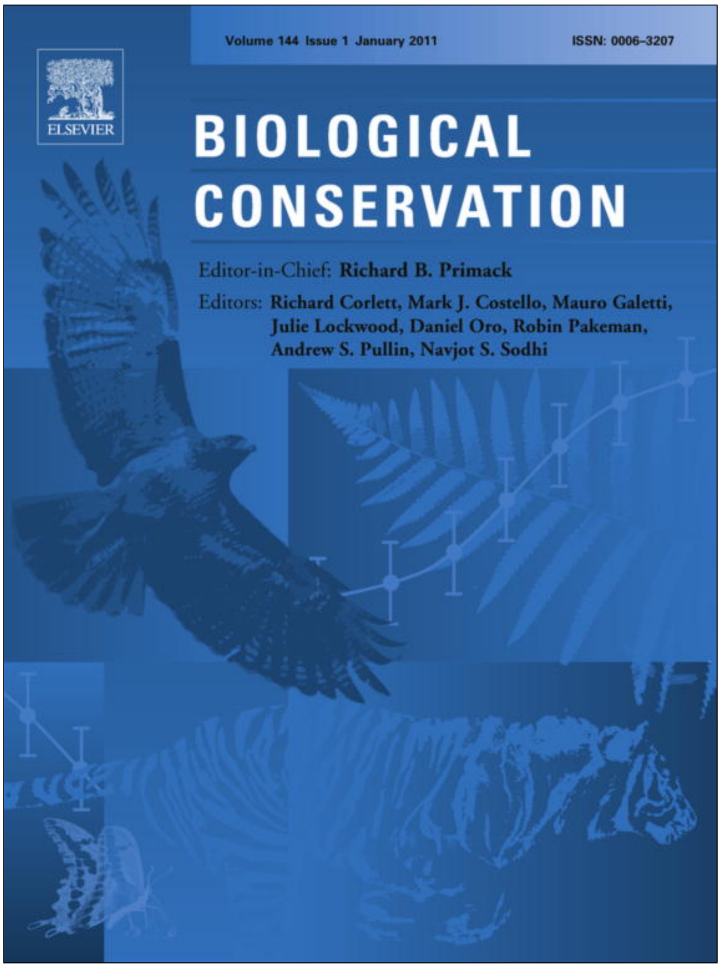
Volume 144 Issue 1 January 2011
ISSN: 0006-3207
ELSEVIER
BIOLOGICAL CONSERVATION
Editor-in-Chief: Richard B. Primack
Editors: Richard Corlett, Mark J. Costello, Mauro Galetti, Julie Lockwood, Daniel Oro, Robin Pakeman, Andrew S. Pullin, Navjot S. Sodhi

Biological Conservation 144 (2011) 383–392

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Global development and the future of the protected area strategy

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ARTICLE INFO

Article history:
Received 12 May 2010
Received in revised form 7 July 2010
Accepted 14 September 2010

Keywords:
Economic development
Gross primary enrollment
IUCN Red List
National park
Urbanization
World Database on Protected Areas

ABSTRACT

Land protection has become increasingly common, and global land protection is now greater than 12%. Prediction of future protected area expansion are uncertain, and depend on understanding the factors that have to date explained the historical pattern and geographic variation in protected area (PA) establishment. We test four major perspectives on factors limiting or facilitating PA creation, differentiating between strict PAs and multiple-use PAs where some resource extraction is permitted. Richer countries had a greater amount of land protection and were more likely to create strict PAs, supporting the view of land protection as an economic amenity, although the magnitude of this effect declines in recent decades. There are also significant differences in amount of protection by political structure, with independent countries tending to protect more land, and education, with countries with high levels of primary education tending to protect more. However, countries with substantial previous protection tend to do less protection and create proportionally fewer strict and more multiple-use PAs. Scenarios of future socio-economic and political conditions suggest that on balance the amount of protection should increase in many countries, driven by economic prosperity, and by 2030 global land protection is forecast to reach 15–29%. The limiting factor in land protection varies among countries, and sub-Saharan African countries in particular will remain a very hard place for land protection because of low per-capita GDP. Overall, however, more land protection may occur in the next 20 years than has occurred in the previous 20 years.

1. Introduction

Protecting land by created parks and other protected areas has become increasingly common, with land protection globally now greater than 12% (Brooks et al., 2004; Chape et al., 2005; Jenkins and Joppa, 2009; Naughton-Treves et al., 2005; Pyke, 2007; Rodrigues et al., 2004). The motivation for this protection has varied widely, from preserving biodiversity to maintaining hunting to protecting scenic beauty to ensuring the sustainable extraction of natural resources (Runte, 1997; Sellars, 1997). Moreover, the timing and extent of land protection has been very uneven among and within countries (Coad et al., 2009; Hoekstra et al., 2005; Soutullo et al., 2008). In this study, we seek to answer a simple question: How much more land is likely to be protected in the next few decades, given demographic, agricultural, and economic growth?

We analyze data for terrestrial protection from 1950 onwards, build statistical models of past trends, and then use our statistical model to make projections of future land protection. We categorize the range of motivations for protected area (PA) creation into two broad categories: "strict" PAs (IUCN categories I–IV), where there is a focus on preserving the natural ecosystem and little resource extraction, and "multiple-use" PAs (IUCN categories V–VI), where there is a focus on the sustainable extraction of natural resources. Input data on the amount and strictness of protection in 5-year intervals is analyzed as a function of time-varying covariates such as population, agricultural land, urbanization, per-capita GDP, political context, and education. In order to sharpen our work, we structure our analysis around four distinct perspectives that seek to explain what drives patterns of PA expansion, each of which implies a different future for the PA strategy. By comparing the observed correlations between a set of explanatory variables and land protection with those predicted by one of our four perspectives, we can evaluate the overall utility of a perspective in explaining the observed pattern. We stress, however, that these perspectives are not mutually exclusive, and more than one of them may be of importance in explaining what drives patterns of PA expansion.

One perspective suggests that PAs are most frequently established in sites that are "worthless" to people, or at least less economically useful (Joppa and Pfaff, 2009; Runte, 1997; Sellars, 1983). For instance, steep slopes, barren soils, or harsh climates might make a site unsuitable for agriculture, and hence more likely to be protected. Regions with a low population density might find

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Abbreviations: IPCC, intergovernmental panel on climate change; GDP, gross domestic product; PA, protected area; SRES, special report on emissions scenario.

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doi:10.1016/j.biocon.2010.09.016

it easier to establish PAs because relatively little of the landscape is put to human use. Strict PAs may be more common because these lands have relatively little productive value. Conversely, protection has been limited in places with significant economic value to people, such as areas of agricultural production or high population density. Multiple-use PAs may be more common because it allows the continued use of at least part of the productive value of the land. This hypothesis implies that in the future land protection may get harder, either because the most worthless sites have already been protected or because the demands of housing and feeding another three billion people forces (UNPD, 2007) much more land to be put to productive use.

Another perspective suggests that environmental protection is an amenity that becomes of greater importance to people once they have satisfied other more basic economic desires (Dinda, 2004; Mikkelson et al., 2007; Pandit and Laband, 2009; Torras and Boyce, 1998). In this view, the correlation between the rapid rise in land protection in the past half century and the contemporaneous increase in economic development are indicative of a causal relationship. Note that while economic theory might tie the decision to protect land to specific variables such as land price, the economic value of alternate use forgone with protection and the willingness to pay for the benefits of protection (Dixon and Sherman, 1991; McNeely, 1988), this detailed data is simply not available for all countries globally since 1950. Instead we, like many econometric studies, use per-capita GDP as a proxy for the overall process of development. This perspective predicts that countries with a greater per-capita GDP will set aside more land for protection. Similarly, they may be able to afford more "strict" protection, and have proportionally more of this type of protection. Barring major global disruptions, continued economic development seems assured, increasing fastest in percentage terms in what are today the less developed countries. This perspective implies that this continued economic development might make land protection easier, as nations would have more resources to invest in this amenity.

A third perspective argues that the conservation movement in general, and land protection in particular is a historical and political process (Gorenflo and Brandon, 2006; Nash, 2001; Smith et al., 2003). The idea of land protection originated in a particular time period and over time gained support in many countries throughout the globe (Nash, 2001). This implies that calendar year will be a significant explanatory variable in a regression analysis, even after accounting for other explanatory variables. Moreover, the political and social context of a country may modify its adoption of the idea of land protection, leading to differences among countries in the extent of protection (Zimmerer et al., 2004). For instance, some have argued the spread of democracy in the past several decades is in part responsible for the rapid land protection (Wells and Williams, 1998), although others have argued that the legacy of colonialism also profoundly shaped the PA networks in many countries (Fabricius et al., 2001). Education is another potentially important variable, because many studies have associated greater education levels with increased activism about environmental issues (e.g., Gillham, 2008; White and Hunter, 2009), presumably including land conservation.

Finally, a fourth perspective argues that international conservation organizations have played a significant role in advocating for land protection, and have concentrated their efforts in places of greater biodiversity significance. For instance, there is some evidence that there is greater land protection in ecoregions with more vertebrate biodiversity (Loucks et al., 2008). This perspective predicts that countries of biodiversity significance, either because of greater species richness or imperilment, will have more area protected and will have relatively more strict PAs.

Our scenarios of the future are based on the four scenarios in the IPCC *Special Report on Emissions Scenarios* (SRES). The A1 and B1 scenarios assume global population growth to around nine billion by 2050 and rapid economic growth leading to convergence in countries' income. In contrast, the A2 and B2 scenario assume greater population growth and greater disparities in economic growth among regions. Relative to the A1 and A2 scenarios, the B1 and B2 scenarios place a greater emphasis on sustainable technology and the environment (IPCC, 2000). Our overall goal in making projections is to define the factors limiting PA creation, and describe how much land could be protected by 2030 if current patterns continue.

2. Materials and methods

2.1. Protected area data

Our information on PAs came from the World Database on Protected Areas (WDPA), as released in 2009, which generally contains information on the date of protection of a parcel as well as its spatial boundary. All IUCN categories of protection (I–VI) are contained in the database, with degree of land protection ranging from, for example, wilderness areas to national forest areas for timber production (but see Leroux et al., 2010). Where the WDPA 2009 dataset seemed to be missing information (e.g., United Kingdom), we used information from the 2007 release of the WDPA or (for the United States) the current Protected Areas Database (DellaSala et al., 2001). We categorized the world's protected areas in two broad categories. First, "strict" PAs were defined as IUCN categories I–IV, which encompasses strict nature reserves, wilderness areas, national parks, national monuments, and habitat/species management areas. Second, "multiple-use" PAs were defined as IUCN categories V–VI, where there is a focus on the sustainable extraction of natural resources, including protected landscapes/seascapes and managed resource PAs such as the national forests in the United States (IUCN-WCMC, 1994). Note that while the WDPA is the best available global data on protected areas, there are data quality issues. We lump the IUCN categories to two broad groups, "strict" and "multiple-use," in part because other papers have recently questioned how accurate and meaningful the IUCN categories are (Brooks et al., 2009; Joppa et al., 2008; Leroux et al., 2010; Nagendra, 2008; Selman, 2009).

Not all PAs had information on date of establishment or PA category, and we conducted a literature search to find information for these parcels, focusing especially on the biggest. Ultimately only 13% and 3% of the area protected was for PAs where we could not assign a date or category, respectively. For each parcel with missing information we have randomly filled in the field, drawing from the distribution of values in the larger dataset. This kind of imputation is common with missing values, and is less likely to change the distribution of values in the dataset or bias the regression coefficients than simply dropping missing values (Little and Rubin, 2002). Preliminary tests with the subset of data with complete information yield qualitatively similar regression results. We projected the WDPA data and all the other spatial layers used in our analysis to a Mollweide equal-area projection at a 1 km resolution.

As most of the potentially explanatory variables occur at the country level (Table S1), we calculated area and percent protected for the countries of the world at 5-year intervals from 1950 to 2005. Five-year intervals were used to match the temporal grain of the potential explanatory dataset. Data from 2005 on were excluded from our analysis out of a concern that there are often a few years of lag between protection and its recording in the WDPA, implying that information over the period 2005–2010 was not complete. We limited our analysis to 1950 onwards since this period contains the great majority of land protection and since country boundaries are relatively stable over this period. In our analysis, we excluded small countries (e.g., Nauru, Monaco), as well as Antarctica and Greenland, which are outliers in global patterns of protection (see Table S2 for a list of countries included in our analysis).

2.2. Static explanatory variables

While most variables in our analysis (Table S1) take the form of time series, there are four important variables that have a static value for each country.

Information on the biodiversity at risk in each country, which might be one factor motivating protection, is taken from the IUCN Red List version 2009.2, in its Table 5, which lists the number of threatened species in each country, by taxonomic group and in total. In our analysis, we have used the total number of species at risk per km^2 of land area, the density of at risk species, as a proxy measure of biodiversity value. Similarly, information on the total number of vertebrate taxa was taken from the WRI EarthTrends database and used in our analysis as the density of vertebrate species (species/km^2). It would be ideal to have these two measures of biodiversity value as time series, that somehow represented the knowledge of conservationists and the level of imperilment in the past, but data limitations force us to treat them as static variables. The implicit assumption with this approach is that current data on where species richness or imperilment is located would have been at least somewhat known in the past, and may potentially have shaped past protection strategies. These two static measures are correlated with each other (Table S3), limiting our ability to separate their effects in a regression model.

Anticipating that there might be regional or country-level variation in the amount of land protection and its type, we created categorical variables for our analysis (Table S1). We classified countries into 10 regions, based upon the classification used by the United Nations (UNPD, 2007): East Asia and Oceania; Eastern Europe; Eastern and Southern Africa; Middle and West Africa; North America/Caribbean/Central America/North and West Europe; South America; South-Central Asia; Southern Europe; Western Asia and North Africa. Regions were designed to have at least 10 countries each. A country-level dummy variable was also created, for use in the first of our two regressions (see below) where there are sufficient observations in each country over the study period to allow the fitting of a country-level effect. Both the regional and country-level effects are treated as fixed effects.

2.3. Economic data

A country's level of economic development was measured by its per-capita gross domestic product (GDP), which is a commonly used proxy in econometric analyses for the relative wealth or poverty of a country (Table S1). Economic theory ties the decision to protect land (Dixon and Sherman, 1991; McNeely, 1988) to a balance of the costs of protection (i.e., the economic value of alternate use forgone with protection, often correlated with land price) with the benefits (often estimated as the willingness to pay for the benefits of protection). However, this detailed data is simply not available for all countries globally since 1950, and even simple measures of land price for many countries are difficult to obtain (Kark et al., 2009; McDonald, 2009), and hence we use per-capita GDP as a proxy variable for the degree of economic development of a country. Similarly, while it would be ideal to have time-series information on investment or effort by conservation NGOs, this data is simply not available for most countries since 1950 (Halpern et al., 2006).

Per-capita GDP information was taken from the most current version of Angus Maddison's historical database (Maddison, 2001). This database presents historical reconstruction for the world's countries, with per-capita GDP standardized over time and among countries to 1990 International Geary–Khamis $US, a measure that corrects for different purchasing power. Several countries split over the time period (e.g., USSR), and we have interpolated data back in time for the current countries (e.g., Georgia) by calculating the ratio of per-capita GDP in a current country divided by the contemporary per-capita GDP for the entire previous country. This ratio was then multiplied by the post per-capita GDP for the larger country. For instance, in 1990 the ratio of per-capita GDP of Georgia ($7616) to that of all former USSR states ($6894) was 1.10, so that if in 1980 the per-capita GDP of the USSR was $6427 then our estimate of the per-capita GDP of Georgia is $7070. Less commonly, countries were merged over the time period of our analysis (e.g., East and West Germany reunited), and we estimated the total per-capita GDP by adding up the GDP of the component countries and dividing by the population of the component countries.

Scenarios of future values of per-capita GDP, as well as the other explanatory variables, are based on the IPCC SRES scenarios. In the case of per-capita GDP, we used the downscaled SRES scenarios of per-capita GDP generated by CIESIN (2002). To harmonize these scenarios with the Maddison historical time series, we calculated the percent change over time since 2005 of the SRES scenarios and multiplied it by the Maddison numbers in 2005 to obtain scenarios of per-capita GDP out to 2030.

2.4. Landscape context

Data on agricultural utilization and population density (Table S1) were taken from the History Database of the global Environment (HYDE) project, version 3.1 (Klein Goldewijk and van Drecht, 2006). Agricultural data is the percent of a ∼10 km grid cell that is used for cropland, while population density is expressed as the average density (people/km^2) for each grid cell. Note that because of the relatively coarse grain of this dataset relative to the WDPA, it is possible for a PA to fall within a cell that overall has a high value of agricultural utilization. As we were interested in how extreme values of agricultural utilization or population density inhibited land protection, we created maps of high agricultural utilization (>20%) or high population density (>50 people/km^2). These thresholds were chosen because visual analysis in the GIS suggested little protection occurred above these values. Preliminary experiments with other thresholds generated qualitatively similar results presented in this paper. Note that areas of high agricultural utilization as defined above have large areas used for agriculture, but may or may not have high yields from areas under production.

For each country, we calculated the proportion of unprotected land in each time period (1950, 1955, 1960, etc.) that was of high agricultural utilization or high population density. These two measures are highly correlated with one another (Table S3). The percent of the population that was urban was also included in our analysis (Table S1), on the theory that the process of urbanization may affect the amount of land protection (McDonald et al., 2009, 2008). Data on percent of the population that was urban was take from the United Nations Population Division (UNPD, 2007).

Scenarios of agricultural utilization and population density were created based on the SRES Scenarios generated from the IMAGE model (IMAGE, 2001). For population density, the percentage increase in each region over a time interval was applied to each grid cell so that population growth was proportional to original population density and the total summed to the regional percentage growth increase predicted by IMAGE. While this approach ignores the possibility of new towns appearing *de novo* far from existing towns, it captures the general historical trend for population growth to occur in or near previous settlements. For agricultural utilization, a similar approach was employed, except that in practice few locations in the HYDE database exceed 85% agriculture. To accommodate this empirical reality, a "tipping bucket" algorithm was employed. Agricultural utilization was proportional to the original agricultural utilization, with the constraint that values for any cell could not grow to exceed this threshold and that the percent growth in total agricultural area, summed over all the cells in a region, matched the percent growth predicted by IMAGE.

We included the cumulative amount of land protected previously (%) as a covariate in our analysis, on the hypothesis that this might affect the amount or type of new protection. On the one hand, countries with substantial amounts of previous protection might have less new protection or might do less strict protection, if there are increasing demands to use the remaining unprotected land for purposes other than conservation. On the other hand, if there are characteristics of a country that make it prone to protect land which persist over time, there may be a positive correlation between the amount of land previously protected and current protection.

2.5. Social context

Political status information (Table S1) was taken from the Polity 4 database, utilizing the "polity2" variable (Marshall and Jaggers, 2009). This variable ranks a particular country in a particular time period on a scale from −10 (Autocratic) to 10 (Democratic). Countries that are in periods of revolution/occupation (Interregnum) or colonization are flagged with special indicator variables. We have simplified this to a three category scale: Autocratic (−10 to −4 on original scale or in Interregnum), Democratic/Mixed (−3 to 10), or Not Independent. Note that the polity2 variable includes some information on the degree of constraints on the executive and the rule of law ("XCONST" variable), but is not strictly a measure of corruption. Unfortunately, measures of corruption such the Corruption Perceptions Index of Transparency International do not extend over our study period, and are hence excluded from our analysis.

Education data (Table S1) was taken from UNESCO's UIS online database for the period 1970–2005, and from UNESCO Statistical Yearbook (UNESCO, 1964, 1975) for the period 1950–1970. We used gross enrollment ratio (GER) in primary schools, enrollment in primary schools divided by the population estimates for that age cohort. Note that because of population estimation errors or immigrant populations not included in official census numbers, it is possible for GER to slightly exceed 1. As there were numerous slight methodological changes in the calculation of GER over the decades, we have chosen to simplify this data to a three category scale of primary education: Limited (0–0.5 GER), Moderate (0.5–0.75), and High (>0.75). We use GER, a common measurement available as a time-series globally, as a proxy measure of how generally educated a population is, which has been shown to be correlated with advocacy for environmental issues (e.g., Gillham, 2008; White and Hunter, 2009). For countries with data, GER is highly correlated with levels of secondary or tertiary education (e.g., UNESCO, 1964, 1975). Interestingly, it is only weakly correlated with per-capita GDP. For instance, in 2005 countries in the high primary education category range from a per-capita GDP of $470 (Burundi) to $30,474 (United States).

Scenarios of future political status are not part of the SRES Scenarios. We created our own scenario of political status by observing that the original Polity 4 variable has increased over time as governments have tended to get more democratic. We have linearly extrapolated this trend over time, with the average gain per year on the Polity 4 variable assumed to continue until 2030. Classified to our scale, this implies that some Autocratic regimes will become Democratic. In this linear extrapolation process, countries in Interregnum in 2005 are assigned a score of 0 on the original Polity 4 variable. A similar process was used for the education variable All four IPCC SRES Scenarios used in our paper had the same scenario of political status and education out to 2030.

2.6. Statistical testing

Our data takes the form of panel data, with information on the amount and type of land protected in each time period in each country. We conducted our statistical analysis in two regressions. First, we regressed the proportion of land protected in a 5-year time period against a set of explanatory variables. Second, we regressed the proportion of new protected area that was either "strict" or "multiple-use" (i.e., the type of protection when it occurs) against the same set of explanatory variables. Future forecasts of both quantities were calculated using the statistical model parameters fit from historical data. Values of explanatory variables in the future are based on the scenarios discussed above.

Amount of protection: Our statistical approach is based on the central concept of Granger causality testing (Pindyck and Rubinfeld, 1998), which is that the change in some variable X can only be seen as causing the change in some variable Y if the change in X occurred prior in time and if all temporal autocorrelation in Y has already been statistically accounted for. Typically, a likelihood ratio test is used to compare the fit of an unrestricted and restricted linear model:

$$\text{Unrestricted}: \Delta Y = \alpha + \beta X_t + \varepsilon \tag{1}$$

$$\text{Restricted}: \Delta Y = \alpha + \varepsilon \tag{2}$$

Since the PA data analyzed have some special distributional properties, we utilize a generalized linear model approach that addresses these properties while being broadly consistent with the central concept of Granger causality testing. First, PAs once established do not disappear, which means the increase in percent protection over time is always 0 or positive. Second, percent protection is bounded between 0 and 1, inclusive. Third, small countries will have higher variance in percent protected than large countries. Fourth, trends in the historical interest of land protection need to be accounted for before testing any particular explanatory variable. Accordingly, we compare the fit of an unrestricted and restricted generalized linear model, in this case a logistic regression:

$$\text{Unrestricted}: g\left(\frac{A_{t+1}}{A_t}\right) = \alpha + \beta_1 Yr_t + \beta_2 Pt_t + \boldsymbol{\beta}\mathbf{X}_t \tag{3}$$

$$\text{Restricted}: g\left(\frac{A_{t+1}}{A_t}\right) = \alpha + \beta_1 Yr_t + \beta_2 Pt_t \tag{4}$$

where A_t is the area unprotected in time t, Yr is the number of years since 1950 of the start of the time interval $t + 1$, Pt is the percent of area previously protected, and $\mathbf{X}_t$ here represents a vector of potential explanatory variables at time t. In words, the proportion of a country's unprotected area that remains unprotected at the end of a time period is a function of the general temporal trend in land protection plus (potentially) the effect of several explanatory variables. In practice, we tested also for higher order polynomial terms of the Yr and Pt effect, and found no indication of further temporal trend. Note that the proportion of unprotected land that is protected over a time interval is just $1 - A_{t+1}/A_t$. Moreover, for multiple time intervals, the total area remaining unprotected is simply expressed as:

$$\frac{A_{t+N}}{A_t} = \prod_{i=1}^{N} \frac{A_{t+i}}{A_{t+(i-1)}} \tag{5}$$

Rather than calculating A_{t+1}/A_t directly, we expressed it as a ratio of the number of 1 km cells (the spatial scale of the GIS analysis) unprotected in time t and $t + 1$. For ease of interpretation, we often report the proportion of area unprotected in time t that is protected, the "amount of protection" (i.e., $1 - A_{t+1}/A_t$).

2.7. Type of protection

For countries that had land protection in a particular interval, the proportion of protected area that is "strict" can be seen as a function of the same set of explanatory variables. Following the logic of the previous section, we compare the fit of an unrestricted and restricted logistic regression:

$$\text{Unrestricted}: g\left(\frac{Strict_{t,t+1}}{All_{t,t+1}}\right) = \alpha + \beta_1 Yr_t + \beta_2 Pt_t + \boldsymbol{\beta}\mathbf{X}_t \tag{6}$$

$$\text{Restricted}: g\left(\frac{Strict_{t,t+1}}{All_{t,t+1}}\right) = \alpha + \beta_1 Yr_t + \beta_2 Pt_t \tag{7}$$

where the logit transform of the ratio of strict protected area to all area protected in a time interval is a function of Yr and $\mathbf{X}_t$. In words, the proportion of a country's land protection that is strict is a function of the general temporal trend in strictness of protection plus (potentially) the effect of several explanatory variables, including how much has been previously protected. Note that because observations were not available for all countries in all time periods, simply because some countries have no land protection over a 5-year interval and thus the strictness of the protection is undefined, the country-level dummy variable causes problems with model estimation and failure of the fitting algorithm to converge. Accordingly for this second logistic regression we only used the region-level dummy variables.

2.8. Model fitting

The significance of individual parameters was tested by likelihood ratio tests. Fitting was done using PROC LOGISTIC in the SAS Software package, which uses the Fisher scoring algorithm to find maximum likelihood solutions, avoiding some of the biases noted with ordinary least square estimation with linear models (Arellano and Bond, 1991; Nickell, 1981). Note that our use of the binomial error distribution accounts for the greater variance in proportions in smaller countries. To improve normality, Yr, per-capita GDP, and the density of threatened species were all log-transformed. Because there was significant overdispersion, the Williams correction for overdispersion was used to correct for this. Results presented are from a Type 3 analysis of effects in SAS.

We first fit a full model, including interaction terms between the Yr term and other continuous variables. Including further interaction terms involving the categorical variables led to quasi-complete separation of our dataset, and these terms were thus not included in our full model. These full models for amount of protection and type of protection are shown in Tables S4 and S5, respectively. To avoid overfitting our logistic regression model, we used backward selection to remove terms that did not significantly improve the model fit. Overfitting of models is particularly problematic when one of the key goals is to make forecasts (Hawkins, 2004). However, care must be taken when removing terms from the model, since removing significant effects from a model might lead to omitted variable bias (Pindyck and Rubinfeld, 1998). Since the "true" model is unknown, we use backward selection to try to find a middle ground between the extremes of an overfitted model and one with omitted variable bias (Clark, 2005). For completeness, we include our full models for interested readers to compare (Tables S4 and S5).

3. Results

From 1950 to 2005, land protection increased to greater than 12% of our study area (Fig. 1A). While several explanatory variables are significant in explaining this trend, there also remains a significant relationship between year and amount of protection (Table 1, S4). This association can be interpreted as evidence that the interest in creating PAs has varied over time, supporting the perspective of land protection as a historical process. Our statistical model (black line in Fig. 1A) incorporating this temporal effect as well as the effect of explanatory variables (Table 1), captures the observed trend relatively well and suggests land protection in 2030 could reach 15–29%. Part of the uncertainty in this forecast is due to the variation in the SRES scenarios, with land protection

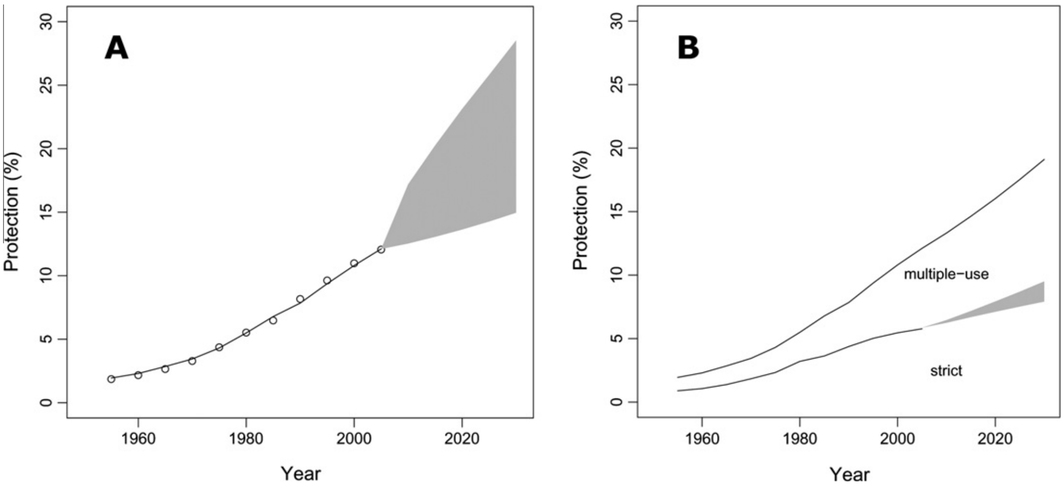

Fig. 1. Historical and future trends in land protection. (A) Proportion of land protected. Circles are observed data, and the black line is model predictions. Grey area shows the 95% confidence interval for forecasts for the four IPCC SRES scenarios. (B) The type of land protection, divided into two categories, strict and multiple-use. Data are in stacked format, with the top line representing total protection (B1 scenario) and the bottom line representing the portion of protection that is strict protected areas. Grey area shows the 95% confidence interval in the split between strict and multiple-use protected areas.

Table 1
Variables affecting the rate of protection. Type 3 analysis of effects in logistic regression model.

Effect	DF	Wald χ^2	Pr > χ^2
Country	159	592.2	<0.0001
Per-capita GDP	1	23.2	<0.0001
Year	1	11.0	0.0009
Per-capita GDP × year	1	37.3	<0.0001
Previous protection	1	126.8	<0.0001
Political form	2	7.5	0.0231
Primary education	2	29.8	<0.0001

in the A1 and B1 scenarios (midpoint estimate 19.4% and 19.1% respectively) being higher than in the A2 and B2 scenarios (midpoint estimate 18.6% in both cases). The remainder of the uncertainty is due to forecast error from imprecision in parameter estimates as well as the overdispersion in the model error distribution accounted for using William's method.

Over our study period, land protection was roughly equally divided between strict and multiple-use PAs (Fig. 1B). In 2005, 48% of total area protected was in the strict category, amounting to 5.8% of the land area strictly protected. Time by itself is not a significant predictor of the proportion of new PAs (Table 2, S5) that are strict or multiple-use, although trends in some of the explanatory variables (Table 2) imply that over the next few decades new PAs will tend to be more frequently designated as multiple-use. In 2030, 42–49% of total area protected will be strict, amounting to 7.9–9.5% of land area using midpoint estimates for total area protected. There is relatively small variation among scenarios in the proportion of new PAs that will be strict, with most variation due to forecast error.

One significant explanatory variable is per-capita GDP (Fig. 2A), which has a significant interaction with the time variable (Table 1). Early in the study period, per-capita GDP has a large effect on amount of protection, with richer countries having greater amounts of protection. Later in the study period, the effect size of per-capita GDP decreases, and an increase in per-capita GDP does not affect amount of protection as much. Per-capita GDP is also a significant predictor of the proportion of new PAs that are strict instead of multiple-use, again in interaction with the time variable (Table 2). Early in the study period, rich countries had a greater proportion of strict PAs than poor countries. Later in the study period, an increase in per-capita GDP does not affect the proportion of strict PAs much. The significance of the interaction term between per-capita GDP and time in both regressions is striking, and suggests that for some reason the effect of country-level wealth on conservation has gotten less pronounced over time. In all four scenarios, per-capita GDP increases (Fig. 2A). This per-capita GDP increase, all else being equal, increases our future projections of amount of land protection and the frequency of strict PAs, although the effect is small because of the interactions with the time variable.

The form of government (Fig. 2B) is related to the amount of land protection (Table 1). Democratic governments protect land faster than non-independent governments (e.g., Western Sahara). Interestingly, autocracies have an amount of protection that is less than that of democracies and more than that of non-independent governments but is statistically indistinguishable ($P > 0.05$) from either group. The form of government is related also to the proportion of new PAs that are strict (Table 2). Democratic and non-independent governments tend to create a higher proportion of strict PAs than autocratic governments. Over time, many non-independent countries (Fig. 2B) have often transitioned to autocratic regimes. These regimes have in turn slowly transitioned into democracies, a trend our scenarios assume continues into the future. All else being equal, the increased frequency of democratic regimes increases our future projections of amount of land protection and the frequency of strict PAs.

Table 2
Variables affecting the type of protection, classified as either strict or multiple-use PAs. Type 3 analysis of effects in logistic regression model.

Effect	DF	Wald χ^2	Pr > χ^2
Region	9	210.9	<0.0001
Per-capita GDP	1	7.2	0.0074
Year	1	3.2	0.0730
Per-capita GDP × year	1	6.9	0.0084
Previous protection	1	9.0	0.0027

Another significant variable is the level of primary education (Fig. 2C), which is related to the amount of land protection (Table 1). Countries with high levels of primary education protect land faster than countries with either low or moderate levels of primary education. Interestingly, countries with low levels of primary education have slightly higher amounts of protection than countries with moderate levels of primary education. Over time, high levels of primary education has become the norm in the majority of world countries (Fig. 2C). All else being equal, this continuing rise in education increases our future projections of amount of land protection. Note that there is no association between level of primary education and the proportion of strict PAs created.

Both the amount of land protection (Table 1) and the proportion of PAs that are strict (Table 2) are statistically related to the amount of previous protection that has occurred (Fig. 2D). Countries with more previous protection have lower amounts of land protection and tend to create less strict PAs than countries with less previous protection, all else being equal. A country with 8% of its land area previously protected has about half the amount of protection it might have had if it had instead 0% of its land area previously protected (i.e., an odds-ratio multiplier of 0.5). Similarly, a country with 8% of its land area previously protected has about 80% the odds of creating strict PAs than it might have had if instead it had 0% of its land area previously protected (i.e., an odds-ratio multiplier of 0.8).

There is little evidence that the amount of land protection is associated with other factors tested in this study, such as the proportion of the population that lives in urban areas, the proportion of the landscape that is heavily populated, the proportion of the landscape that is relatively flat and easily usable, the proportion of the landscape that is heavily used for agriculture, or the density of vertebrate species or threatened IUCN Red List species in the country (cf., Tables S4 and S5).

Certain countries are, because of one or more factors, predicted to have low amounts of land protection by our model (Fig. 3A). While there are examples of countries that have these limiting factors and still have had significant land protection, countries with these factors have had on average a lower amount of land protection. First, countries with low per-capita GDP (<$1500) and on average lower amounts of land protection are located in much of sub-Saharan Africa and a few other countries in the world. This GDP threshold corresponds on average to a 20% decrease in the amount of land protection. Second, countries lacking high levels of primary education and having on average lower amounts of land protection are located primarily in sub-Saharan Africa. Third, non-independent governments are located in a few countries, although the large decrease in the number of these governments in recent decades suggests this explanatory variable may be of limited importance currently as compared with the first decades of our study period. These different limiting factors, partially overlapping and often mechanistically related with one another, show the complex geography of future conservation efforts.

However, there are countries such as Senegal that have protected more than 15% of their land surface yet have one or more

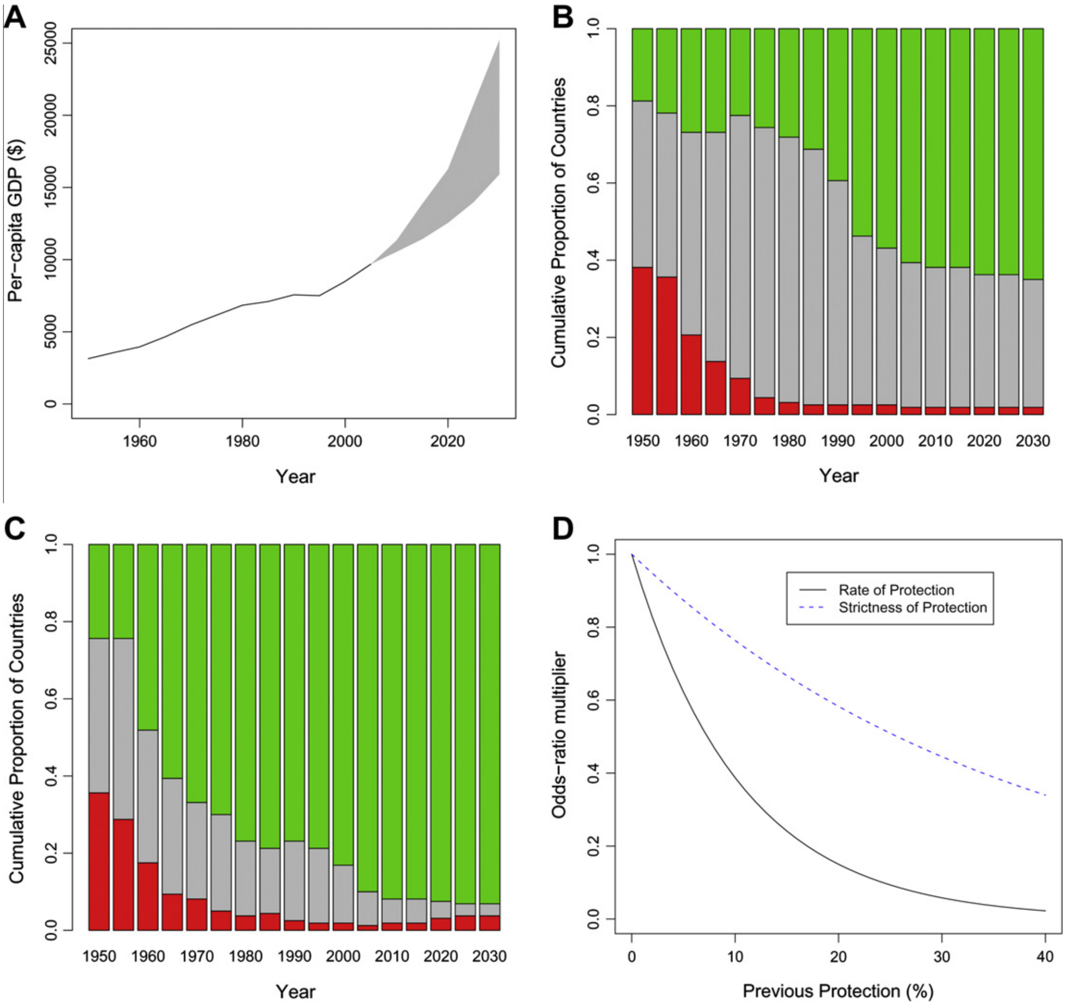

Fig. 2. Historical and future trends in explanatory variables. (A) Average per-capita gross domestic product, in 1990 Geary–Khamis dollars ($). Black line is the observed historical trend. Grey area shows the range for the four IPCC SRES scenarios. (B) Cumulative proportion of countries having a given type of political structure. Red represents colonized countries, grey represents autocracy, and green represents democracies. (C) Cumulative proportion of countries having a given level of primary education. Red represents low levels, grey represents high levels, and green represents countries with high levels of primary education. (D) The modeled effect of previous land protection (%) on the amount of current land protection and its strictness. Effect size is shown as the odds-ratio multiplier for a country relative to the odds-ratio if it had no previous protection (reference case). For instance, at 7.3% previous protection, the amount of protection is half of that of the reference case. Similarly, at 25.6% previous protection, the odds of a new protected area being strict is half of that of the reference case. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of these limiting factors (Fig. 3B). Conversely, one can identify countries such as Ireland where there has to date not been much protection (less than 5%) but which lack any of these limiting factors. Thus, while our statistical models capture the relationship between explanatory variables and protection globally, for any individual country land protection may vary considerably. It is possible that some of this variance may be due to direct investment by conservation organizations. While time-series data of investment amounts by country was not available for our analysis, we conducted an *ad hoc* analysis comparing funding by the big international nongovernmental conservation organizations over fiscal year 2002 (Halpern et al., 2006) to the amount of land protection over the period 2000–2005, the last time interval used in our historical dataset. There is no significant correlation between the two quantities ($R = 0.03$, $P > 0.05$).

4. Discussion

The future of the PA strategy appears bright. By 2030, global land protection could reach 15–29% of the Earth's surface (Fig. 1A), suggesting that more land may be protected in the next 20 years than in the previous 20 years. However, new PAs will tend increasingly to be multiple-use PAs (Fig. 1B). This result is in accord with other studies that have noted the rise of multiple-use PAs, sometimes run by non-state actors such as indigenous groups (Borrini-Feyerabend et al., 2004; Naughton-Treves et al., 2005).

Our results support two of the four perspectives about PA creation. There is support for the notion of the land protection movement as a historical and political process that gained support over a particular temporal trajectory. Our time variable in the regression analysis captures this trajectory for the period 1950–2005, and it is one of the most powerful explanatory variables in both regressions. Similarly, the form of government and level of primary education are related to the amount of land protection and the proportion of PAs that are strict. Our results also offer some support for the idea of land protection as an environmental amenity, in that greater per-capita GDP leads to greater protection. There is little support for the worthless lands perspective, in that none of these explanatory variables were significant in the final model. Similarly, there is little support for the perspective that biodiversity value drives where land is protected, in that neither of these explanatory variables were significant in the final model.

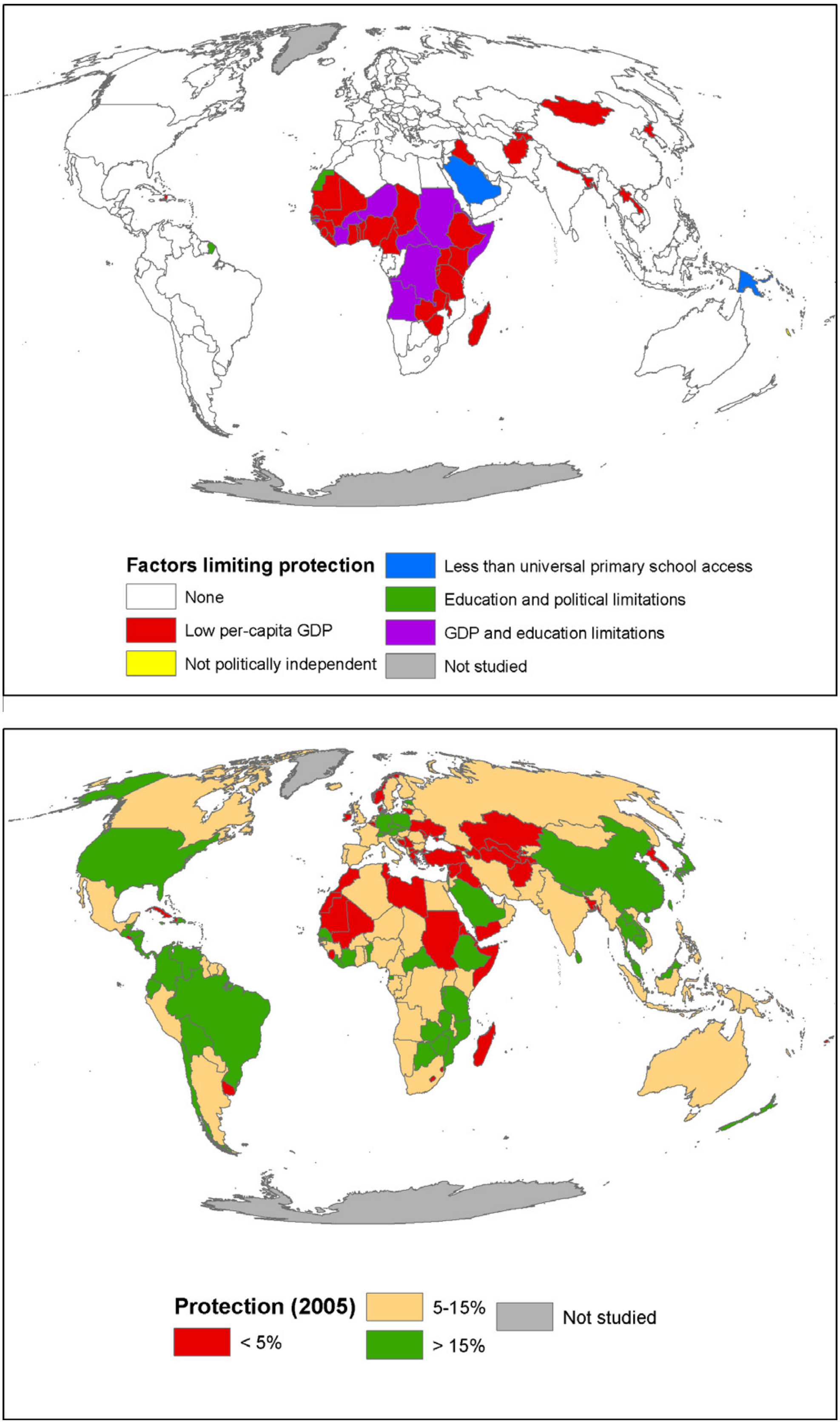

Fig. 3. (A) Three major factors potentially limiting land protection: low per-capita GDP (<$1500), lack of high levels of primary schooling, or lack of political independence. (B) Countries that had more than 15% of their area protected (green) and countries which have had less than 5% of their area protected (red). Note that while on average the amount of land protection is less in countries with one or more limiting factors, some countries with limiting factors still have substantial land protection. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

It is important to note that perspectives that were not important in explaining the amount or type of protected area creation in our global country-level analysis may be very important at explaining patterns within countries. For instance, each country may tend to create protected areas on what is their least useful land, but the overall proportion of the country protected may not vary much from country to country. This phenomenon would not be detected by our analysis, which merely shows that countries with more useful land (or land of higher biodiversity value) do not have a greater proportion of their area protected. Scale issues may also explain why we did not find support for the biodiversity value perspective, while another recent study at the ecoregion scale did (Loucks et al., 2008). Land protection may target certain high biodiversity ecoregions or biomes, while also being affected by national-level issues related to economic development and political form. For instance, tropical rainforest are a biome of high biodiversity value and a focus for conservationists, and yet clearly more land has been protected in the Brazilian Amazon than the D.R. Congo. Our results merely suggest that at the global scale biodiversity conservation value and systematic conservation planning (e.g., Rodrigues et al., 2004) are less important for determining the amount and type of protection than socioeconomic and political factors. Many other studies have made similar points, talking about the challenges for protected area creation and governance in poor countries (Bruner et al., 2004; Sanderson and Redford, 1998; Struhsaker et al., 2005) and the persistent mismatch between global conservation priorities and conservation funding (Halpern et al., 2006).

The amount and strictness of future land protection is thus the sum of several countervailing trends, and different factors may be limiting PA creation. In some countries, extreme poverty is a limiting factor to future land protection. There has been substantial discussion of ways to improve the relationship between existing PAs and poor communities, both in terms of equity (Brockington et al., 2006) (how can we insure that PAs do not limit poor people's livelihood?) and park maintenance (Peres and Zimmerman, 2001; Sanderson and Redford, 1998) (how can poor countries effectively guard PAs against illegal logging or hunting?). In other countries, the limiting factor may be the form of government or the lack of high levels of primary education. These issues, while not on the agenda of most conservationists, appear to be correlated with land protection. Finally, countries with significant previous protection might find the creation of new protected areas difficult (Fig. 2D), suggesting there are limits to the PA strategy.

Most importantly, our forecasts only describe what will likely happen if past correlations between explanatory variables and land protection continue in a similar way into the future. Historical patterns are not destiny. The future of the PA strategy will ultimately be determined not by some statistical model but by societal interest in and political will for land protection.

Acknowledgements

The authors thank The Nature Conservancy and its donors for supporting their research. Most importantly, this analysis would not be possible without the hard work that created the input databases, and we are indebted to scientists and organizations for sharing their data.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2010.09.016.

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