs represented a wide range of management effectiveness, varying from some sites with none of the basic management elements to others with all of them present. This range, however, is relevant to only the most basic management elements assessed here, and these are not expected to be exhaustive or prescriptive, i.e., the survey did not necessarily cover all elements required for an effectively managed MPA nor are all the elements it covered necessarily needed for an MPA to be effectively managed. All the percentages presented here represent values for the number of MPAs that responded to that particular question.

Responses for questions concerning presence of inputs (staff, facilities and equipment, and funding; Figure 3.3) showed that 6% of the MPAs for which responses were received for all those questions (n = 7/123) had no staff, facilities or funding whatsoever, and an additional 11% (n = 14/123) described all of these inputs as inadequate or no-existent. Furthermore, 2% of the MPAs (n = 3/122) were described as having none of the basic management elements covered in the questionnaire: no staff, no facilities, no funding, no management plan, no management objectives, no resource use rules, no enforcement capacity, no stakeholder involvement, and no monitoring and evaluation. While most MPAs had at least some staff, facilities and equipment, and funding (72%; n = 88/123), few of the participants (9%; n =11/123) considered them to be present at levels that were good for management needs.

Responses regarding funding were highly variable, although comparable to those from other studies. Around 79% of respondent MPAs (n = 98/124) were described as having at least some funding available for management, with 13% (n = 16/124) having funding that was considered good for management needs. The amount of funding received during the most recent financial year by the respondent MPAs that reported receiving funding ranged from about \$1 per km^2 to more than \$1 million per km^2 (in year-2012 US dollars adjusted for purchasing power parity) with a median of \$2,186 per km^2, which is more than two times the value of \$775 per km^2 (year-2000 US dollars) reported by Balmford *et al.* (2004) for annual expenditure of MPAs. The figure for the respondent MPAs represented here is similar to the amount of \$1,800 reported by Hargreaves-Allen *et al.* (2011; in year-2005 US dollars). One-fifth (n = 26/124) of respondent MPAs, had no funding available, a figure very similar to reports from other survey research citing 23% (Gravestock *et al.* 2008), 22% (Hargreaves-Allen *et al.* 2011) and 23% (Balmford *et al.* 2004) of respondent MPAs as having no funding. Due to the low item response rate for this question (Table 3.3), the results should be interpreted with caution.

Responses concerning the adequacy of enforcement capacity (i.e., equipment, personnel, funding, fuel, surveillance technology) were comparable to scores for other management input elements: staff, facilities and equipment, and funding (Figure 3.4). "Acceptable but could be improved" described the enforcement capacity of the largest proportion of MPAs (43%; n = 52/121). A similar proportion of MPAs (41%; n = 50/121) were described as having inadequate enforcement capacity or none at all. On the other hand, only 15% of MPAs (n = 18/121) had enforcement capacity that was good for management needs. Enforcement capacity was found to be significantly positively correlated with the development status of the country in which the MPA was located (assessed according to the country's HDI ranking; Spearman's rho = 0.20, p = 0.03; approximate p-value reported), although sample size varied greatly between groupings (Figure 3.4). Despite these apparent shortfalls in enforcement capacity, overall compliance was reported to be good with 63% of respondent MPAs (n = 74/118) reporting that more than 66% of users complied with MPA regulations. Of the respondent MPAs, 11% (n = 14/124) indicated that there were no rules and regulations for controlling resource use and activities in the MPA. This brings into question whether these sites can be considered protected areas according to the widely applied IUCN definition (Dudley 2008).

Attainment of protected area objectives and maintenance of protected area values are primary measures of management effectiveness (Hockings *et al.* 2006). Looking at these two indicators more closely, less than half of respondent MPAs (42%; n = 52/123) were reported to have mostly or almost entirely achieved their management objectives; 16% did not even have defined management objectives (n = 20/126). According to the perceptions of participants, in most cases the condition of natural features within the MPA had either improved in comparison to their condition when the MPA was first established or had remained the same, but were in a good condition to begin with (68% and 65% of MPAs for marine species and habitats, respectively; n = 77/113 and 71/109, respectively).

Overall, scores for different indicators of MPA management effectiveness were positively correlated in all pairwise comparisons except three (out of 561). In most cases the correlations were statistically significant (88% at the 5% level using Spearman's rank correlation) and moderate (Spearman's rho >0.35 in 63% of comparisons). Indicators for the condition of natural features generally had weaker and less significant correlations with the other indicators of management effectiveness than observed for the remainder of the pairwise comparisons.

3.3.4 Overall management effectiveness

A frequency distribution of composite measures of MPA management effectiveness is presented in Figure 3.5. Measures of management effectiveness ranged from about 6 to 91, out of a maximum of 100. Overall the distribution is skewed towards the upper range. The mean measure of effectiveness across all MPAs (~55) is very comparable to the measure of Vonk (2010), who calculated the average management effectiveness of a non-random sample of global MPAs to be 0.51 (out of a maximum of one) – a figure comparable to that calculated for terrestrial and marine protected areas combined (0.53; Leverington *et al.* 2010). The composite measure of management effectiveness presented here provides only an indication of the relative spread of MPA management effectiveness; it is not intended to provide an absolute grading of management failure or success.

The management effectiveness calculated for responses received from participants involved in MPA management were on average significantly higher than for responses received from participants with no connection to MPA management. Participants who held a position at the MPA management authority ($n = 100$) reported answers that resulted in an average management effectiveness measure of 57, whereas the average management effectiveness measure calculated for responses received from participants without such an affiliation ($n = 40$) was 47 (Kruskal-Wallis $\chi^2 = 5.89$, df = 1, $p = 0.02$). This difference held for participant connection to the MPA, i.e., when participants with a connection to the site's management ($n = 105$) were compared to other participants ($n = 34$; means 56 and 48, respectively; Kruskal-Wallis $\chi^2 = 4.1$, df = 1, $p = 0.04$).

An additional test compared participants whose *only* connection to the MPA was via management ($n = 75$) with participants that had other connection(s) to the MPA (in addition to a connection via management; $n = 30$). When participants were compared in this way, there was no difference in mean management effectiveness (Kruskal-Wallis $\chi^2 = 0.19$, df = 1, $p = 0.66$), indicating that any management involvement by the survey participant – regardless of whether there were other connections to the site – could impact the composite measure of management effectiveness. There was no difference in the rate of missingness in survey responses received from managers and other participants (Kruskal-Wallis $\chi^2 = 0.08$, df = 1, $p = 0.78$).

3.3.5 Trends in MPA management effectiveness

The respondent MPAs could not be clearly partitioned into groups of similarly managed sites. A scree plot of the sum of squared error (SSE) showed no clear 'elbow' to identify the optimal number of clusters. Using the silhouette criterion (Rousseeuw 1987) revealed that the optimal (two-cluster) solution had an average silhouette width of 0.39, indicating weak structure in the data and that the clusters could be artificial (Kaufman and Rousseeuw 1990). These results are interpreted to mean that the solution space is relatively flat, without significant structure in the data. This could be a result of the correlation across indicator scores, which are almost all positively correlated.

A number of contextual variables have been suggested as having links to MPA effectiveness. Relevant to this research were those variables potentially related to MPA *management* effectiveness and its elements (Table 3.2). Figure 3.6 shows that MPA management effectiveness measures, as calculated in this research, were both high and low in various contexts. One might expect, for example, that MPA management effectiveness would be poorer in more corrupt countries (as identified by the Control of Corruption Index; Kaufmann *et al.* 2009), but this does not seem to be the case in this research; management effectiveness was both high and low across different levels of national corruption. A similar pattern was observed with regards to latitude: all regions included some well managed and some poorly managed MPAs. Similar patterns were apparent in the national-averaged data (Figure 3.7).

Relationships between predictor variables and the MPA management effectiveness measure were explored using Spearman's rank correlation, which is able to detect non-linear monotonic relationships (Table 3.4). The results show that there was a weak positive relationship between MPA management effectiveness and population growth, seafood consumption and EPI. Percentage unemployment exhibits a moderate negative relationship to MPA management effectiveness, whereas population size, latitude of the MPA and EEZ size display weak negative relationships to MPA management effectiveness. Unemployment and EPI were the only variables found to have a significant relationship to nationally averaged MPA management effectiveness.

After adjusting p-values for multiple comparisons, the only relationship to remain statistically significant was between unemployment and MPA management effectiveness for the site-level dataset (Spearman's rho = -0.40, n = 121, $p < 0.001$). This relationship was also significant after removing extreme values in the unemployment dataset (Spearman's rho = -0.36, n = 115, $p = 0.0001$). However, there is no clear theoretical basis for a relationship between protected area management effectiveness and unemployment. None of the relationships for the national-averaged dataset remained significant after adjustment.

Creating a global linear model including all predictor variables for site-level MPA management effectiveness (Appendix D2) showed that the data could be reasonably explained using a linear relationship (determined by the fairly randomly distributed residuals; Figure D.2.1(A)), and that the data could be assumed to be normal (based on the sample size and the quantile-quantile plot; Figure D.2.1(B)). Only one of the variables in this global model, population density, was significant at the 5% level, and the overall variance explained was low (adjusted $r^2 = 0.12$; Table D.2.1). Although some MPAs represent a combination of relatively extreme values for the predictor variables (Figure D.2.1(D)), upon closer inspection these were concluded to be accurate and not due to measurement error. The global linear model for nationally averaged MPA management effectiveness was not significant (F-statistic = 0.781, p = 0.66; Table D.2.2; diagnostic plots in Figure D.2.2).

The top-ranking models, ordered according to their AICc values (Appendix D3), showed some consistent results (Table D.3.1 for models of site-level management effectiveness, and Table D.3.2 for models of nationally averaged management effectiveness). Certain variables appear consistently in the 'best' models (with ΔAICc < 2), most notably EPI. Among the models of site-level MPA management effectiveness, population size, latitude of MPA, year of MPA establishment and EPI are included most frequently (Table D.3.1). In the top-ranking models of nationally averaged MPA management effectiveness (Table D.3.2), no variables other than EPI appear consistently. Interestingly, the model with the second-lowest AICc (ΔAICc = 0.14) includes only EPI.

The variables determined to have the highest relative importance across all possible models are in agreement with the variables incorporated most frequently in the top-ranking models. EPI is the most important variable among models explaining both the site-level and national-average MPA management effectiveness (Table 3.5). MPA latitude and year of establishment are both important variables in modeling site-level management effectiveness. Thereafter the relative variable importance drops to 0.62 for population size.

Due to the lack of *a prior* knowledge of the factors that influence protected area management effectiveness and the lack of strong, theoretically sound relationships among the variables examined here, it was not possible to build a comprehensive model of MPA management effectiveness. Instead, these results can provide information on useful variables for future investigation in explaining patterns of MPA management effectiveness on a global scale.

3.4 Discussion

The aim of this research was to improve understanding of the management effectiveness of MPAs globally, and to explore relationships between MPA management and contextual variables. The overarching goal was to develop a predictive tool for estimating MPA management effectiveness – and hence, the likely ecological effectiveness – of MPAs for which management had not been directly evaluated.

To collect empirical information on MPA management effectiveness, a self-administered survey questionnaire was designed and distributed to a randomly selected sample of MPAs around the world. While steps were taken to avoid coverage and sampling error, MPAs in less developed countries were not adequately represented among the respondent MPAs, indicating potential bias towards better managed sites. This should be taken into consideration when interpreting the results drawn from this dataset. There are likely to be differences between, first, the global universe and the sampling frame (coverage error), and second, the sampling frame and the respondent MPAs (non-response error) due to:

- The constant state of update of the MPA database maintained by the *Sea Around Us* and used to construct the sampling frame;
- Inconsistencies amongst data sources used to update the database (this could have, for example, resulted in a bias toward 'high-profile' MPAs and MPAs with more financial, material, and human resources available for management);
- The exclusion of certain sites from the sampling frame due to a lack of data;
- Lack of contact information for some MPAs, which therefore could not be included in the survey; and
- The low response rate (37%).

Coverage error, as with non-response error, is a function of the proportion of MPAs that are not represented and the degree to which the MPAs represented and those not represented differ in terms of management effectiveness. Taking into consideration the sources of potential bias in this research and their combined effect, it seems likely that the measures of management effectiveness presented here represent an overestimation of MPA effectiveness, and these results should be interpreted with this in mind. At certain points, the introduction of bias was unavoidable, for example, as a result of the nature of the sampling frame and respondent MPAs. In other instances, bias was introduced where necessary with the aim of being conservative, for example, when selecting basic management indicators for the survey or when combining multiple responses for a single MPA.

It was anticipated that a self-administered survey of MPA management effectiveness could result in a biased respondent dataset, with MPAs that have fewer resources being less likely to be represented, contactable and able to respond. It is within this context of potential bias that subsequent analyses took place and options were explored for identifying contextual variables that could be used to predict the effectiveness of those sites for which there was no management effectiveness information.

The survey responses revealed a wide range of management effectiveness amongst the respondent MPAs, despite the potential bias towards better-managed sites. MPAs ranged from those with good levels of all three major types of management inputs (funding, staff, and facilities and equipment) to those without any of the basic management elements. Most MPAs fell somewhere in between. While the majority of respondent MPAs (71%) had some level of these three basic inputs, far fewer (9%) had them present at levels that were considered good for management needs.

Of the MPAs represented here, one-fifth were reported to have no funding, while only 13% had funding that was considered good for management needs. This highlights a major obstacle to effective management. The general lack of tools to guide management, such as defined management objectives (which were missing at 16% of the respondent MPAs) and a management plan (which was absent at 36% of them), indicates two additional, commonly reported gaps. It is not the intention of this research to diminish the crucial role of management and managers in the effective implementation of MPAs, but rather to highlight accomplishments as well as the challenges that threaten MPA success. The management elements investigated here are considered to be among the minimum standards for effective protected area management (Carabias *et al.* 2004), and the shortcomings are clear.

Yet, despite the apparent inadequacy of basic inputs, almost half (42%) of the respondent MPAs were reported to be achieving their objectives, possibly indicating that additional resources were not necessary for achieving MPA objectives or that the participants' assessments of input adequacy or achievement of objectives were not accurate. Furthermore, most of the participants reported that the condition of marine species and habitats within the MPA had either improved compared to when the MPA was first established or had remained the same, but was good to begin with.

To get a more general indication of the management effectiveness of MPAs, a composite measure of MPA management effectiveness was generated for each site based on the survey responses. Initially, a number of techniques were explored with the aim of addressing issues of data distortion and manipulation that can be introduced while developing such a composite measure. Pairwise comparisons of the resultant composite measures showed that they were strongly positively correlated, demonstrating robustness in the survey as an evaluation tool and the measure of management effectiveness employed here. This is at least partly explained by the fairly consistent positive and moderate correlation across individual indicator scores. Such a finding raises the possibility that future research might benefit from using fewer survey questions to arrive at a comparable measure of management effectiveness.

The composite measure of management effectiveness used in this research retains limitations, however. For one, it assumes equal importance of management indicators. Additionally, it incorporates information on only basic management elements. This means that the management effectiveness measures should be interpreted only in relative terms, and that even high-ranking MPAs do not necessarily have effective management in place given their diversity of contexts, objectives and governance regimes, and hence, their specific management needs. Furthermore, by designing the survey questions to contribute to quantifying an overall concept, rather than to provide for a detailed exploration of individual management elements, in-depth insights into management and the contextual situation of the respondent MPAs were not possible. Other general limitations of such scorecard methodologies include their implicit link to conservation impacts (Stem *et al.* 2005), as well as the comparability of responses from different participants with different opinions (Hockings *et al.* 2006).

Participants involved in management generally reported higher levels of management effectiveness than other participants in this survey. There are at least three possible explanations for this: (1) MPAs with managers have more effective management, (2) the opinions of managers are comparatively optimistic, or (3) the opinions of individuals not involved in management are comparatively pessimistic. The tendency of managers to over-estimate protected area effectiveness has been suggested elsewhere (e.g., Vanclay 2001; Dudley *et al.* 2007), but to my knowledge, has not been previously demonstrated.

It is surprising that no correlation with HDI, the primary predictor variable of interest in this research, emerged here. Leverington *et al.* (2010) reported, in their meta-analysis of protected area management effectiveness evaluations, that protected area management effectiveness was higher in countries with high and medium development (identified using HDI). The Environmental Performance Index (EPI) measures national progress towards meeting environmental policy objectives related to public health and promoting ecosystem health and sound resource management (Emerson *et al.* 2012). Given its partial focus on natural resource management, EPI seems a good candidate for a correlative relationship to MPA management effectiveness, and potentially, to the value placed by a country on natural – including marine – resources, which is expected to influence the design, implementation and ecological performance of MPAs (Mascia 2004). In this research, such a positive relationship between EPI and management effectiveness was observed in both bivariate and multivariate analyses.

The length of time a protected area has been in existence is expected to influence the effectiveness of its management with older MPAs having more time to develop a comprehensive and efficient management system (Dudley *et al.* 2004; Dudley *et al.* 2007). In their study aggregating results from 330 protected area management effectiveness evaluations conducted using a scorecard tool, Dudley *et al.* (2007) report a significant negative relationship between protected area gazettal date and management effectiveness. Finding the converse relationship here is surprising and difficult to explain indicating it is likely to be spurious. The same can be said of MPA latitude which was explored as a potential predictor of MPA ecological outcomes, due to its relationship with temperature and primary productivity, although other, prior analyses revealed that the survey indicators measuring improvement in the condition of natural features were not as frequently and strongly correlated with other indicators of management effectiveness as would be expected.

The results of 'data dredging' exercises such as the ones employed here have their pitfalls when it comes to determining true relationships, and they should not be relied upon during hypothesis testing (Burnham and Anderson 2002; Whitlock and Schluter 2009; Zuur *et al.* 2010). However, in the context of this type of exploratory analysis, they have their benefits and can be instrumental in generating new hypotheses for subsequent research. While some of the relationships identified (Tables 3.4 and 3.5) might be later corroborated, determining which ones is difficult with the current dataset. Rather, new research should be conducted to independently test the hypotheses arising here (Zuur *et al.* 2010).

The outcomes of this research did not permit the development of a predictive model for MPA management effectiveness. There are a number of reasons why this might be so, each offering an avenue for future efforts to improve understanding of MPA management effectiveness. The particular nature of this dataset, for both the response variable (MPA management effectiveness) and predictor variables (contextual profiles), could have resulted in the current outcome. With regards to the response variable, measurement error could have been introduced via the survey (e.g., through poor design, biased responses) or during the scoring and aggregation process. Bias in management effectiveness of the respondent MPAs as compared to MPAs globally could have resulted in a lack of contrast in the data.

Another possibility, not precluded by the suggestions above, is that local factors have an influence on management effectiveness that obscures the detection of global-scale trends. This suggestion is not novel (Hockings *et al.* 2006; Ostrom 2007; Cinner *et al.* 2009) and seems likely given the diversity of management effectiveness observed in the range of socio-economic contexts investigated here. Because the dataset used in this research was composed of readily available or calculable predictor variables that could be widely applied to estimate MPA management effectiveness on a global scale, many of the predictor variables offer only national-level resolution, masking differences in local context. Other types of data and analyses are necessary to detect local influences, and a strong body of research investigating these relationships has already developed (e.g., Pollnac *et al.* 2001; Cinner *et al.* 2009; Pollnac *et al.* 2010; Daw *et al.* 2011). In one study, Pollnac *et al.* (2010) investigated the relationship between no-take MPA ecological performance and socio-economic context in three regions, the Philippines, Caribbean and Western Indian Ocean. The authors found that fish biomass was most strongly related to human population density and compliance with MPA rules, but the effects were region-specific. The relationship between fish biomass and human population density, for example, was negative in the Caribbean and positive in the Western Indian Ocean. Patterns like this could be masked if the data for different regions were aggregated. The basis for these variable trends was unclear, although Pollnac *et al.* (2010) suggested that they could be explained by regional differences in human mobility and *ex situ* fishing intensity.

Research that explores the influence of combinations of MPA management and design features, social and ecological factors, and their influence on ecological performance measures are gaining ground, and operating at larger scales. Recently published research from Edgar *et al.* (2014) assessed the ecological effectiveness of 87 MPAs around the world in relation to five MPA design and management features: whether or not they were no-take, well enforced, old (>10 years), large (>100 km^2) and isolated by deep water or sand. By harnessing volunteer divers around the world, the authors were able to gather on-the-ground survey data for a large number of sites – although these were not randomly selected. Their results showed that conditions within MPAs with only three of these features were indistinguishable from fished sites, but ecological benefits increased exponentially with the presence of three or more of the features. Unfortunately, of the MPAs they studied, most (59%) had only one or two of the key features and were therefore ineffective.

Studies such as the one by Edgar *et al.* (2014) reaffirm the need to the move beyond area-based global conservation targets. By looking below the surface of MPA coverage and considering the influence of particular MPA design and management features on effectiveness, we can gradually identify what role different factors play in determining the realization of conservation benefits. Edgar *et al.* (2014) also make explicit the critical link between effective management and ecological outcomes – often assumed in studies of management effectiveness, such as this one. Without an awareness and acknowledgement of this relationship and the inadequacies of many MPAs' management, we risk creating the impression that MPAs are ineffective conservation tools, for example, when pooling information on the ecological outcomes of poorly managed, enforced or designed sites with those that are effectively implemented (Guidetti *et al.* 2008). This could undermine the trust of policymakers and other stakeholders in the effectiveness of MPAs as a viable and valuable tool.

It is hoped that the results and discussion presented here offer a useful contribution to the understanding of MPA management effectiveness globally and a basis for future initiatives. It is clear that MPAs around the world face significant challenges in realizing effective management, and with more MPAs being designated each year, it is unclear how these difficulties will be addressed. Against the backdrop of continuing calls for more protected area within our oceans, it is critically important that we aim to understand the effectiveness of what has already been designated to ensure the ultimate objective of biodiversity conservation is met in the water, rather than simply reaching a numerical target on paper.

Table 3.1 Alternative methods applied at different steps of the scoring process to create composite measures of MPA management effectiveness. * indicates the methods used to calculate the composite measure of management effectiveness employed in subsequent analyses.

Aspect of scoring	Methods	
Imputation of missing data	Median substitution	Sample
		Group
		Case
	Mean substitution	Sample
		Group
		Case*
Grouping of questions into overarching themes	None*	
	12 sections corresponding to groupings used in the survey questionnaire (Appendix A): MPA boundary, staff, facilities and equipment, current funding, management objectives, management plan, resource-use rules, enforcement, education and awareness program, stakeholder involvement, monitoring and evaluation, and condition of natural features	
	6 sections corresponding to overarching themes: inputs, management planning, enforcement & compliance, stakeholder involvement, monitoring & evaluation, condition of natural features	
Weighting of each question and group	Equal*	
	Analogous to comparable scorecard systems for assessing management effectiveness (Staub and Hatziolos 2004; Stolton *et al.* 2007)	
Aggregation to produce composite measure	Addition*	
	Non-parametric ordination (Pitcher and Preikshot 2001; Pitcher *et al.* 2013)	

Table 3.2 Factors potentially related to the effectiveness of MPA management or its components (as assessed in this research), literature where the factors are mentioned, and the indicators used to approximate them. Some indicators are listed as proxies for more than one factor.

Hypothesized factor	**References**	**Indicator used in this research**
Social and economic		
Level of development	Crawford *et al.* (2000); Clausen and York (2008); Cinner *et al.* (2009); Leverington *et al.* (2010); Nolte *et al.* (2010)	UNDP's Human Development Index (HDI); GDP per capita in PPP; national GDP in PPP
Urbanization	Clausen and York (2008)	Percentage of population living in urban areas
Education	Crawford *et al.* (2000)	Average years of education
Population size	Crawford *et al.* (2000); Pollnac *et al.* (2001); Clausen and York (2008); Christie *et al.* (2009); Pollnac and Seara (2011)	Total population
Population growth	Crawford *et al.* (2000); Pollnac *et al.* (2001)	Annual population growth rate
Population density	Alder (1996)	Coastal and national population density
Values and attitudes towards coastal resources	Crawford *et al.* (2000); Mascia (2004)	Yale University's Environmental Performance Index (EPI)
Dependence on coastal resources	Alder (1996), Crawford *et al.* (2000); Pollnac *et al.* (2001)	Percentage of population employed in fisheries; seafood consumption
Size of area under jurisdiction	Crawford *et al.* (2000)	EEZ area
Governance		
Government instability	Crawford *et al.* (2000); Pollnac *et al.* (2001); Lundquist and Granek (2005), Mora and Sale (2011)	Transparency International's Corruption Perceptions Index; The Fund for Peace's Failed States Index; The World Bank's Control of Corruption and Rule of Law indicators
Degree of democracy	Crawford *et al.* (2000)	Freedom House/Imputed Polity democracy index

Hypothesized factor	References	Indicator used in this research
MPA characteristics		
MPA size	Crawford *et al.* (2000); Pollnac and Seara (2011)	MPA area
Age of MPA	Dudley *et al.* (2004), Dudley *et al.* (2007)	Year of MPA establishment
Distance of MPA from market	Crawford *et al.* (2000), Pollnac *et al.* (2001), Cinner *et al.* (2012)	Distance of MPA from coast
Fisheries		
Number of fishers	Pollnac *et al.* (2001)	Percentage of population directly employed in fisheries
Fishing pressure	Burke *et al.* (2011)	Yale University's Environmental Performance Index: fisheries component

Table 3.3 Item response rates for each survey question or management indicator. Certain indicators (*) are the combination of two questions covering the same topic (for example, presence of funding and its adequacy). This reflects how the questions were scored (see Appendix A).

Question type	Indicator		Response rate (%)
Open-ended	Staff	Number	65
	Funding	Annual amount	14
Closed-answer	MPA boundary	Management staff	94
		Key users	92
		Other stakeholders	87
		Demarcated	99
	Staff	Adequacy*	92
		Volunteers	93
	Facilities	Adequacy*	98
		Condition	97
	Funding	Adequacy*	98
		Secure	96
	Management objectives	Determined	99
		Achieved	95
		Assessment method	96
	Management plan	Presence	99
		Implemented	99
		Review	97
	Rules	Definition & clarity*	97
		Awareness	93
		Compliance	92
	Enforcement	Adequacy*	96
		Coverage adequacy	95
		Punishment	90
	Outreach	Extent	99
	Stakeholder involvement	All groups	97
		Planned	97
		Direct participation	95
		Trust	97
		Conflict resolution	93
	Monitoring and evaluation	Biophysical	98
		Socioeconomic	96
		Governance	95
		Adaptive management	95
	Natural condition	Species change	88
		Habitat change	85

Table 3.4 Correlations between contextual variables and the composite measure of site-level MPA management effectiveness, as well as nationally averaged measures of MPA management effectiveness.

	MPA management effectiveness			
	Site level		National average	
Variable	Spearman's rho	n	Spearman's rho	n
Socioeconomic & governance				
Human Development Index (HDI)	-0.05	124	0.25	40
Population density (people/km^2)	0.13	124	0.21	40
Population size	-0.19*	124	-0.23	40
Population growth (%)	0.21*	124	-0.02	40
Control of Corruption Index	-0.05	120	0.05	36
Unemployment (% of total labour force)	-0.40***	121	-0.36*	37
Seafood consumption (kg/capita/year)	0.21*	117	0.13	33
Employment in fisheries (% of population)	0.12	120	-0.15	36
EEZ size (km^2)	-0.19*	124	-0.30	40
MPA characteristics				
Latitude of MPA (degrees N or S)	-0.26**	124	-	-
Year MPA established	0.13	123	-	-
MPA size (km^2)	0.14	124	-	-
Distance of MPA from coast (km)	0.03	124	-	-
Environmental performance				
Environmental Performance Index (EPI)	0.26**	111	0.40*	28
EPI component: fisheries	0.18	123	0.04	39

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
Reported p-values are unadjusted and approximate (due to tied ranks).

Table 3.5 Relative importance of predictor variables in models of MPA management effectiveness.

	MPA management effectiveness			
	Site level		National average	
Variable	Rank	Importance	Rank	Importance
Environmental Performance Index (EPI)	1	1.00	1	1.00
Year MPA established	2	0.99	--	--
Latitude of MPA	3	0.93	--	--
Population size	4	0.62	8	0.17
Population density	5	0.48	3	0.24
Control of Corruption Index	6	0.44	2	0.40
Seafood consumption	7	0.37	5	0.21
Human Development Index (HDI)	8	0.35	4	0.22
Population growth	9	0.35	7	0.19
Employment in fisheries	10	0.35	10	0.17
Unemployment	11	0.31	9	0.17
EEZ size	12	0.29	11	0.17
EPI component: fisheries	13	0.29	6	0.21
Distance of MPA from coast	14	0.24	--	--
MPA size	15	0.24	--	--

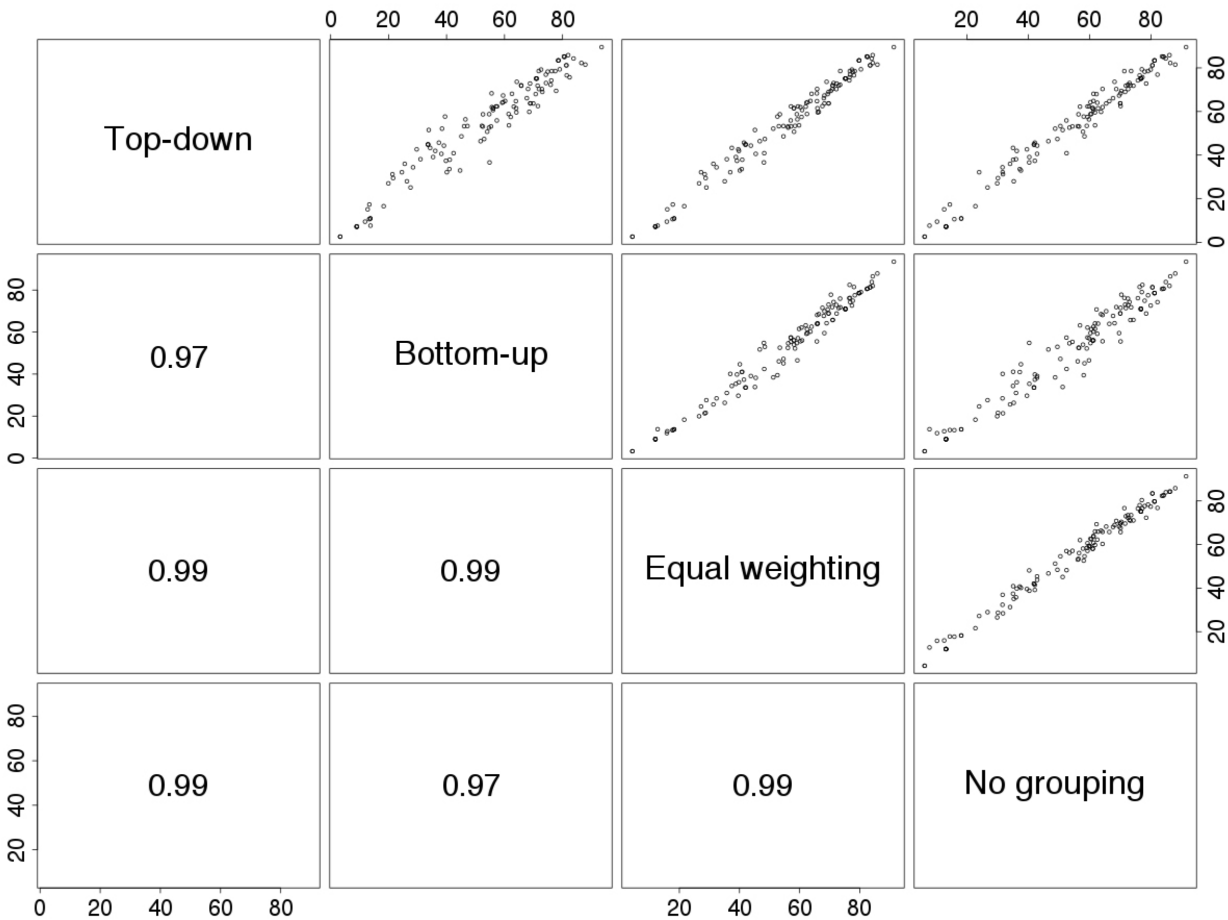


Figure 3.1 Scatterplots (upper panel) and Pearson correlation coefficients (lower panel) comparing four composite measures of MPA management effectiveness. In the top-down scenario, inputs, and enforcement & compliance were weighted three times more than the other sections in the survey. In the bottom-up scenario, stakeholder involvement was weighted three times more than the other sections. Equal weighting refers to the composite measure calculated with equal weighting of all six sections. In the final dataset, the composite measure of MPA management effectiveness was calculated using simple addition of equally weighted question scores (i.e., without any grouping into sections).

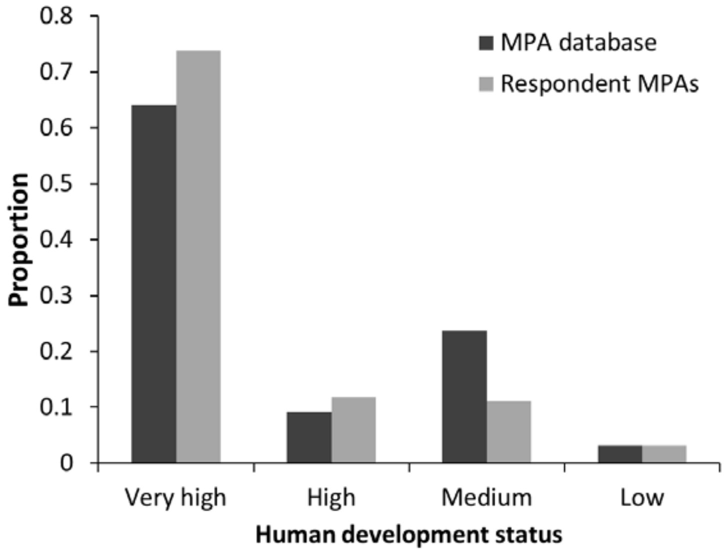


Figure 3.2 Comparison of the proportion of respondent MPAs and MPAs in the global database representing countries in each of four development categories (low, medium, high and very high).

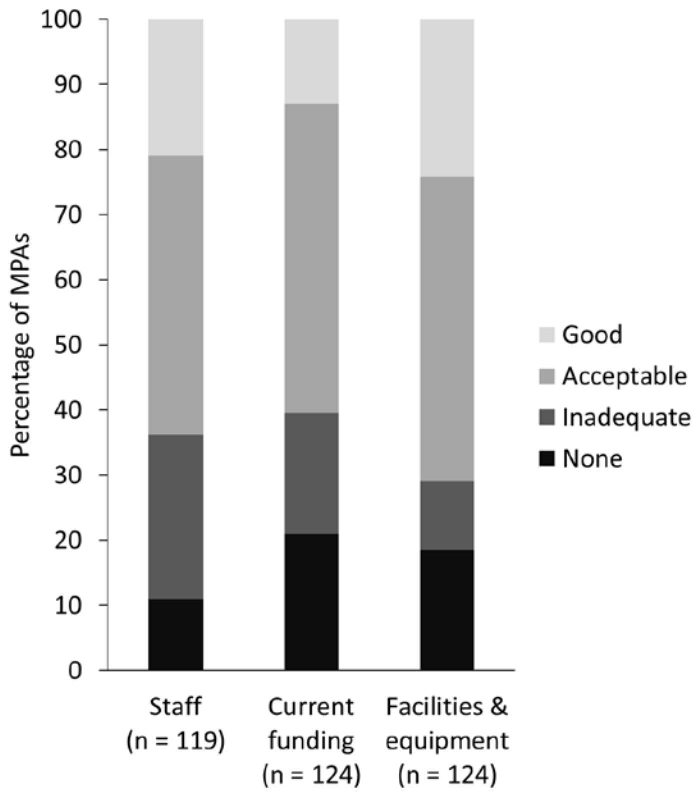


Figure 3.3 Adequacy of management inputs relative to management needs for respondent MPAs.

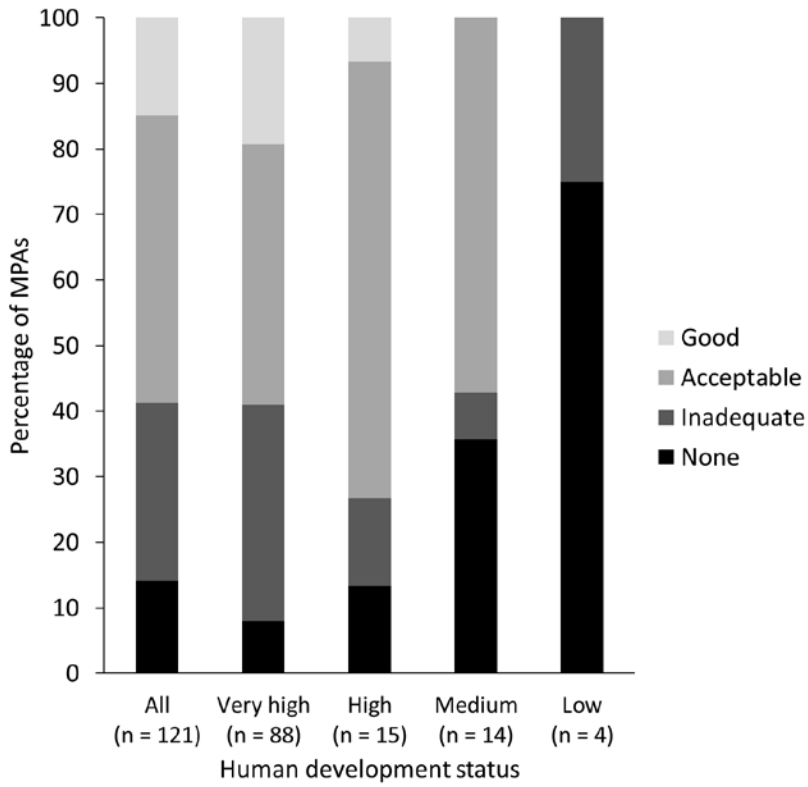


Figure 3.4 Adequacy of enforcement capacity for respondent MPAs split into groups of MPAs from countries with similar levels of development.

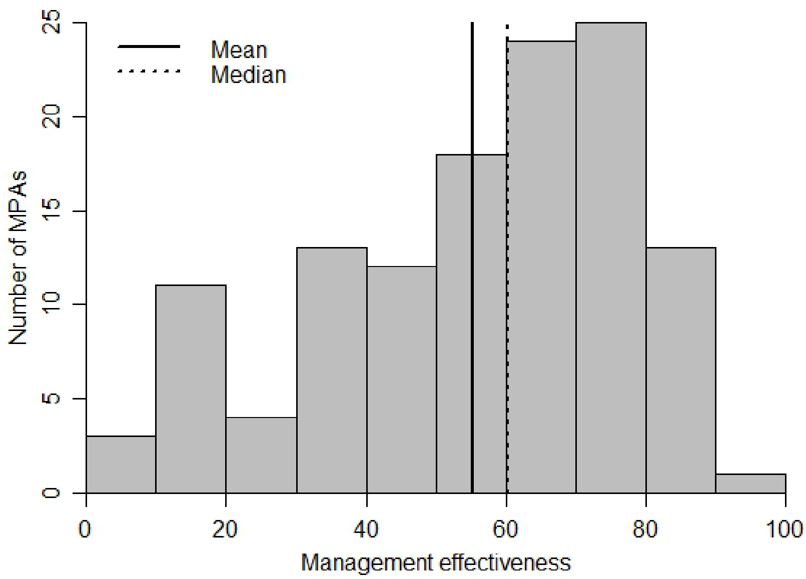
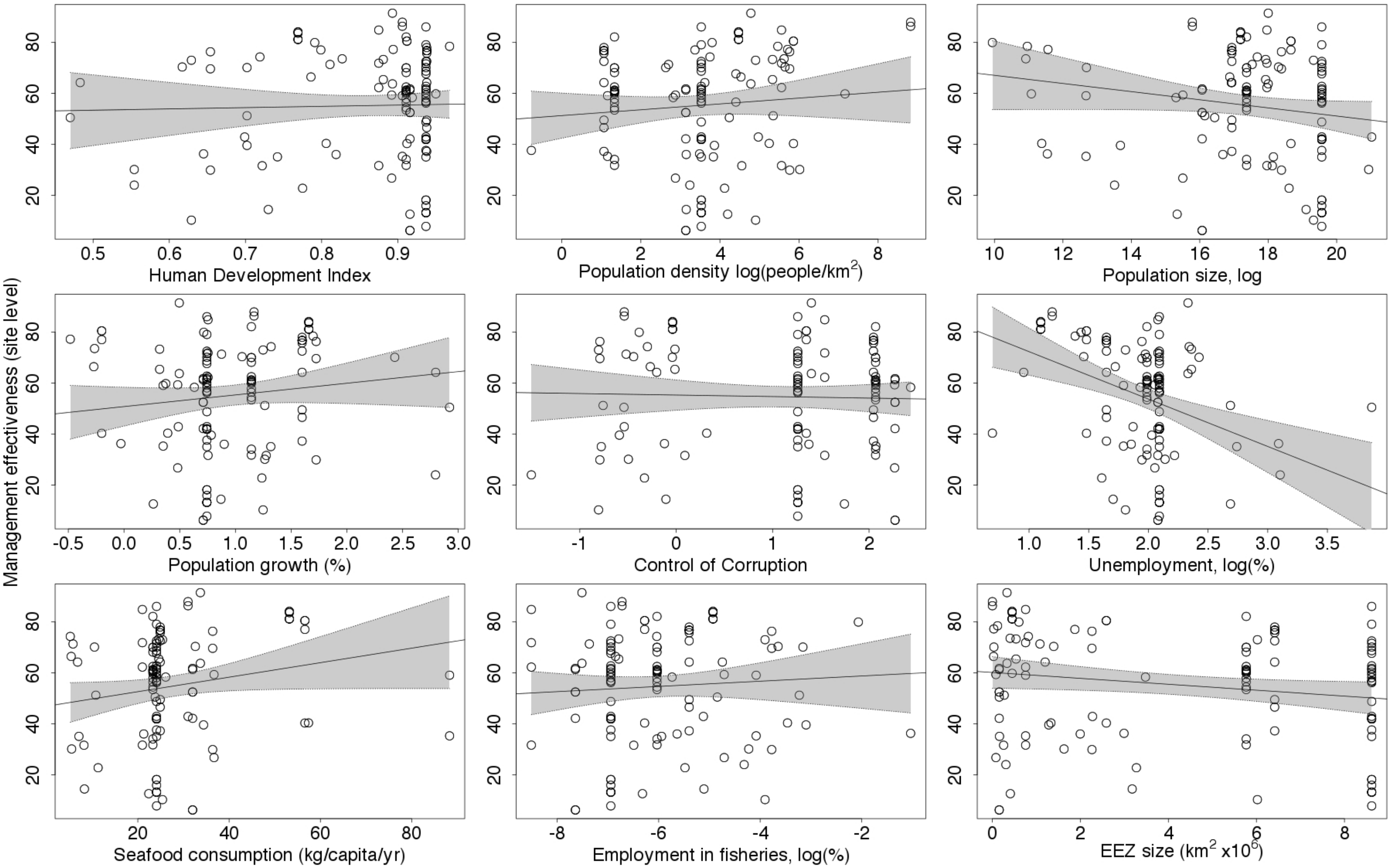


Figure 3.5 Frequency distribution of the composite measure of MPA management effectiveness.

(A)



Management effectiveness (site level)
Human Development Index
Population density log(people/km^2)
Population size, log
Population growth (%)
Control of Corruption
Unemployment, log(%)
Seafood consumption (kg/capita/yr)
Employment in fisheries, log(%)
EEZ size (km^2 x10^6)

(B)

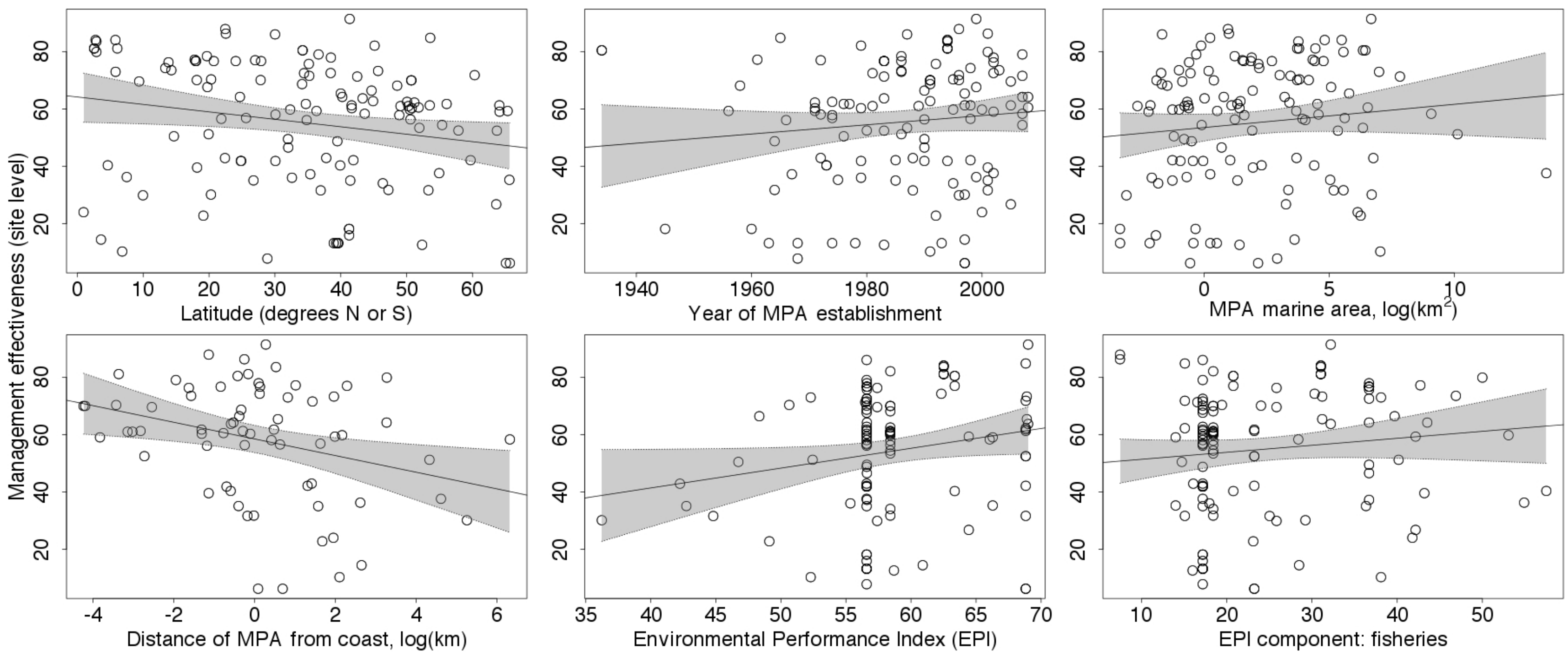
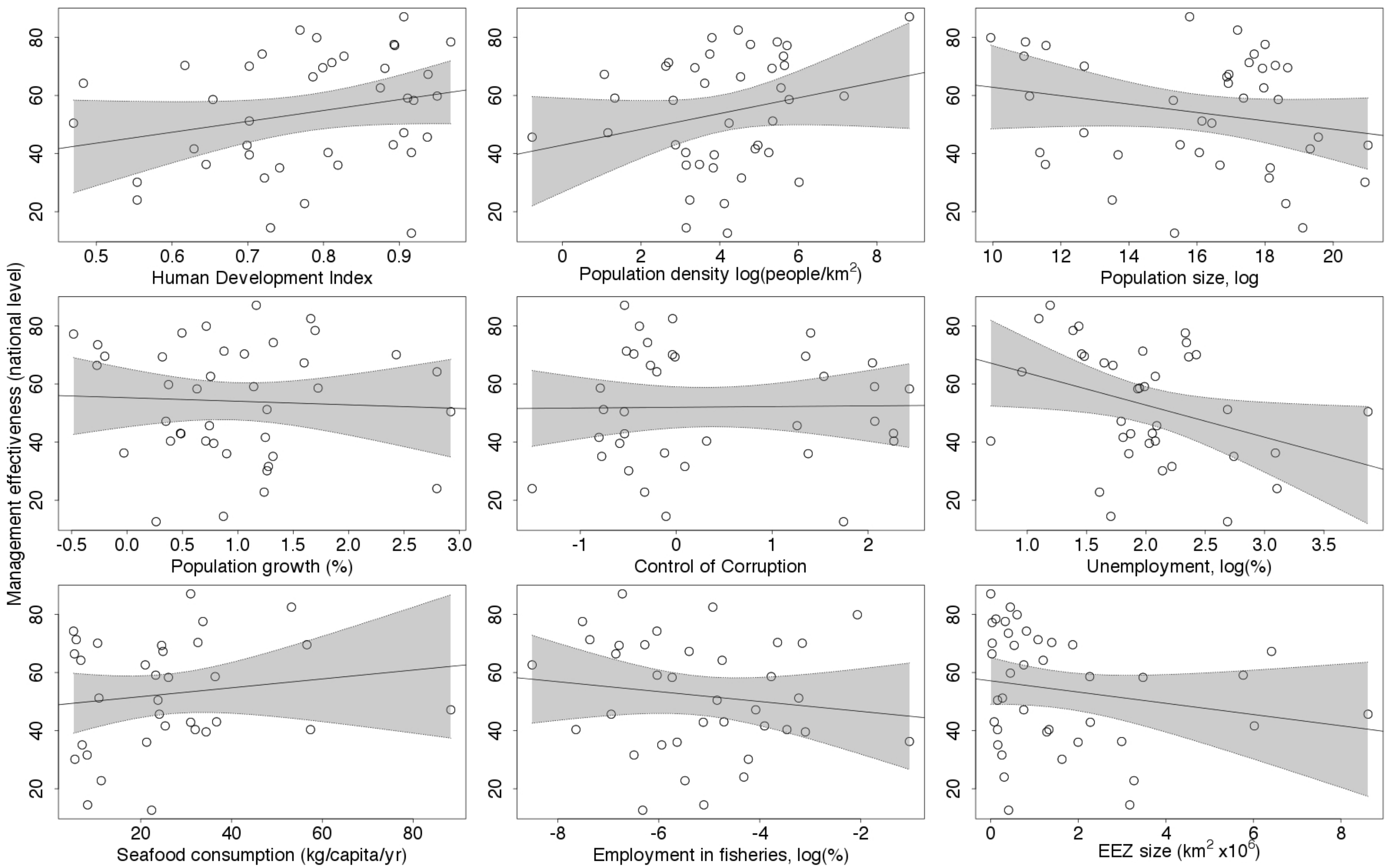


Figure 3.6 Scatter plots of the site-level composite measure of MPA management effectiveness against (A) socio-economic & governance predictor variables, and (B) MPA characteristics and environmental performance predictor variables. Linear regression lines and 95% confidence intervals are presented to aid visual interpretation.

(A)


Management effectiveness (national level)
Human Development Index
Population density log(people/km2)
Population size, log
Population growth (%)
Control of Corruption
Unemployment, log(%)
Seafood consumption (kg/capita/yr)
Employment in fisheries, log(%)
EEZ size (km2 x106)

(B)

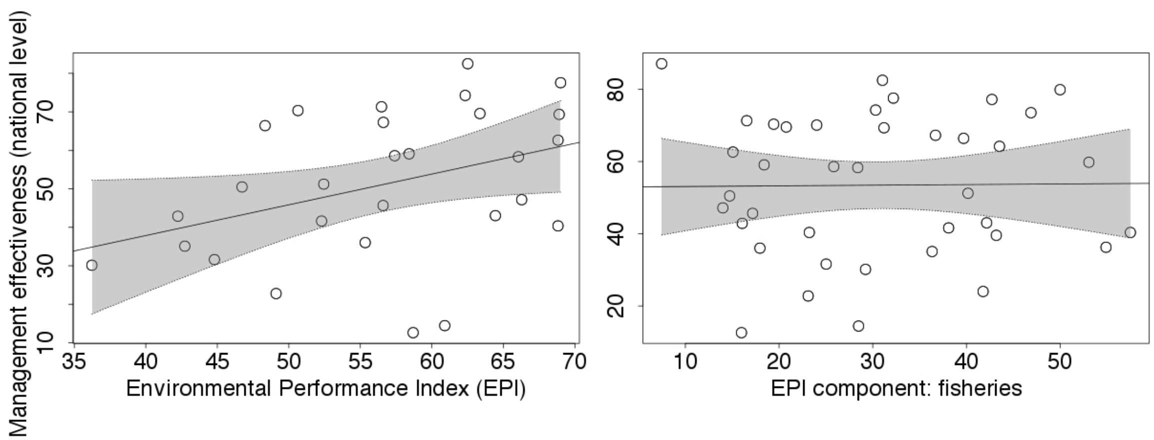


Figure 3.7 Scatter plots of the nationally averaged composite measure of MPA management effectiveness against (A) socio-economic & governance predictor variables, and (B) environmental performance predictor variables. Linear regression lines and 95% confidence intervals are presented to aid visual interpretation.

Chapter 4: Conclusion

4.1 General conclusions

The number and extent of MPAs around the world has grown rapidly during the past century. More than 6,000 MPAs worldwide cover 11.9 million km^2, or 3.27%, of the world's oceans (Chapter 2). The recent growth in areal coverage has been dramatic due to the establishment of a few very large MPAs (Chapter 2; Toropova *et al.* 2010; Spalding *et al.* 2013). Generally established in remote locations, far from human pressures, these very large MPAs can be thought of as the low-hanging fruit of marine protection – located in areas residual to extractive activities (Devillers *et al.* 2014), and whether the current pace of protected area expansion can be maintained remains to be seen. Hypothetical future scenarios presented in Chapter 2 (Figure 2.3) suggest that we will see diminishing returns – as the low-hanging fruit run out – rather than a continued accelerated increase. Without drastic changes to the classification or extension of ocean protection, attainment of 10% global coverage by 2020, as specified by Aichi Target 11 for protected areas (CBD 2010), could be compromised. Yet simply broadening the definition of what counts as an MPA should be considered a 'shortcut' to reaching 10% (MPA News 2012b), rather than real conservation progress.

The objectives for currently established MPAs are generally meagre with only one-fifth of MPA area estimated to be no-take. This equates to 0.63% of the global ocean, or 2.2 million km^2. About one-third of this area is contained within a single protected area, the British Indian Ocean Territory (Chagos) MPA. On top of this, the actual conservation benefits of the global suite of MPAs remain unclear, particularly as a growing number of studies show that MPAs are not effectively implemented (e.g., Kelleher *et al.* 1995; Mora *et al.* 2006; Vonk 2010; Burke *et al.* 2011) – although when they are, there are significant benefits for biodiversity (e.g., Edgar *et al.* 2014).

Without an understanding of the effectiveness of MPA implementation, we cannot deduce anything about MPA success as a conservation tool. There are expectations that MPAs will maintain and restore biodiversity and ecosystems, provide socioeconomic benefits and improve fisheries production (Sumaila *et al.* 2000), yet unless MPAs are implemented adequately – with appropriate design, high protection levels and effective management – we cannot assume that these expectations will be met. Pooling results for the ecological outcomes of effectively and ineffectively implemented MPAs – which essentially represent two treatment conditions – could have the effect of masking actual outcomes (Guidetti *et al.* 2008; Gelcich *et al.* 2012). This could in time undermine stakeholders' and policymakers' trust in the use of MPAs as a management tool, the concept of which is not flawed, but rather, more often, the execution.

This research has attempted to investigate some of the areas where MPAs might fall short and fail to reach their objectives, namely as a result of poor protection levels (Chapter 2) and ineffective management (Chapter 3). While a global estimate of MPA management effectiveness was not attainable in this effort, it provides some initial inroads into exploring the management effectiveness of MPAs globally – a research avenue that offers one way to take measures of protection beyond the simple metrics of coverage. The wide range of management effectiveness observed across different socio-economic contexts, indicates that local variables could act as the overriding influence, disguising global patterns.

Although no conclusive findings were made at the global-scale, the results add to the growing evidence that MPAs face huge management challenges. Such insufficiencies are likely to influence the ecological effectiveness of MPAs, and need to be understood and addressed, to ensure that MPAs are meeting their conservation objectives.

4.2 Future directions

Management and protection level are not the only factors that influence MPA ecological effectiveness (Figure 1.1). There are other influences related to MPA design (e.g., size, placement) and context (e.g., large-scale threats, management beyond the MPA's boundaries), and the ultimate measure of an MPAs effectiveness is determined by its ability to produce conservation outcomes (Kapos *et al.* 2008). While the results presented here give insights into the effectiveness of certain aspects of MPA implementation globally, and hence their *likely* ecological effectiveness, they cannot provide the full picture.

Future research aiming to assess the effectiveness of MPAs should take into account the other aspects of protected area implementation that are needed for conservation outcomes to be realized. One way to readily improve the quality of such an assessment of likely effectiveness is to combine MPA management effectiveness evaluation with a classification of MPA objectives. This would be particularly valuable in instances where research (as attempted here) defines management effectiveness as the achievement of objectives, which can be diverse. It is true that MPAs intended to contain some fisheries should be considered management successes if their objectives are met, and conversely, no-take MPAs that allow poaching within their bounds should be considered to have ineffective management (Robb *et al.* 2011). However, when the research goal is to assess the likely contribution of MPAs to achieving the broad objective of long-term nature conservation (according to the IUCN definition of protected area; Dudley 2008), the objectives of the protected area should be taken into account. We do not want a situation where MPAs meeting modest management objectives are considered more effective than those partly achieving more ambitious goals (Jones 2002).

Combining measures of management effectiveness – the degree to which MPAs are achieving their objectives – with a measure of the management objectives themselves, would greatly enhance any such assessment. Using even a coarse scale, one could assess, for example, the proportion of no-take, partly-no take and multiple-use MPAs that are achieving their objectives. While the IUCN management categories theoretically offer a classification system based on objectives, there are gaps that need to be addressed (Day *et al.* 2012) before they can reliable. The Marine Protected Area Classification System (MPACS) offers another tool for this purpose, although it has not been widely applied (Al-Abdulrazzak and Trombulak 2012).

Ground-truthing the conservation outcomes of MPAs with different combinations of objectives and management effectiveness would be an invaluable next step. These two factors can only ever provide a measure of the *likely* conservation value of an MPA; rigorous fieldwork would be needed to cross-check. Through ecological monitoring and surveying at a select number of sites, one could assess how these two factors interact with local conditions to produce outcomes such as improved fish and invertebrate biomass, density and diversity. It is through a combination of detailed case studies and large-scale surveys that these kinds of patterns can be thoroughly elucidated and investigated with the ultimate goal of enhancing the capacity of MPAs to contribute to biodiversity conservation.

There are large-scale projects, operating beyond the scope of a graduate thesis, addressing questions about MPA quality. The Global Ocean Refuge System (GLORES)[17] aims to develop objective, standardized criteria to measure and accelerate progress towards strongly protected MPAs. Based on

[17] http://globaloceanrefuge.org/

these criteria, MPAs will be assigned a Global Ocean Refuge status of: Gold, Silver or Bronze – or no status, if they do not meet the minimum standards. Another initiative, the IUCN Green List of Well Managed Protected Areas,[18] aims provide a benchmark for recognizing effective and equitable management in marine and terrestrial protected areas. The motivation behind this is to assist countries in meeting Aichi Target 11, which states that protected areas should be "effectively and equitably" managed (CBD 2010). While both systems aim to incentivize improvements in protected area quality, GLORES is more concerned with level of protection, whereas the IUCN Green List is concerned with management effectiveness. Initiatives to generate global standards – such as GLORES and the IUCN Green List – could stimulate (natural) progression towards quality protection and avoid complacency with 10% coverage. Although using a certification system for protected areas also has possible disadvantages, among them time and financial costs, diversion of resources from actual management, and further marginalization of already-marginalized sites (Dudley *et al.* 2004).

Interest in assessment of MPA governance has also grown. Peter Jones and colleagues have developed a framework for systematically evaluating and comparing the governance of individual MPAs around the world (Jones *et al.* 2011). Governance in this context covers MPA management, as a component, but goes further to consider all incentives used to steer human behavior. This framework has been applied to 20 case studies (Jones *et al.* 2011; Jones *et al.* 2013a), which together yielded insights into different governance approaches, or models, that share common attributes. The key theme to emerge is resilience through diversity: that using a combination of diverse governance approaches leads to institutional stability and resilience, in the same way that a diversity of species leads to ecosystem stability and resilience (Jones 2014).

It is now widely acknowledged that protected area designation is only the first step. As the *New York Times* editorial board succinctly put it, "The creation of a marine-protected area is only the start of an effective conservation effort, not the end" (To save fish and birds 2014). Developments in the field of MPA science show a growing emphasis on assessing, understanding and improving the quality of MPAs in terms of their ecological representativeness, protection levels, social acceptance, stakeholder cooperation, management – often specifically enforcement and compliance – and financial sustainability. In the policy-making arena, the Parties to the CBD adopted new international conservation targets during 2010, the Aichi Targets, which clearly emphasize goals for protected areas

[18] http://www.iucn.org/about/work/programmes/gpap_home/gpap_quality/gpap_greenlist/

beyond simple, area-based ends. This shift in focus is necessary to ensure that we do not reach 10% coverage with nothing more to show for it than a false sense of security in a system of paper parks.

Equally necessary is thinking beyond MPA boundaries. Protecting a percentage of ocean will not solve all marine conservation issues (Margules and Pressey 2000; Agardy *et al.* 2003; Troubled waters 2011). To counter the diversity of threats a diversity of tools and approaches is needed, including effective management beyond MPA boundaries, changes to law and policy, education and awareness, and economic incentives (Salafsky *et al.* 2002), in addition to effective protected areas.

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Appendices

Appendix A Survey questionnaire

This survey appears in the same format as it was sent to recipients (in the Word version), but also includes question numbers and answer scores. (Starts on the following page.)

Marine protected area management survey

Please note the instructions (*in italics*) for certain questions and answers. These can save you time by telling you how to skip ahead when questions don't apply.

If the site is both a marine and land protected area, please limit your answers to the marine section where possible.

Space is provided at the end of the questionnaire for additional comments.

1. Marine protected area details

Full name of the marine protected area:

What is main authority that governs how the marine protected area is managed and used? *(If there isn't a management authority, write "none")*

How big is the marine protected area?

Total area: ____________________ *Specify unit (e.g., km², ha):*__________

Marine area only: ____________________ *Specify unit (e.g., km², ha):*__________

How much of the marine protected area is designated as no-take (where all extractive activities are prohibited year-round)?

- ☐ None
- ☐ All
- ☐ Some → *Please specify the percent that is no-take:* ______*%*

2. Marine protected area boundary

What portion of management staff, key user groups and other stakeholders know the location of the boundary of the marine protected area? *(Check one option for each group)*

	None	Some (<33%)	About half (33-66%)	Most (66-95%)	All (>95%)
2.1 Management staff	**0**	**0.25**	**0.5**	**0.75**	**1**
2.2 Key user groups	**0**	**0.25**	**0.5**	**0.75**	**1**
2.3 Other stakeholders	**0**	**0.25**	**0.5**	**0.75**	**1**

2.4 Is the boundary of the marine protected area currently marked in the field (e.g., buoys, signs)?

1 Yes **0** No

3. Staff | Those people responsible for management of the site.

3.1 Are there any people responsible for managing the marine protected area?

(none) Yes **0** No → ***If no, skip to section 4.***

3.2 How many people, both paid and unpaid, are responsible for managing the marine protected area on a full-time and part-time basis?

Full-time: _________

Part-time: _________

3.3 To what extent does staff capacity meet management needs?

0.33 Inadequate for basic management needs

0.66 Acceptable but could be improved

1 Good for management needs

3.4 Is there additional personnel support from local communities, volunteer programs, etc.?

1 Yes **0** No

4. Facilities and equipment | Includes infrastructure (e.g., office space, guard house), enforcement tools (e.g., binoculars, cellphones, radios, boats) and supporting equipment (e.g., dive equipment, GPS).

4.1 Are there any facilities or equipment to support management of the marine protected area?

(none) Yes **0** No → ***If no, skip to section 5.***

4.2 To what extent do the facilities and equipment meet management needs?

0.33 Inadequate for basic management needs

0.66 Acceptable but could be improved

1 Good for management needs

4.3 What is the overall condition of the facilities and equipment?

0 Poor

0.5 Average

1 Good

5. Current funding | Financial resources for managing the marine protected area.

5.1 Is there any funding available for management of the marine protected area?

(none) Yes *1* No → ***If no, skip to section 6.***

5.2 To what extent does funding meet management needs?

0.33 Inadequate for basic management needs

0.66 Acceptable but could be improved

1 Good for management needs

5.3 Is there secure funding for management for more than one year?

1 Yes **0** No

5.4 How much funding was received for management of the marine protected area during the most recent financial year?

_____________________ *Specify currency:*_______________ ☐ Don't know

6. Management objectives | Goals that the marine protected area was established to achieve.

6.1 Have management objectives for the marine protected area been determined?

1 Yes **0** No → ***If no, skip to section 7.***

6.2 Based on monitoring data or your perceptions, to what extent have the management objectives been achieved?

0 Not at all
0.33 Somewhat
0.66 Mostly
1 Almost entirely

6.3 Is the assessment of the achievement of objectives based on monitoring data or your perceptions?

1 Monitoring data
0 Your perceptions
1 Both

7. Management plan | Document specifying a set of activities and goals to guide management of the marine protected area.

7.1 Is there a management plan for the marine protected area?

1 Yes **0** No → ***If no, skip to section 8.***

7.2 To what extent has the management plan and its components been implemented?

0 Not at all
0.33 Somewhat
0.66 Mostly
1 Almost entirely

7.3 Is there an established process for periodic review of the management plan?

1 Yes **0** No

8. Resource use rules | Laws, regulations, formal and informal policies, codes of conduct or social norms for controlling resource use and activities (e.g., fishing) in the marine protected area.

8.1 Are there any rules for controlling resource use and activities in the marine protected area?

(none) Yes **0** No → ***If no, skip to section 9.***

8.2 Which statement best describes the resource use rules?

0.25 Not clearly defined
0.5 Partially defined
0.75 Clearly defined
1 Clear and legally enforceable

8.3 What portion of users are aware of the resource use rules?

0 None
0.25 Some (<33%)
0.5 About half (33-66%)
0.75 Most (66-95%)
1 All (>95%)

8.4 What portion of users comply with the marine protected area legislation and rules?

0 None
0.25 Some (<33%)
0.5 About half (33-66%)
0.75 Most (66-95%)
1 Almost all (>95%)

9. Enforcement

9.1 Is there any capacity (e.g., equipment, personnel, funding, fuel, surveillance technology) to enforce marine protected area rules and legislation?

(none) Yes **0** No → ***If no, skip to section 10.***

9.2 To what extent does enforcement capacity meet management needs?

0.33 Inadequate for basic management needs
0.66 Acceptable but could be improved
1 Good for management needs

9.3 To what extent is monitoring and surveillance (enforcement coverage) sufficient for preventing illegal activities?

0 Inadequate for preventing illegal activities
0.5 Acceptable but could be improved
1 Good for preventing illegal activities

9.4 What portion of infractions that are caught are punished (e.g., fines levied, gear confiscated)?

0 None
0.25 Some (<50%)
0.5 Most (>50%)
0.75 There are no infractions
1 No infractions are caught

10. Education and awareness program | Activities to ensure users, local communities and other stakeholders are aware of the marine protected area, and its rules, values and purpose.

10.1 What is the extent of education and awareness activities for the marine protected area?

0 None
0.33 Limited
0.66 Systematic, but some gaps
1 Comprehensive

11. Stakeholder involvement | Stakeholders are individuals, groups, communities or organizations interested in or affected by the marine protected area.

11.1 Are stakeholders involved in any part of the management process?

(none) Yes **0** No → ***If no, skip to section 12.***

For each statement below, check the option that corresponds with your perception of stakeholder involvement at the marine protected area.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
11.2 Stakeholder involvement includes people from all relevant ethnic, religious and user groups.	**-0.5**	**-0.25**	**0**	**0.25**	**0.5**
11.3 Stakeholder involvement is informal and not part of a planned program.	**0.5**	**0.25**	**0**	**-0.25**	**-0.5**
11.4 Stakeholders participate directly in all management decisions.	**-0.5**	**-0.25**	**0**	**0.25**	**0.5**
11.5 There is open communication and trust between managers and stakeholders.	**-0.5**	**-0.25**	**0**	**0.25**	**0.5**
11.6 There are conflict resolution mechanisms (formal and informal processes for resolving disputes) in place.	**-0.5**	**-0.25**	**0**	**0.25**	**0.5**

12. Monitoring and evaluation | Collecting information over time to assess performance.

12.1 Is there any monitoring and evaluation of the marine protected area?

(none) Yes **0** No → ***If no, skip to section 13.***

How are biophysical, socioeconomic and governance indicators monitored and evaluated? *(Check one option for each group of indicators)*

	Not at all	*Ad hoc* data collection	Systematic, but some gaps	Comprehensive system
12.2 Biophysical[1]	**0**	**0.33**	**0.66**	**1**
12.3 Socioeconomic[2]	**0**	**0.33**	**0.66**	**1**
12.4 Governance[3]	**0**	**0.33**	**0.66**	**1**

[1] Examples: abundance, diversity or size of fish and other species; habitat cover; pollution levels
[2] Examples: community perceptions; resource-use patterns; livelihood trends
[3] Examples: number of infractions; enforcement coverage; stakeholder participation

12.5 Is there an established process for using the results of monitoring and evaluation to improve management activities (i.e., adaptive management)?

1 Yes **0** No

13. Condition of natural features | Natural features include marine species (e.g., fishes, crabs, corals, turtles, seabirds) and habitats (e.g., reefs, mangroves, seagrass beds).

13.1 In what year was the marine protected area established?

YYYY __________

What was the overall condition of the marine species and habitats when the marine protected area was first established?

	Poor	Average	Good
13.2 Marine species	**(no score)**	**(no score)**	**(no score, but when paired with an answer of "about the same" for the following question a score of 0.5 assigned for that question)**
13.3 Habitats	**(no score)**	**(no score)**	**(no score, but when paired with an answer of "about the same" for the following question a score of 0.5 assigned for that question)**

What is the current overall condition of the marine species and habitats compared to when the marine protected area was first established?

	A lot worse	Somewhat worse	About the same	Somewhat better	A lot better
13.4 Marine species	**-0.5**	**-0.25**	**0**	**0.25**	**0.5**
13.5 Habitats	**-0.5**	**-0.25**	**0**	**0.25**	**0.5**

14. Respondent details

What is your job title?

14.1 At what type of organization do you hold this position?

- ☐ Management authority for the marine protected area
- ☐ Non-governmental organization
- ☐ Academic institution
- ☐ Other ⟶ *Specify the type of organisation:* ____

  ____

14.2 What is your connection to the marine protected area? *(Check all that apply)*

- ☐ Involved in management
- ☐ Volunteer at the site
- ☐ User (e.g., fisher, diver, boater, beachgoer)
- ☐ Local community member
- ☐ Involved in site design/establishment
- ☐ Other ⟶ *Specify your connection to the marine protected area:*________________________

  ____

THANK YOU AGAIN

Results from this research will be made available on the Sea Around Us Project website (http://www.seaaroundus.org/) on Lisa Boonzaier's profile page during the first half of 2014.

Comments | *If there is any additional information you think will benefit this study, please add the relevant details below.*

Appendix B Final list of predictor variables.

Variable	Description	Year	Primary source	Supplementary data
Socioeconomic				
Human Development Index (HDI)	Combines indicators of health (life expectancy at birth), education (mean years of schooling and expected years of schooling) and income (gross national income per capita); ranges from 0 to 1	2013	UNDP (2013) http://hdr.undp.org/en/data	Hastings (2009)
Population density	National population density (people per km^2) including all of the country's residents regardless of legal status or citizenship (except refugees not permanently settled)	2011	World Development Indicators, The World Bank http://data.worldbank.org/data-catalog/world-development-indicators	CIA World Factbook https://www.cia.gov/library/publications/the-world-factbook/; Populstat http://www.populstat.info/
Population size	Total national population including all of the country's residents regardless of legal status or citizenship (except refugees not permanently settled)	2012	World Development Indicators, The World Bank http://data.worldbank.org/data-catalog/world-development-indicators	--
Population growth	Annual percentage growth based on all of a country's residents regardless of legal status or citizenship (except refugees not permanently settled)	2012	World Development Indicators, The World Bank http://data.worldbank.org/data-catalog/world-development-indicators	--

Variable	Description	Year	Primary source	Supplementary data
Control of Corruption Index	Measure of perceptions of corruption, conventionally defined as the exercise of public power for private gain; ranges from -2.5 to 2.5)	2009	Worldwide Governance Indicators, The World Bank, via Quality of Government Basic Dataset (Jan *et al.* 2013) http://www.qog.pol.gu.se	--
Unemployment	Percentage of labor force without jobs	multiple	CIA World Factbook https://www.cia.gov/library/publications/the-world-factbook/	World Development Indicators, The World Bank (http://data.worldbank.org/data-catalog/world-development-indicators)
Seafood consumption	Fish supply in live weight per person (kg/capita/yr)	2009	UN Food and Agriculture Organization Statistics (FAOSTAT; Laurenti 2011) http://www.fao.org/fishery/statistics/global-consumption/en	--
Number of fishers	Number of people employed directly in fisheries as a proportion of the total population (%)	2003	Teh and Sumaila (2013) (number of people employed in fisheries) and World Development Indicators (for population size)	--
EEZ size	Size of exclusive economic zone (km^2)	N/A	*Sea Around Us* http://www.seaaroundus.org/	--

Variable	Description	Year	Primary source	Supplementary data
MPA characteristics				
Latitude of MPA	Latitude of central point of MPA (degrees N or S)	N/A	*Sea Around Us* MPA database	--
Year of MPA establishment	Year MPA was originally established	N/A	*Sea Around Us* MPA database	--
MPA size	Size of MPA (km^2)	N/A	*Sea Around Us* MPA database	--
Distance of MPA from coast	Distance of MPA from coast (km)	N/A	Coordinate data from *Sea Around Us* MPA database; distance calculated using ArcGIS	--
Environmental performance				
Environmental Performance Index (EPI)	Combines 22 performance indicators covering aspects of environmental public health and ecosystem vitality; ranges from 0 to 100	2012	Yale University (Emerson *et al.* 2012) http://epi.yale.edu/	--
EPI: fisheries component	Combines the fraction of EEZ with overexploited and collapsed stocks and catch from trawling and dredging gears; ranges from 0 to 100	2012	Yale University (Emerson *et al.* 2012) http://epi.yale.edu/	--

Appendix C Response frequencies

Response frequencies for each question in the MPA management effectiveness survey (see Appendix A for complete question wording) prior to scoring and accounting for skip logic, and aggregated across 144 responses. Certain questions (indicated by *) were used to facilitate skip-logic.

2.1 MPA boundary: known by management staff

Response	Count	%
None	1	1
Some (<33%)	11	8
About half (33-66%)	10	7
Most (66-95%)	21	16
All (>95%)	92	68
Sum	135	100

2.2 MPA boundary: known by key user groups

Response	Count	%
None	2	2
Some (<33%)	32	24
About half (33-66%)	24	18
Most (66-95%)	37	28
All (>95%)	37	28
Sum	132	100

2.3 MPA boundary: known by other stakeholders

Response	Count	%
None	5	4
Some (<33%)	54	43
About half (33-66%)	25	20
Most (66-95%)	31	25
All (>95%)	10	8
Sum	125	100

2.4 MPA boundary: marked

Response	Count	%
Yes	52	37
No	90	63
Sum	142	100

**3.1* Staff: exist

Response	Count	%
Yes	128	90
No	15	10
Sum	143	100

3.3 Staff: adequacy

Response	Count	%
Inadequate	35	30
Acceptable	57	48
Good	26	22
Sum	118	100

3.4 Staff: additional support exists

Response	Count	%
Yes	88	74
No	31	26
Sum	119	100

**4.1* Facilities & equipment: exist

Response	Count	%
Yes	113	80
No	29	20
Sum	142	100

4.2 Facilities & equipment: adequacy

Response	Count	%
Inadequate	14	12
Acceptable	68	60
Good	31	27
Sum	113	100

4.3 Facilities & equipment: condition

Response	Count	%
Poor	9	8
Average	48	44
Good	53	48
Sum	110	100

*5.1 Funding: available

Response	Count	%	50 100
Yes	110	78	
No	31	22	
Sum	141	100	

5.2 Funding: adequacy

Response	Count	%	50 100
Inadequate	29	26	
Acceptable	68	60	
Good	16	14	
Sum	113	100	

5.3 Funding: secure for >1 year

Response	Count	%	50 100
Yes	93	85	
No	17	15	
Sum	110	100	

*6.1 Management objectives: determined

Response	Count	%	50 100
Yes	116	82	
No	26	18	
Sum	142	100	

6.2 Management objectives: extent of achievement

Response	Count	%	50 100
Not at all	3	3	
Somewhat	53	48	
Mostly	40	36	
Almost entirely	15	14	
Sum	111	100	

6.3 Management objectives: assessment based on

Response	Count	%	50 100
Monitoring data	9	8	
Perceptions	36	32	
Both	67	60	
Sum	112	100	

*7.1 Management plan: exists

Response	Count	%	50 100
Yes	91	64	
No	52	36	
Sum	143	100	

7.2 Management plan: extent of implementation

Response	Count	%	50 100
Not at all	0	0	
Somewhat	43	48	
Mostly	30	33	
Almost entirely	17	19	
Sum	90	100	

7.3 Management plan: review process exists

Response	Count	%	50 100
Yes	72	80	
No	18	20	
Sum	90	100	

*8.1 Resource use rules: exist

Response	Count	%	50 100
Yes	127	90	
No	14	10	
Sum	141	100	

8.2 Resource use rules: adequacy

Response	Count	%	50 100
Not clearly defined	4	3	
Partially defined	16	13	
Clearly defined	29	23	
Clear & legally enforceab	77	61	
Sum	126	100	

8.3 Resource use rules: portion of users aware of rules

Response	Count	%	50 100
None	0	0	
Some (<33%)	12	10	
About half (33-66%)	22	18	
Most (66-95%)	71	59	
All (>95%)	15	13	
Sum	120	100	

8.4 Resource use rules: portion of users that comply

Response	Count	%	50 100
None	0	0	
Some (<33%)	17	14	
About half (33-66%)	24	20	
Most (66-95%)	66	55	
All (>95%)	12	10	
Sum	119	100	

**9.1* Enforcement: capacity exists

Response	Count	%	50 100
Yes	118	83	
No	24	17	
Sum	142	100	

9.2 Enforcement: capacity adequacy

Response	Count	%	50 100
Inadequate	38	33	
Acceptable	59	51	
Good	18	16	
Sum	115	100	

9.3 Enforcement: coverage adequacy

Response	Count	%	50 100
Inadequate	45	39	
Acceptable	52	46	
Good	17	15	
Sum	114	100	

9.4 Enforcement: portion of infractions punished

Response	Count	%	50 100
None	8	7	
Some (<50%)	52	49	
Most (>50%)	41	38	
No infractions	5	5	
No infractions caught	1	1	
Sum	107	100	

10.1 Education and awareness program: extent

Response	Count	%	50 100
None	16	11	
Limited	65	45	
Systematic	49	34	
Comprehensive	13	9	
Sum	143	100	

**11.1* Stakeholder involvement: exists

Response	Count	%	50 100
Yes	115	82	
No	25	18	
Sum	140	100	

11.2 Stakeholder involvement: all relevant groups

Response	Count	%	50 100
Strongly disagree	1	1	
Disagree	7	6	
Neutral	27	24	
Agree	44	39	
Strongly agree	35	31	
Sum	114	100	

11.3 Stakeholder involvement: informal & not planned

Response	Count	%	50 100
Strongly disagree	8	7	
Disagree	52	45	
Neutral	15	13	
Agree	28	24	
Strongly agree	12	10	
Sum	115	100	

11.4 Stakeholders involvement: direct participation

Response	Count	%	50 100
Strongly disagree	13	12	
Disagree	38	34	
Neutral	23	21	
Agree	32	29	
Strongly agree	6	5	
Sum	112	100	

11.5 Stakeholder involvement: open communication

Response	Count	%	50 100
Strongly disagree	4	3	
Disagree	9	8	
Neutral	44	38	
Agree	39	34	
Strongly agree	19	17	
Sum	115	100	

11.6 Stakeholder involvement: conflict resolution

Response	Count	%	50 100
Strongly disagree	4	4	
Disagree	14	13	
Neutral	29	27	
Agree	34	31	
Strongly agree	28	26	
Sum	109	100	

**12.1* Monitoring & evaluation: exists

Response	Count	%	50 100
Yes	115	82	
No	26	18	
Sum	141	100	

12.2 Monitoring & evaluation: biophysical

Response	Count	%	50 100
Not at all	5	4	
Ad hoc	28	24	
Systematic	58	50	
Comprehensive	25	22	
Sum	116	100	

12.3 Monitoring & evaluation: socioeconomic

Response	Count	%	50 100
Not at all	27	24	
Ad hoc	52	46	
Systematic	30	27	
Comprehensive	4	4	
Sum	113	100	

12.4 Monitoring & evaluation: governance

Response	Count	%	50 100
Not at all	29	26	
Ad hoc	31	28	
Systematic	42	38	
Comprehensive	10	9	
Sum	112	100	

12.5 Monitoring & evaluation: adaptive management

Response	Count	%	50 100
Yes	80	71	
No	32	29	
Sum	112	100	

13.2 Condition of natural features: spp. at establishment

Response	Count	%	50 100
Poor	7	5	
Average	60	46	
Good	63	48	
Sum	130	100	

13.3 Condition of natural features: habitats at establishment

Response	Count	%	50 100
Poor	8	6	
Average	51	41	
Good	66	53	
Sum	125	100	

13.4 Condition of natural features: spp. Change

Response	Count	%	50 100
A lot worse	1	1	
Somewhat worse	16	13	
About the same	56	44	
Somewhat better	39	31	
A lot better	15	12	
Sum	127	100	

13.5 Condition of natural features: habitats change

Response	Count	%	50 100
A lot worse	1	1	
Somewhat worse	15	12	
About the same	64	52	
Somewhat better	31	25	
A lot better	12	10	
Sum	123	100	

Appendix D Supplementary figures and tables for Chapter 3

D.1 Comparison of the characteristics of the respondent MPAs and the universe of MPAs from which they were drawn.

Table D.1.1 Comparison of the age of respondent MPAs and of the universe of MPAs from which they were drawn.

	Age (years)			
	Universe		Sample	
Median	21		23	
Min	5		5	
Max	114		79	
	Number	**%**	**Number**	**%**
<10	850	14	11	9
10-20	1,778	30	40	32
20-30	1,201	20	31	25
30-40	911	15	20	16
40-50	449	8	14	11
>50	411	7	7	6
unknown	386	6	3	2
Total	5,986	100	126	100

$\chi^2 = 9.9$, df = 6, p = 0.13

Table D.1.2 Comparison of the geographic distribution (by latitude) of respondent MPAs and of the universe of MPAs from which they were drawn.

	Universe		Sample	
	Number	**%**	**Number**	**%**
>60°N	243	4	9	7
60 to 40°N	1,916	32	36	29
40 to 20°N	1,373	23	37	29
20 to 0°N	1,350	23	20	16
0 to 20°S	439	7	8	6
20 to 40°S	367	6	10	8
>40°S	92	2	3	2
unknown	206	3	3	2
Total	5,986	100	126	100

$\chi^2 = 10.01$, df = 7, p = 0.19

Table D.1.3 Comparison of the size of respondent MPAs and of the universe of MPAs from which they were drawn.

	Size (km^2)			
	Universe		**Sample**	
Median	~4		~5	
Min	<0.05		<0.05	
Max	954,511		865,087	
	Number	**%**	**Number**	**%**
<1	2,177	36	41	33
1-10	1,574	26	33	26
10-100	1,144	19	25	20
100-1,000	736	12	20	16
>1,000	355	6	7	6
Total	5,986	100	126	100

$\chi^2 = 1.89$, df = 4, p = 0.76

Table D.1.4 Comparison of the development context (determined by HDI)[19] of respondent MPAs and of the universe of MPAs from which they were drawn.

	HDI			
	Universe		Sample	
Median	0.91		0.91	
Min	0.33		0.47	
Max	0.97		0.97	
	Number	**%**	**Number**	**%**
Very high	3,836	64	93	74
High	546	9	15	12
Medium	1,415	24	14	11
Low	189	3	4	3
Total	5,986	100	126	100

p = 0.0041

[19] Human development categories were assigned by ranking all countries and territories with MPAs according to their Human Development Index (HDI; UNDP 2013) and subsequently dividing the list into quartiles (a relative ranking system also used by the United Nations).

D.2 Summary statistics for global linear models of MPA management effectiveness.

Table D.2.1 Summary statistics for the global linear model of site-level MPA management effectiveness incorporating all predictor variables.

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	-335	308	-1.09	0.28
Human Development Index (HDI)	27.30	69.30	0.39	0.69
Population density*	0.06	0.03	2.02	0.05
Population growth	5.62	6.94	0.81	0.42
Population size	~0	~0	-1.65	0.10
Control of Corruption Index	2.53	5.64	0.45	0.66
Unemployment	-0.28	0.56	-0.50	0.62
Seafood consumption	0.28	0.22	1.30	0.20
Fishers	-730	549	-1.33	0.19
Latitude	-0.43	0.29	-1.49	0.14
Year of MPA establishment	0.19	0.16	1.18	0.24
MPA size	~0	~0	-0.16	0.88
Distance of MPA from coast	~0	0.04	-0.06	0.95
EEZ size	~0	~0	-0.05	0.96
Environmental Performance Index (EPI)	-0.01	0.61	-0.01	0.99
EPI: fisheries component	0.18	0.37	0.50	0.62
Multiple r^2 = 0.24 Adjusted r^2 = 0.12 F-statistic = 1.98, p = 0.02				

* $p < 0.05$

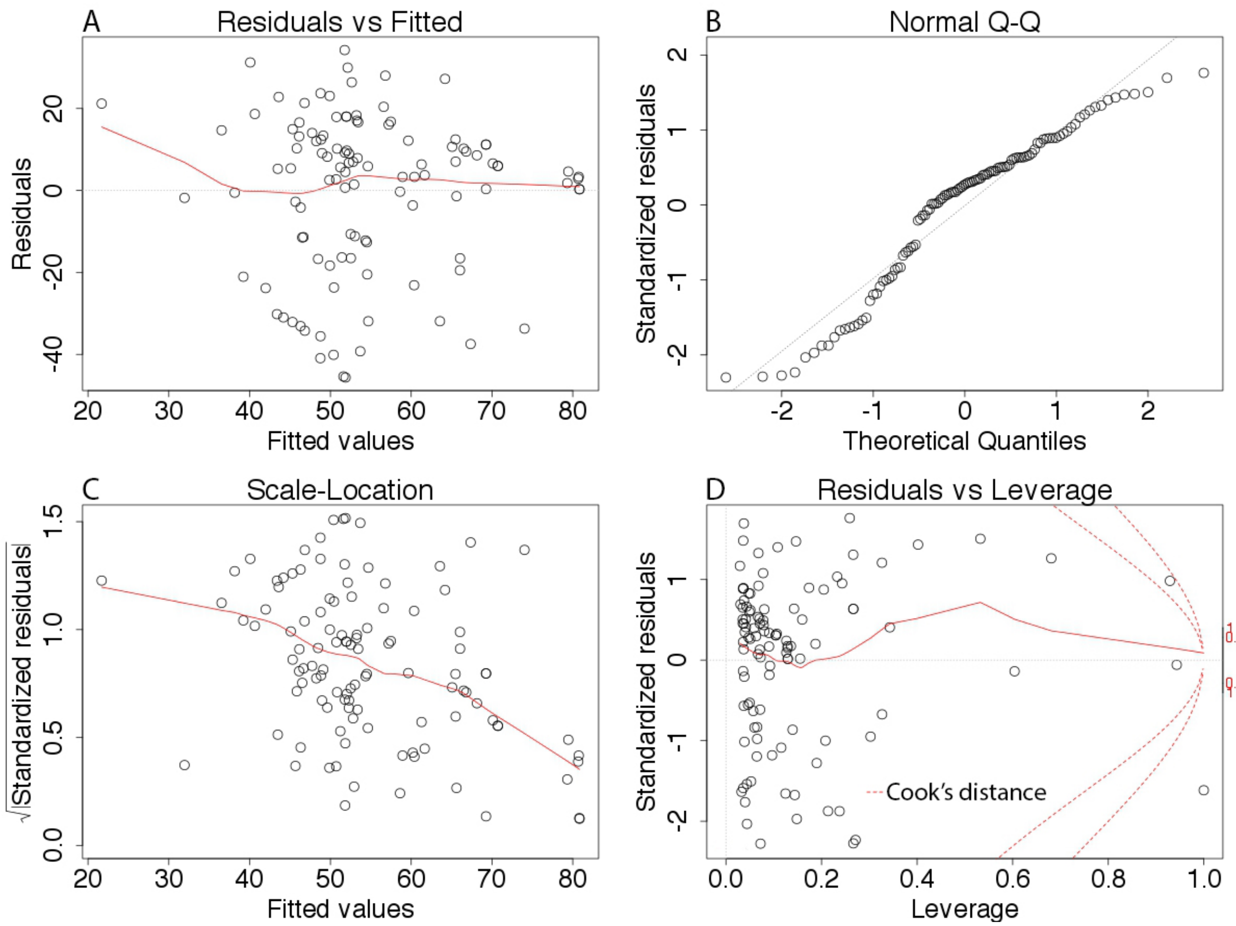

Figure D.2.1 Summary plots used to evaluate assumptions of the global linear model of site-level MPA management effectiveness incorporating all predictor variables: (A) residuals versus fitted values, (B) quantile-quantile plot for normality, (C) standardized residuals versus fitted values, (D) standardized residuals versus leverage with Cook's distance statistic superimposed.

Table D.2.2 Summary statistics for the global linear model of nationally averaged MPA management effectiveness incorporating all national-level predictor variables.

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	-21.5	72.4	-0.30	0.77
Human Development Index (HDI)	11.6	80.5	0.14	0.89
Population density	0.06	0.06	1.11	0.28
Population growth	3.39	9.47	0.36	0.73
Population size	~0	~0	-0.71	0.49
Control of Corruption Index	-6.89	6.49	-1.06	0.30
Unemployment	-0.05	0.7	-0.08	0.94
Seafood consumption	0.43	0.31	1.39	0.18
Fishers	-721	621	-1.16	0.26
EEZ size	~0	~0	0.42	0.68
Environmental Performance Index (EPI)	0.74	0.76	0.97	0.35
EPI: fisheries component	0.45	0.51	0.88	0.39
Multiple r^2 = 0.35 Adjusted r^2 = -0.1 F-statistic = 0.78, p = 0.66				

Note: none of the variables were significant.

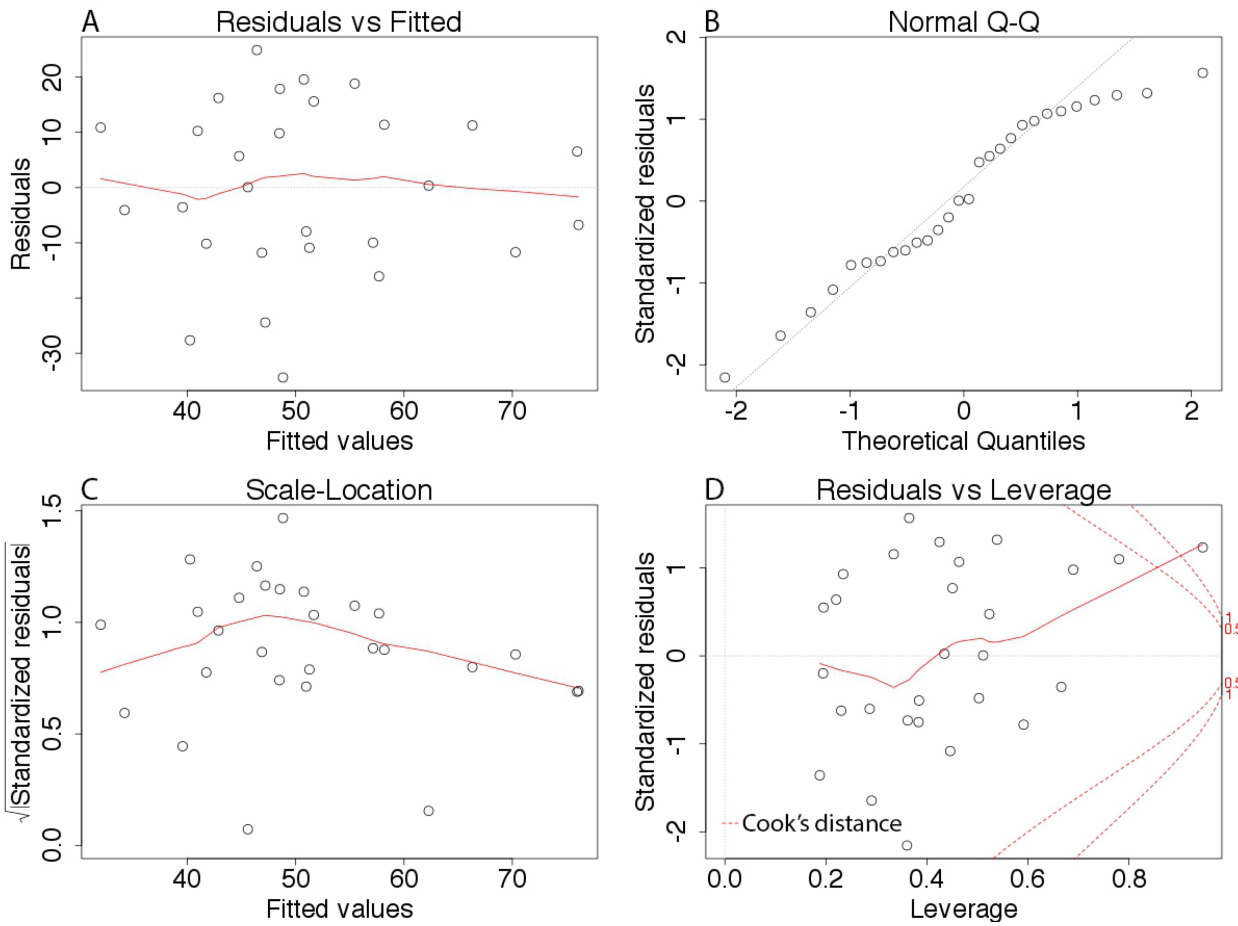

Figure D.2.2 Summary plots used to evaluate assumptions of the global linear model of nationally averaged MPA management effectiveness incorporating all national-level predictor variables: (A) residuals versus fitted values, (B) quantile-quantile plot for normality, (C) standardized residuals versus fitted values, (D) standardized residuals versus leverage with Cook's distance statistic superimposed.

D.3 Summary statistics for top-ranking models of MPA management effectiveness.

Table D.3.1 Summary statistics for the top-ranking models (with ∆AICc < 2) of site-level MPA management effectiveness.

Model rank	HDI	Population density	Population size	Corruption	Unemployment	Seafood consumption	Employment in fisheries	Latitude of MPA	Year MPA established	EPI	AICc	∆AICc
1		0.04	~0	7.43				-0.64	0.16	0.49	982.61	0.00
2			~0					-0.45	0.09	0.82	983.00	0.39
3			~0	4.09				-0.61	0.12	0.76	983.32	0.70
4	56.08	0.04	~0					-0.53	0.17	0.41	983.55	0.94
5		0.05	~0	6.84			-418.79	-0.66	0.19	0.36	983.73	1.11
6			~0		-0.55			-0.43	0.09	0.68	983.80	1.18
7	28.07		~0					-0.53	0.12	0.72	983.94	1.32
8				4.81				-0.63	0.15	1.09	984.02	1.41
9		0.06	~0	6.08		0.24	-651.81	-0.60	0.23	-0.01	984.27	1.66
10	28.72	0.05	~0	5.39				-0.63	0.18	0.39	984.36	1.75
11			~0			0.16		-0.42	0.11	0.61	984.37	1.76
12			~0				-315.10	-0.50	0.11	0.76	984.40	1.78
13		0.04	~0	7.22		0.12		-0.61	0.17	0.33	984.40	1.79
14								-0.45	0.12	1.21	984.47	1.85
15		0.04	~0	6.70	-0.33			-0.60	0.15	0.43	984.48	1.86
16		0.03		7.42				-0.66	0.18	0.94	984.58	1.97

Table D.3.2 Summary statistics for the top-ranking models (with ∆AICc < 2) of nationally averaged MPA management effectiveness.

Model rank	Intercept	HDI	Population density	Corruption	EPI	AICc	∆AICc
1	-18.64			-6.02	1.29	245.89	0.00
2	5.91				0.80	246.04	0.14
3	16.75	-41.67			1.18	247.40	1.51
4	-5.43		0.04		0.93	247.42	1.52