

Short communication

Forecasting global biodiversity threats associated with human population growth

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Abstract

The size and growth of the human population are often cited as key factors in threats to Earth's biodiversity, yet the extent of their contribution to the endangerment and extinction of other species has remained unclear. Moreover, it could be valuable to know what additional threats may arise from continued human population growth. Here we quantify a model of the relationship between human population density and the number of threatened mammal and bird species by nation. Our multiple regression analysis revealed that two predictor variables, human population density and species richness (of birds and mammals), account for 88% of the variability in log-transformed densities of threatened species across 114 continental nations. Using the regression model with projected population sizes of each nation, we found that the number of threatened species in the average nation is expected to increase 7% by 2020, and 14% by 2050, as forecast by human population growth alone. Our findings strongly support the notion that abating human population growth is a necessary, if not sufficient, step in the epic attempt to conserve biodiversity on the global scale.

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1. Introduction

Underlying anthropogenic changes to natural environments (Sala, 2000; Wakermagel et al., 2002; Rosser and Mainka, 2002), one of the greatest threats to species biodiversity and ecosystem function may result from the high density and rapid growth of the human population (Kerr and Currie, 1995; Forester and Machlis, 1996; Kirkland and Ostfeld, 1999; Thompson and Jones, 1999; Cincotta, Wisniewski, and Engelman, 2000; Cincotta and Engelman, 2000; Abbitt et al., 2000; McKinney, 2001; Harcourt, Parks and Woodroffe, 2001; Harcourt and Parks, 2003; Balmford et al., 2001; Ceballos and Ehrlich, 2002). The growth and expansion of pre-human and human populations has long displaced other species and led to their extinction, starting in the Pliocene and accelerating in the Holocene (Klein, 2000; Alroy, 2001; McKee, 2001, 2003).

Although human population growth rates determine future population sizes, current growth rates do not appear to serve as good estimators of existing biodiversity threats. Forester and Machlis (1996) found no significant correlation between biodiversity loss and national population change between 1980 and 1990. Associations of current human population growth with biodiversity "hotspots" are clear (Cincotta et al., 2000; Cincotta and Engelman, 2000), but biased by the inclusion of population density and growth effects in the definition of hotspots (Myers et al., 2000).

However, recent research has shown a clear relationship between human population size and biodiversity threats. In the United States, human population size was one of seven significant variables in models proposed by Kirkland and Ostfeld (1999) that estimated threatened mammal taxa per state with up to 80.7% accuracy. In Britain, Thompson and Jones (1999) could explain about 35% of the variation in the proportion of threatened plants by human population density.

On a global scale, Kerr and Currie (1995) found human population density was the anthropogenic factor

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most closely related to the proportion of threatened bird species per nation, although the number of threatened mammal species was more closely tied to per capita GNP. McKinney (2001) calculated that log-transformed population density accounted for 16–33% of the variation in nation-by-nation levels of threat to continental mammal and bird species, with a stronger association among mammals than birds.

Although McKinney found a strong and significant correlation, he noted that the “corollary is of course that this leaves about two thirds of the extinction threat variation remaining to be explained by other factors” (2001: 53). Implicit in this statement is that variations in human exploitation of natural resources may explain a large portion of the residuals, but we hypothesized that much of the residual variation could be explained by ecological differences among nations.

Given the undeniable relationship between human population density and threats to other species, our goal was to build a statistical model with improved explanatory value, incorporating population data and ecological characteristics of nations, to better understand the nature of the relationship and to project how future population growth may threaten other species.

2. Data and methods

We focused our study on mammals and birds, as their species richness and conservation status are best known and documented. Our analysis was based on data reported by nation. Although the geographic variability within and among nations renders the data less than ideal, it allows the compilation of data on biodiversity threats, human population size, and ecological variables. Whereas economic variables such as GNP are probably related to species threats, our goal was to focus on the relative effects of human population size rather than variations in human activity, using only variables that can reasonably be forecast for the foreseeable future.

We compiled IUCN Red List (2000) data on threatened (critically endangered, endangered, and vulnerable) mammal and bird species. The total numbers of known mammal and bird species per nation were collected from the UNEP–WCMC Animals of the World Database. Climatic data on mean annual temperature and mean annual precipitation per nation were also included (Mitchell and Hulme, 2000). Human census data for the year 2000 came from the world database of the US Census Bureau.

Following the protocol of Forester and Machlis (1996), island nations and extremely small nations (e.g. Monaco) were excluded due to exceptionally high human population densities and severe ecological disruption that skewed the data in favor of high corre-

lations between density and biodiversity threats (McKinney, 2001). Other nations were excluded due to missing data, particularly from the former Soviet block. Ultimately we used 114 of the 230 initially compiled nations.

Preliminary analysis of a correlation matrix was conducted in order to establish potential variables that would be significantly correlated with the number of threatened species of birds and mammals. All frequency variables were divided by each nation’s geographic area (in 10^6 km²) to account for size differentials among nations. The variables were log-transformed (base 10) to normalize their distributions, excepting growth rate, temperature and precipitation. A stepwise procedure was used to select a subset of predictor variables for use in a multiple regression analysis.

In order to make projections regarding future effects of population growth on threatened species, we used US Census Bureau projected population sizes for each country for 2020 and 2050 in the model, and compared them to the model’s output for 2000.

3. Results

The correlates of threatened bird and mammal species per unit area are shown in Table 1. As in other studies, the current human population growth rate was not significantly correlated with species threats. However, human population density alone was significantly and strongly correlated with threatened species per unit area ($r^2=0.402$, $P<0.001$). The greatest correlation of threatened species was with number of bird and mammal species per unit area, or “species richness” ($r^2=0.819$, $P<0.001$). Mean annual precipitation was significantly correlated, whereas mean annual temperature was not.

A stepwise linear regression selected human population density and species richness as the most effective combined predictors of the numbers of threatened species per unit area ($r^2=0.879$, $P<0.001$; Fig. 1). The residuals were normally distributed, all fell within the 95% confidence interval, and showed no patterning against the predicted outcomes.

Table 1
Linear regression correlates of the number of threatened mammal and bird species per unit area (log 10)

	<i>r</i> value	Significance (two-tailed)
Growth rate	−0.081	0.090
Population density (log10)	0.634	0.000
Species richness (log 10)	0.905	0.000
Mean temperature	0.047	0.149
Precipitation	0.440	0.000

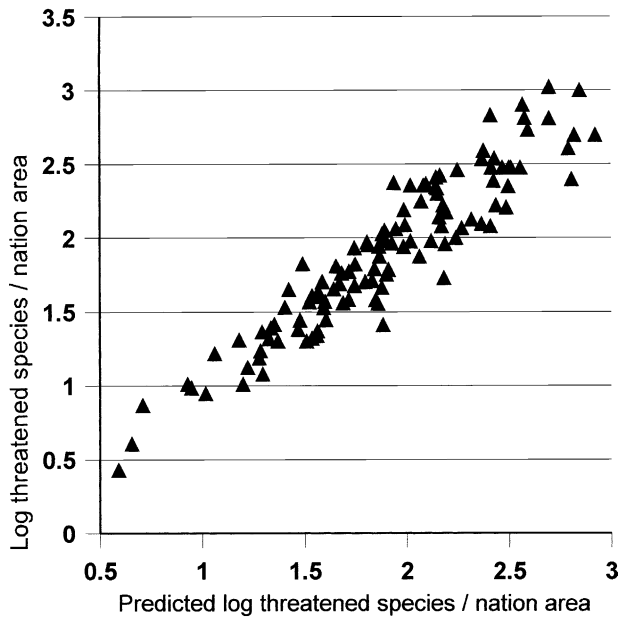


Fig. 1. Predicted vs. actual values of log-transformed density of threatened species per nation for the year 2000 based on the multiple regression model: $\log \text{ threatened species per } 10^6 \text{ km}^2 = -1.534 + 0.691 \times \log \text{ species richness} + 0.259 \times \text{human population density}$.

The model's outcome was transformed to raw numbers of threatened species per nation to detect the range of error. Brazil by far had the greatest net error, with the model underestimating their number of threatened species by 45 (26%). This, however, is under 2% of the total number of species, as was the case for most of the predicted frequencies (95 of 114 nations).

Species richness correlates with climatic parameters that could affect the number of threatened species, as these variables added no statistically significant value to explaining the residuals. Under the assumption that the species richness figs. are a proxy for general ecological character of each nation, we kept the species richness values constant for the projections.

The model predicted significant increases in biodiversity threats for those nations with growing populations, and modest declines for nations expected to experience population losses (Fig. 2). The median projected increases in the number of threatened mammal and bird species per nation are 1.6 within the next 20 years, and 3.0 species by 2050. This represents average increases of 7 and 14.3% respectively. The greatest projected increase in threats by 2050 would be 26 additional threatened species in Congo, a 38% increase, reflecting its high biodiversity and large potential human population size stemming from its 3.19% growth rate. Even with the more modest 0.91% population growth rate in the United States, an additional 10 species are forecast to become threatened in association with human population density increases by 2050.

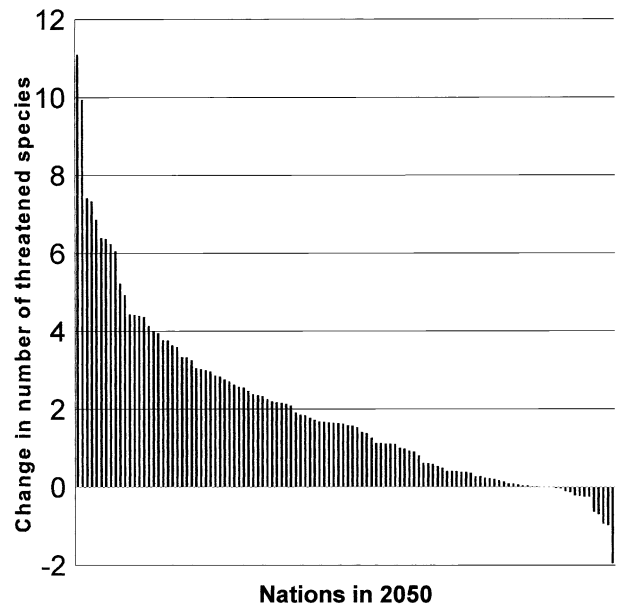


Fig. 2. Forecast changes in number of mammal and bird species threatened for each of 114 nations in 2050.

4. Discussion

Our model demonstrates that among the 114 nations measured, 87.9% of the variation in the numbers of threatened species of mammals and birds can be accounted for by human population density and species richness. In other words, the density of people is a key factor in species threats, depending upon the ecological nature of a nation and the number of species “available” for the threat of extinction. This simple relationship allows us to project likely extinction threats into the future based on trends in human population growth. With national variations in anthropogenic factors being roughly equivalent, population growth may be expected to precipitate a global increase of 14.7% more species threatened by 2050. If other taxa follow the same pattern as mammals and birds, as is sometimes assumed (Ceballos and Ehrlich, 2002), then we are facing a serious threat to global biodiversity associated our growing human population.

Other ecological factors, such as the degree of endemism, may play a role in explaining the remaining 12.1% of the variability in proportions of threatened species. The percentage of mammals endemic to a nation could not be directly included in the model because they were not normally distributed, and the log-transformation eliminated countries with zero endemic mammals from the analysis. However, on the average, nations that were underestimated by the model have more than twice the proportion of mammals being endemic to their borders, a difference which is statisti-

cally significant ($P < 0.01$) in a Kolmogorov–Smirnov test. This is consistent with the notion that endemism in hotspots is an important consideration for conservation priorities (Myers et al., 2000).

As the forecasts of the statistical model presented here are based on population projections within each nation, exogenous population factors affecting biodiversity have yet to be considered. For example, whereas a nation such as South Africa could expect as many as four species to be removed from the threatened list due to projected population declines, climate change caused by human population growth and economic development elsewhere could vitiate the projected biodiversity gains (Rutherford et al., 2000). Nevertheless, the projections for 2020 are that 100 of the 114 nations should show an increase in the number of threatened species, but because of projected population declines, 10 of those nations should show a decrease in threatened species by 2050.

Some of the errors of the model elucidate the exogenous factors. Brazil's number of threatened species was underestimated by the model due to its relatively low population density. Yet economic factors due to population demands in countries with which Brazil does business necessarily influence the rate of habitat destruction, and hence the number of threatened species. Such a country may be the exception that proves the rule regarding the importance of global human population growth and threats to other species, but to verify such an assumption will require further research incorporating components not only of GNP, but of trade practices.

Clearly socio-economic disparities and conservation ethics play a role in each nation (Sala et al., 2000; Kirkland and Ostfeld, 1999), and mediate variations in how dense human populations affect the viability of other species. More elaborate models considering the range of anthropogenic effects associated with economic development could refine the model, if such long-range economic conditions could reasonably be forecast. Nevertheless, the simple and statistically significant relationship between human population density and relative threats to mammal and bird species concurs with the notion that such variables are crucial in identifying future threats to species (Harcourt and Parks, 2003). We further suggest that slowing or halting human population growth will be a key component to biodiversity management and conservation.

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