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Explaining global patterns and trends in marine protected area (MPA) development

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ABSTRACT

The relative paucity and heterogeneous distribution of marine protected areas (MPAs) indicates the need for better understanding of factors that foster MPA establishment at local, sub-national, and national levels. The relationship between national-level MPA establishment and geographic, ecological, social, and political factors that may drive patterns and trends in MPA establishment were assessed. A country's coastline length is the strongest predictor of both the number and spatial extent of MPAs. Controlling for coastline, the Human Development Index (HDI) and spatial overlap with designated conservation priority areas are positively correlated with MPA establishment. Surprisingly, some factors influencing MPA establishment in case studies, such as percentage of fishers within a population, were not correlated with MPA establishment on a national scale. These national dynamics explain a relatively small proportion of variation, however, indicating that other biological or social factors, as well as sub-national processes, also influence MPA establishment. Positive and negative outliers illuminate the importance of policy engagement at both national and local levels. Ensuring a supportive enabling environment at the national or even multi-national level can enhance success at the local level.

1. Introduction

Marine protected areas (MPAs) are a core management response to many of the pervasive human impacts on the world's oceans [1]. MPAs can increase abundance of important organisms, restore food webs, protect key habitats, and sustain ecosystem services [2–4]. As a result, Parties to the Convention on Biological Diversity (CBD) recently re-committed to the target of "at least 10% of each of the world's marine and coastal ecological regions effectively conserved by 2020" [5]. Despite declarations of increasingly large "world's largest" MPAs, it seems clear these CBD targets will not be met [6–8].

Moreover, protection of the oceans through MPAs has not kept pace with anthropogenic threats or with terrestrial conservation efforts [6,9,10]. Although the spatial extent of MPAs globally has increased rapidly in recent decades – at a rate of 4.6% per year (1984–2006), and faster since – MPAs covered only 1.17% of the ocean's surface (approximately 4.21 million km^2) at the time of the 2010 CBD meeting of the Conference of the Parties [8]. Terrestrial protected areas, by contrast, cover more than 12% of the earth's land surface [9]. The spatial extent of MPAs varies widely across marine ecoregions and biogeographic provinces, with most MPAs concentrated in intertidal or near-coastal waters [6–8].

Though it makes sense ecologically to examine MPA patterns and trends across ecoregions, MPA establishment is an inherently political process. The distribution of MPAs varies widely among nations, from zero to over 30% of a country's Economic Exclusion Zone (EEZ). Only 12 of 151 coastal countries exceed the 10% MPA target [8,11]. Differences among nations in rates and patterns of protected area establishment may arise in part due to country-level factors, such as conservation leadership and institutional infrastructure [12]. Much of the recent, rapid growth in spatial extent of MPAs has been driven by the establishment of very large ($>100{,}000$ km^2) MPAs in places with sparse human populations [8], such as Papahanaumokuakea Marine National Monument, USA, 2006; Phoenix Islands Protected Area, Kiribati, 2008; and Chagos Islands Marine Reserve, UK, 2010 [13,14].

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Small MPAs can have significant biological responses [15], however, and – where integrated within sustainable fisheries management strategies in poor countries – are likely more important contributors to local food security [16].

The rapid but heterogeneous expansion of MPAs in recent decades raises a fundamental scientific question: *why do patterns and trends in MPA establishment vary among nations*? Social science research highlights the roles that geographic, organizational, economic, and political factors play in the diffusion of novel policies and practices [17]. Building upon these ideas, the impacts of conservation investments and geographic, socioeconomic, and political context on MPA establishment globally are examined. In exploring this basic scientific question, this work informs a longstanding policy debate over *what steps can decision-makers take to accelerate the establishment of MPAs*? Understanding the variation in MPA establishment among nations can provide insights into how to create "enabling environments" that accelerate and scale up the formation of MPAs [18].

2. Methods

2.1. Pre-analysis

The number of MPAs and their total area for 152 coastal countries (i.e., including only countries with a marine coastline) were calculated. Country-specific data on the number, spatial extent, and year of establishment of MPAs are from the MPA Global database ([19], 2010 update), a comprehensive marine-specific update of the World Database on Protected Areas that includes data for all MPAs designated through statutory and non-statutory mechanisms [6]. Total length of coastline (ctry3m shapefile, ESRI) for each country was determined using ArcGIS 9.

Factors were identified that might shape patterns and trends in the total number and spatial extent of MPAs among countries, as well as proxy variables for each of these factors. The most complete freely available country-level datasets for each were then obtained (Table 1). Of 18 possible variables, any that were highly correlated ($R > 0.7$, Table S2) or based on the same underlying data were eliminated (e.g., the number of fishers per kilometer coastline was already included in coastline length, and so eliminated, but fishers per capita was included). Additionally, since the indices of human development (HDI) and governance (World Bank governance score) used in this analysis are composites of underlying factors, principal component analysis (PCA, varimax rotation using JMP) of these variables was conducted to see if any strong correlations emerged from a more detailed analysis (see Supplementary Information for description of PCA methodology and results).

Table 1
Sources of datasets used in country-level analysis.

Dataset (and variable)	*Source*
Length of coastline (ln km)	CIA World Factbook https://www.cia.gov/library/publications/the-world-factbook
Human Development Index (HDI)	Human Development Report – UNDP http://hdr.undp.org/en/statistics/data/
Number of people employed in fishing (ln #)	EarthTrends – World Resources Institute http://earthtrends.wri.org
Total population	HNP Stats – World Bank http://go.worldbank.org/N2N84RDV00
WWF priority marine ecoregion (ln km)	WWF (Grieve & Short 2007)
Number of decked fishery vessels	EarthTrends – World Resources Institute http://earthtrends.wri.org/
Unemployment rate (%)	CIA World Factbook https://www.cia.gov/library/publications/the-world-factbook

2.2. Predictor variables

Six predictor variables and their principal components were used for analyses: geography (coastline length), socioeconomic context (unemployment rate, Human Development Index), fisheries variables (fishers per capita, number of decked fishery vessels), and conservation effort (proxied by WWF in-house shapefiles for priority marine ecoregions). Rationale for including each variable follows:

- Geography: coastline length relates to area of MPAs in a country, with a longer coastline indicating more potential area to be protected.
- Socioeconomic context: reducing unemployment rate is correlated with reduction in poverty, yet poverty can have an ambiguous impact on conservation [20]. Human Development Index (HDI) is a composite index ranging from zero to one that measures the average achievements in a country in three basic dimensions of human development: a long and healthy life, access to knowledge, and a decent standard of living. These dimensions are operationalized as life expectancy at birth, adult literacy and combined gross enrollment in primary, secondary and tertiary level education, and gross domestic product (GDP) per capita in purchasing power parity (PPP) US dollars. In terrestrial systems, HDI is correlated with conservation impediments, such as deforestation in countries with biodiversity hotspots [21].
- Fisheries variables: evidence suggests that a country's fisheries may variously foster or undermine MPA development. Fishers may support an increased number of MPAs to rebuild fish stocks and reduce conflicts between fishers or between fishers and other industries such as tourism [2,22]. Conflict reduction can result from the implementation of zoning to specify the allowed activities in areas of the MPA (e.g., [23]). Fisher support for MPAs would lead to a higher number of MPAs with more fishers. Alternatively, fishers may oppose MPAs because of real or perceived reduced access to fish [24,25], leading to fewer MPAs located in countries with a higher number of fishers.
- Conservation investment: areas prioritized for biodiversity conservation by international nongovernmental organizations (NGOs) tend to receive greater conservation investment [26,27]. These conservation prioritization schemes rarely include marine systems comprehensively, though, and are often biased toward tropical coral reef habitats as well as marine areas adjacent to terrestrial priorities. However, WWF's Global 200 [28] does include marine systems comprehensively, by systematically classifying the oceans according to marine major habitat type and identifying key ecoregions within those habitats. These areas have been further refined as priority marine ecoregions [29], which were used as a proxy for conservation investment (Fig. 1). The marine ecoregions of the world classification [30] is globally comprehensive but does not include prioritization.

2.3. Analysis

2.3.1. Spatial patterns

Linear regression was used for MPA spatial extent and a generalized linear model (GLM) was used for number of MPAs

(Table S3). The strength of predictor variables was interpreted via standardized regression coefficients (standardized β [i.e., coefficients on variables were standardized by subtracting the mean and dividing by the standard deviation]). Four of the six variables were found to have significant coefficients in the full model; therefore the non-significant variables were removed (number of decked fishery vessels and unemployment rate), which increased the number of countries included from 97 in the full model to 134 in the reduced model (since fewer countries were eliminated from the regression due to fewer missing values). For both sets of linear models the geographic factor (length of coastline) was replaced with EEZ area, with no significant changes in results.

2.3.2. Change over time

Linear regressions were used to examine percentage change in spatial extent of MPAs over time between 1980 and 2010. These response variables were compared to trends in governance and HDI (and their principal components, see Supplementary Information), to determine if these drivers corresponded to trajectories of MPA establishment.

2.3.3. Conservation investment

The linear relationship between number and spatial extent of MPAs and their overlap with conservation investment priorities (WWF priority ecoregions) was assessed. Wilcoxon rank sums tests and two-sample t-tests were used to examine if number or spatial extent of MPAs was correlated with countries that did or did not have area within WWF priority ecoregions in 2010.

2.3.4. Comparison to terrestrial protected areas (PAs)

Finally, patterns and trends of PA growth in marine and terrestrial environments were compared using Pearson's correlations. Data on terrestrial PAs for coastal countries was acquired from the World Database on Protected Areas [31].

3. Results

3.1. Spatial patterns

National-level factors explain a small but statistically significant level of variation in the number and spatial extent of MPAs in a country (Tables 2 and 3). The factor with the strongest effect on MPA establishment in a country (as reflected by the standardized β regression coefficient) was length of coastline, although positive and negative outliers exist (Fig. 2(a) and (b)). A one-unit change (in standard deviation of coastline length) resulted in a 0.64 change in the spatial extent of MPAs. The next strongest variable

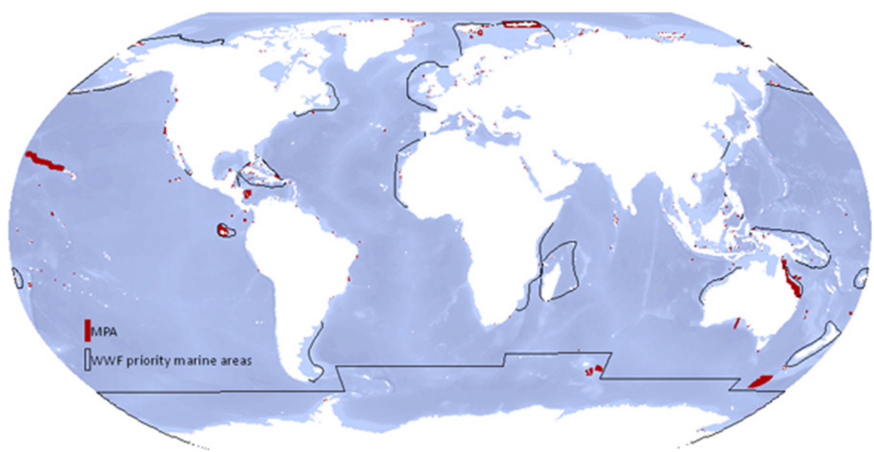

Fig. 1. Global MPAs (solid red) and WWF focal marine ecoregions (outlined). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2
Reduced model results for number of MPAs – generalized linear model parameter estimates.

		Psuedo R^2		Significance (p)		
MPA Count–GLM		0.236		< 0.0001		
Term	Estimate	Standard error	L–R ChiSquare	Significance (p)	Lower CL	Upper CL
Coastline (ln km)	0.5701796	0.0758456	58.773169	< .0001*	0.4230091	0.7207663
Priority perimeter (ln km)	0.1093829	0.0430509	7.2509672	0.0071*	0.028648	0.1984698
Fishers per capita(ln [fishers/pop'n])	12.230309	17.025852	0.4868404	0.4853	−23.86512	42.781711
HDI	2.3269639	0.8768857	7.8284139	0.0051*	0.6702298	4.1062195

Table 3
Reduced model results for MPA spatial extent – linear regression parameter estimates.

Variables	Standardized β	Standard error	Test statistic (t or F)	p	r	R^2	Adjusted R^2
Coastline (ln km)	0.637	0.131	9.018	< 0.001*			
HDI	0.131	1.278	2.075	0.04*			
Priority perimeter (ln km)	0.104	0.059	1.413	0.16			
Fishers per capita (ln [fishers/pop'n])	0.043	21.083	0.62	0.49			
Model ANOVA			35.802	< 0.001	0.725	0.526	0.511

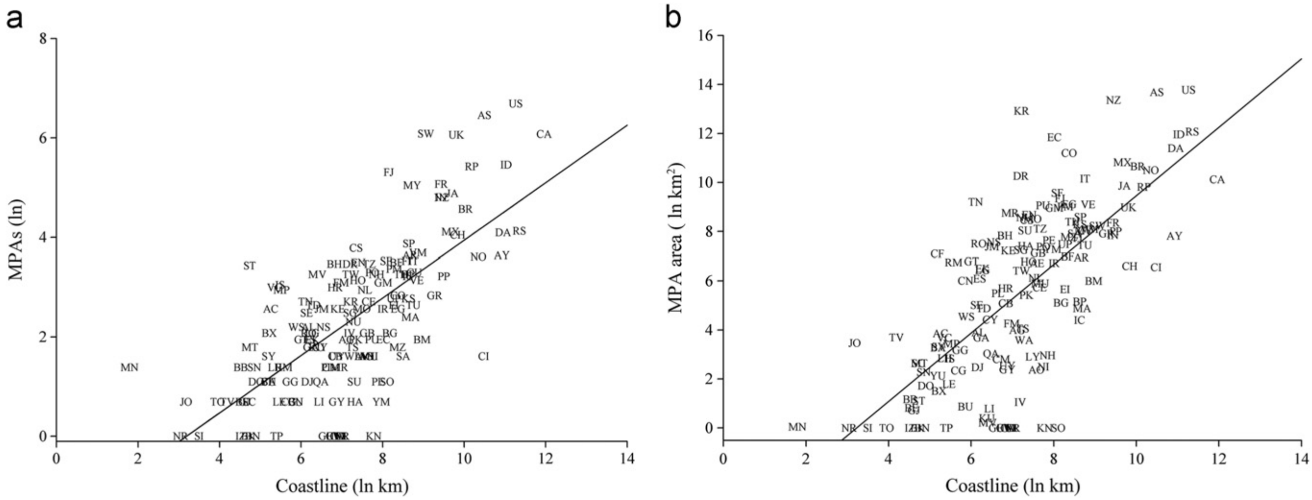

Fig. 2. Relationship between length of national coastline and (a) number and (b) total area of MPAs. Countries with greater MPA area than expected based on the regression line (residuals >4.0 ln km^2) include: Colombia (CO), Dominican Republic (DR), Ecuador (EC), Kiribati (KR), New Zealand (NZ), Republic of the Congo (CF), and Tonga (TN). Those with lesser (residuals <-4.0 ln km^2, excluding countries without any MPAs) include: Cote d'Ivoire (IV), Kuwait (KU), and the Maldives (MV). See Table S1 for a complete list of country codes. Regression line equations for (a) $y=-1.841017+0.578141x$; $p<0.0001$, $R^2=0.49138$ and (b) $y=-4.492728+1.39582x$; $p<0.0001$, $R^2=0.50788$.

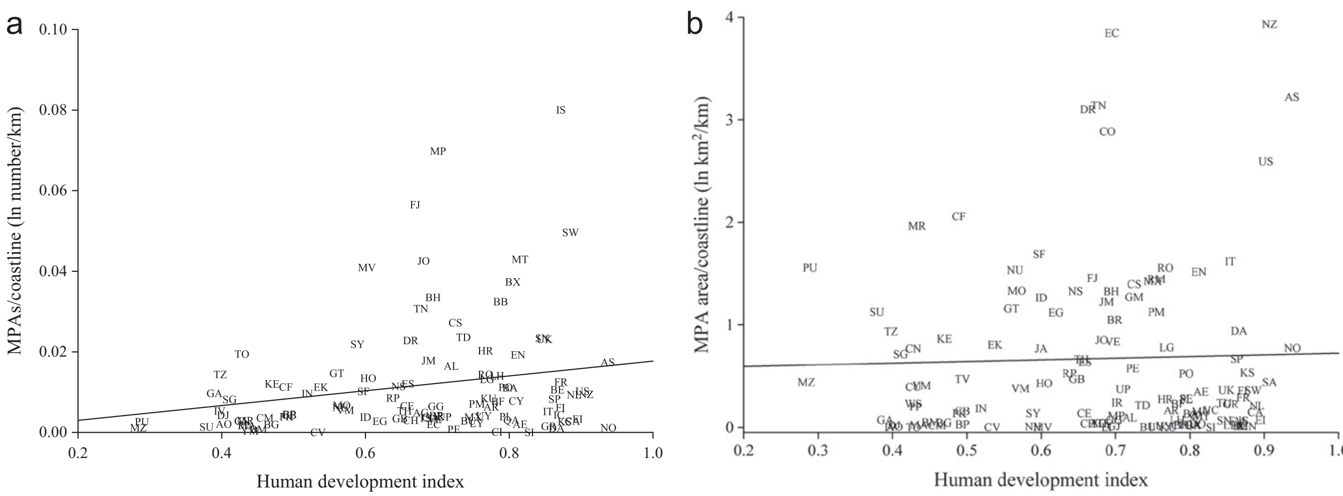

Fig. 3. Relationship between Human Development Index and (a) number and (b) total area of MPAs. Countries with greater MPA area than expected based on the regression line (residuals >2.0 ln km^2/km) include: Australia (AS), Colombia (CO), Dominican Republic (DR), Ecuador (EC), Kiribati (KR), New Zealand (NZ), and Tonga (TN); those with lesser (residuals <-0.069 ln km^2/km) include Slovenia (SI) and Monaco (MN). Regression line equations for (a) $y=-0.0006984+0.018382x$; $p=0.0299$, $R^2=0.044102$ and (b) $y=0.5616+0.1614x$; $p=0.7571$, $R^2=0.0008$.

was HDI (Fig. 3(a) and (b)), with standardized β values of 0.13 (Table 2). In the generalized linear model, coastline length, HDI and conservation investment were positively correlated with the number of MPAs in a country ($p=<0.0001$, Psuedo $R^2=0.236$, Table 3). Some countries have relatively more, smaller MPAs than expected for their coastline length (e.g., Sweden, United Kingdom, and the Maldives) and some have relatively fewer, larger MPAs (e.g., Ecuador, Kiribati, and Colombia; Fig. 4).

3.2. *Change over time*

Trends in MPA spatial extent relative to shifts in governance and socioeconomic context were examined for the period 1980–2010. MPA spatial extent was positively correlated with HDI health components but negatively correlated with HDI income values. Change in education was not related. However, these factors only represent about 8% of the variation (Table 4). Analysis of MPA changes over time compared to governance factors did not yield significant results.

3.3. *Conservation investment*

When examined categorically, countries included at least partly within WWF priority marine ecoregions (the proxy for conservation investment) have more and larger MPAs than those wholly outside priority ecoregions (Wilcoxon rank sums test, $S=3847$, $Z=-4.43747$, $p<0.0001$ [number] two-sample t-test, $t=4.72$, $df=139.4$, $p<0.0001$ [spatial extent]). However, when length of coastline (km) was controlled for the differences between countries with or without conservation investment were not significant (Wilcoxon rank sums test, $S=4908$, $Z=-0.10205$, $p=0.9187$ [number] two-sample t-test, $t=1.580$, $df=139.1$, $p=0.1160$ [spatial extent]). In the linear models, length of coastline (km) included in a priority ecoregion in a country was positively correlated with the number of MPAs in a country (Chi square=7.25, p=0.0071) but not the spatial extent of these MPAs (t=1.413, p=0.16; Table 2). However, neither number nor spatial extent of MPAs were significantly correlated with conservation investment in a simple linear regression (Fig. 5(a) and (b)). Some countries, such as Canada, Antarctica, and China, have long coastlines in WWF priority marine ecoregions but relatively little area within MPAs. Conversely, countries such as Kiribati and Tonga have relatively high coverage of MPAs but are not in priority marine ecoregions (Fig. 5(b).

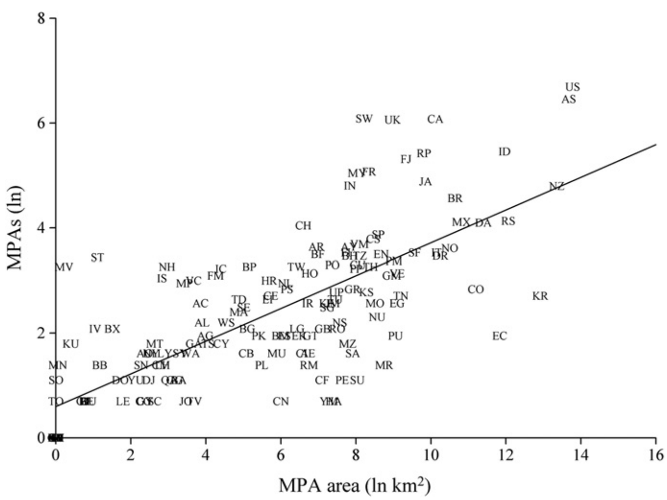

Fig. 4. Relationship between number and area of MPAs. Countries above the trendline have relatively more MPAs per area (i.e., more, smaller MPAs, as in Sweden (SW), Canada (CA), the Philippines (RP) or the United States (US). Countries below this line have relatively more area than number (i.e., fewer, larger MPAs, as in Ecuador (EC) and Kiribati (KR)). Regression line equation $y=0.59587+0.31191x$; $p<0.0001$, $R^2=0.5484$.

3.4. Comparison to terrestrial PAs

Although the number of terrestrial PAs and the number of MPAs (adjusted for country size and coastline, respectively) were positively correlated (p=0.0369, R^2=0.034, N=129; Fig. 6(a), the spatial extents of terrestrial and marine PAs were not (Fig. 6(b). Some countries have both high marine and high terrestrial PA coverage (e.g., Dominican Republic, Nicaragua, and Belize). Other countries have high terrestrial PA but low MPA coverage (e.g., Bahamas, Malta, and Mauritius) or low terrestrial PA coverage but high MPA coverage (e.g., Tonga, Ecuador, and Australia).

4. Discussion

4.1. Understanding patterns and trends in MPA establishment

MPA number and spatial extent varies among countries, habitats, and over time, similar to studies of terrestrial protected area expansion [12]. Possible explanations for this variation were examined, building on studies that analyzed the CBD's MPA targets for feasibility and monitored progress towards these national and global goals [8,9,32]. Among the factors examined for their influence on MPA establishment, coastline length had the strongest effect on variation in MPA number and spatial extent, with countries with longer coastlines having correspondingly

Table 4
MPA change (as percent of EEZ) from 1980 to 2010 – linear regression parameter estimates.

Variables	Standardized β	Standard error	Test statistic (t or F)	p	r	R^2	Adjusted R^2
Change in health factors	0.001	<0.001	2.47	0.016*			
Change in income factors	-0.001	<0.001	-2.48	0.016*			
Change in education factors	>-0.001	<0.001	-0.46	0.64			
Model ANOVA			3.0059	0.037*	0.354	0.125	0.084

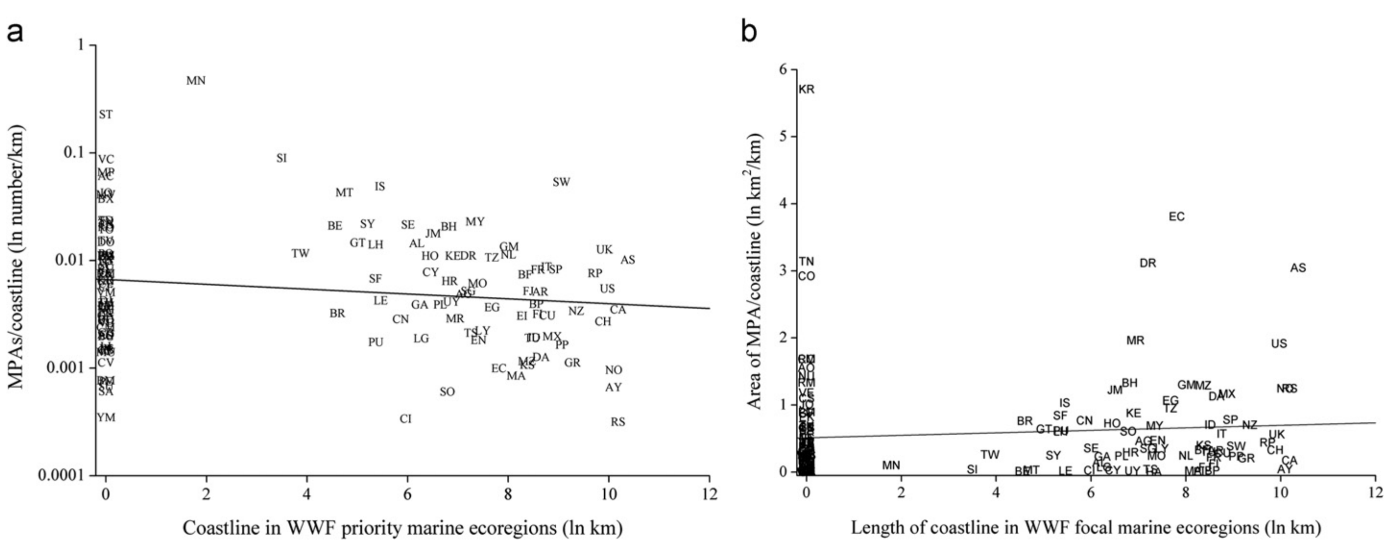

Fig. 5. Relationship between WWF priority marine ecoregions and (a) number and (b) total area of MPAs. (a) Total number and (b) area of MPAs (adjusted for coastline) are not correlated with the length of a country's coastline in WWF priority marine ecoregions. Regression line equations for (a) $y=0.01326+0.0007282x$; $p=0.5456$, $R^2=-0.0057$ and (b) $y=0.52370+0.01693x$; $p=0.3317$, $R^2=-0.0004$.

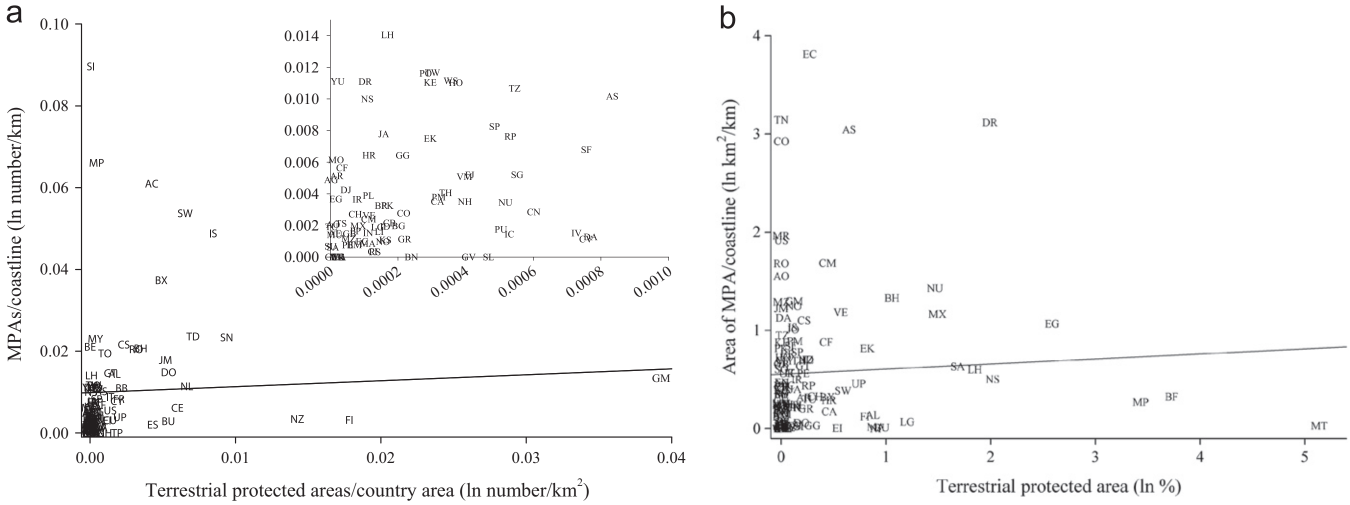

Fig. 6. Relationship between marine and terrestrial protected areas (adjusted for coastline and area, respectively). (a) Number of MPAs is not significantly correlated with the number of terrestrial PAs. Note zoomed inset of countries near origin. (Countries with no marine or terrestrial PA are not shown, also excluded from figure, but included in regression, are the outliers Estonia (EN) [ln#MPA/coastline=0.00182/km, ln#TPA/country area=0.1716/km^2] and St. Lucia (ST) [ln#MPA/coastline=0.2248/km, ln#TPA/country area=0.00446/km^2]; regression line equation $y = 0.009877 + 0.1443\,x$; $p = 0.2633$, $R^2 = 0.00932$). (b) Total area in MPAs is not correlated with the percentage of a country's land within a terrestrial PA. Countries with relatively greater marine than terrestrial protection include: Australia (AS), Bahamas (BF), Ecuador (EC); those with relatively lesser include: Malta (MT), Mauritius (MP), Tonga (TN) $y = 0.55097 + 0.05352\,x$; $p=0.5217$, $R^2=0.0035$.

more and larger MPAs (Fig. 2(a) and (b)). Socioeconomic context has been suggested as an explanatory variable for other policy innovations [17] and previous work with terrestrial systems highlighted the importance of national-level factors [12], but a country's socioeconomic context (as proxied by HDI) explains only a small amount of variation in MPA establishment (Fig. 3(a) and (b)).

Although strong economies and educated populations – as measured by HDI – may lead to slightly greater MPA establishment, the correlation is very weak and perhaps contradicts existing conventional wisdom. Previously, HDI was found to be positively correlated with terrestrial protected area coverage in high income countries [33]. Of the elements that factor into HDI values, education has been linked to environmental consciousness once schooling becomes more widespread and improves in quality [34]. Support for MPA establishment has been hypothesized to depend on societal values [35] and often increases with education at a regional level [35,36].

As with terrestrial systems [26], conservation investment and number of MPAs were positively correlated. This finding is consistent with previous research indicating that increased conservation investment in East Africa has led to an increase in MPA establishment [37]. MPAs in general are under-funded, even in countries with relatively strong economies and well educated populations [38]. This suggests that targeted conservation investments can influence rates of MPA establishment, but the impacts of these investments are usually likely to be modest. Some ecologically-important countries might merit increased investments.

These findings also challenge conventional wisdom that fisherfolk impede MPA establishment, as fishers per capita had no significant relationship with either number or spatial extent of MPAs. More fine-grained analysis is necessary to understand the role of fishers in MPA establishment, as the metric of fishers per capita obscures numerous complex factors associated with fishers and fisheries (e.g., level of threat to the marine environment, political mobilization for or against MPAs, ocean awareness, etc.). Moreover, fishers engage in political decision making processes around MPAs at a sub-national level; for example, the impact of MPAs on fishers, and fisher support for MPAs, may vary between urban and more isolated areas. Since fishers in urban areas often have more than one occupation they may be less likely to oppose MPA establishment than fishers in isolated areas who lack other livelihood options [39]. Thus, while fishers at the local level may vociferously oppose MPAs as reducing access in some contexts (e.g., [24,25,40]), fishers are also the motivating force behind the rapid expansion of community-based MPAs in other contexts [41]. Overall, no evidence suggested that fishers per capita hinder MPA establishment at the national level.

Considerable political ecology and political economy literature has pointed to the important role of political factors and governance in protected area formation (e.g., [12,42]), yet no evidence suggested that macro-scale governance influenced patterns and trends in MPA establishment. Sector-specific national governance, governance at sub-national scales, and local socioeconomic conditions may be more important than generic national scale factors. Because governance can vary widely among sectors and at sub-national levels, better tracking and understanding these factors would be a productive avenue for future work. Clearly, correlation does not imply causation; comparative case studies of PA patterns and trends can shed further light on these factors. Like case studies of common pool resource governance [43] or conservation and development projects [43,44], however, this approach is limited for testing hypotheses given the difficulties of collecting enough relevant data at a range of appropriate temporal and spatial scales.

These findings suggest that different social processes are at work in the establishment of different types of MPAs. Much of the focus of MPA establishment is on ensuring sufficient area is protected to safeguard ecological processes [7], fulfill political commitments [45] and generate recognition [14]. "Signature" mega-MPAs such as Phoenix Island Protected Area, Papahanaumokuakea Marine National Monument in the Northwest Hawaiian Islands, and the Great Barrier Reef Marine Park may reflect national-scale influence over the establishment process. For example, Ecuador's position as a positive outlier in MPA spatial extent resulted largely from the passage of the Special Law for Galapagos in 1998 [46], which established the 133,000 km^2 Galapagos Marine Reserve. In contrast, devolving authority for MPA establishment can empower communities to conserve their marine environment [41,47]. In the Philippines, passage of the National Integrated Protected Areas System (NIPAS) Act in 1992 institutionalized the participation of indigenous and local communities in the land and marine management process, leading to a dramatic increase in MPA formation. Today, there are more than 600 MPAs in the Philippines, most of which are very small and were established primarily as tools for fisheries management [47].

Similarly, these findings suggest that different social processes are at work in the establishment of MPAs and terrestrial protected areas. Although the number of MPAs and terrestrial PAs in a country were positively correlated, their spatial extents were not. Correcting for coastline length may not be the most appropriate controlling measure for the very large MPAs surrounding very small islands such as the Phoenix Islands or Northwest Hawaiian Islands. Country-level drivers, such as globalization and priorities of conservation organizations [12], may manifest differently in marine and terrestrial environments. Terrestrial PA coverage correlates strongly with endemic and threatened species and variably to vertebrate biodiversity [48], although other studies have found that terrestrial PA growth did not differ significantly between countries with different numbers of unprotected species [27]. MPAs are likely not correlated accordingly, given the paucity of information about the distribution of species in marine systems.

4.2. Implications for science and policy

Policy initiatives in many fields have taken a ‘‘leaders and laggards’’ approach to identify ‘‘leaders’’ (countries, schools, businesses, etc.) that are innovating, learn from them, and understand what elements led to success (e.g., [17,49]). These lessons can be passed onto the ‘‘laggards,’’ who themselves may be motivated to perform better by having been named as such. ‘‘Leaders and laggards’’ in MPA establishment are evident among both developed and developing countries, although local-level dynamics cannot be explained based on national level data (an ‘‘ecological inference fallacy;’’ [50]). Nonetheless, ensuring a supportive enabling environment at the national or even multinational level can enhance success with conservation planning and implementation at the local level (e.g., Ecuador, Philippines).

In assessing the progress of ‘‘leaders’’ and ‘‘laggards’’ toward the CBD 2020 targets, it is important to look beyond simplistic metrics of MPA coverage. Twelve leaders in MPA establishment (Dominican Republic, Ecuador, Estonia, Germany, Guam, Heard and McDonald Islands, Jordan, Kiribati, New Zealand, Northern Mariana Islands, South Africa, and the U.S. Minor Outlying Islands) have already reached the CBD’s 2020 target of 10% [8]. Some of these ‘‘leaders’’ have established very large MPAs in relatively remote, sparsely populated areas. While these remote mega-MPAs lead to noteworthy increases in MPA growth and achievement of area targets, questions remain regarding the contribution of these mega-MPAs to the more difficult to measure ‘‘representative’’ and ‘‘effective’’ dimensions of these 2020 targets. Moreover, establishing MPAs far from human use or interaction does little to enhance the flow of social benefits through ecosystem services (e.g., food security, storm protection).

As new analyses emerge to guide priorities for the establishment of MPAs (e.g., [51]), targeted inquiry should further clarify relationships between MPA establishment and different ecological and socioeconomic factors at national, sub-national, and local levels. Understanding the particulars that catalyzed MPA establishment for ‘‘leaders’’ (or undermined it for ‘‘laggards’’) can highlight policies and practices that may merit replication elsewhere, and the contextual factors that foster or hinder success. Other important next steps include research to demonstrate the biological and social impacts of MPAs, explain variation in these outcomes, and identify keys to the design and management of successful MPAs. Understanding the processes that are transforming governance of the oceans through MPA establishment and management is essential to ensuring MPA effectiveness and to meeting conservation targets established under international law.

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Appendix A. Supporting materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2012.02.007.

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