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Effects of economic growth on biodiversity in the United States

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Abstract

For many citizens and policymakers, the empirical relationship between economic growth and biodiversity conservation has not been sufficiently established for purposes of identifying the types of economic policies amenable to biodiversity conservation. Some think economic growth conflicts with biodiversity conservation; others think economic growth conduces biodiversity conservation. With panel data from 1997-2011, encompassing US continental states, we developed a series of statistical models to investigate the relationships among species endangerment, human population, and economic growth as indicated by GDP and per capita GDP. Species endangerment is highly correlated with population and GDP, and per capita GDP is a significant regressor of species endangerment. Across US continental states, competitive exclusion of non-human species occurs via human economic growth and population growth.

Keywords: Biodiversity conservation; competitive exclusion; economic growth; economic policy; GDP.

1. Introduction

Scholars have long addressed the relationship between the human economy and the "economy of nature" (Worster, 1994), but few have focused, with empirically derived detail, on the relationship between economic growth (increasing production and consumption of goods and services in the aggregate) and biodiversity conservation. Typically, "human activities" have been identified as the cause of biodiversity decline (Kerr and Currie, 1995), leaving the policy implications unclear. More recently, the relationship between economic growth and biodiversity conservation has been purposefully investigated and explicated (Asafu-Adjaye, 2000; Czech *et al*., 2000; Naidoo and Adamowicz, 2001; Dietz and Adger, 2003; Antoci *et al*., 2005; McPherson and Nieswiadomy, 2005; Clausen and York, 2008; Czech, 2008; Mills and Waite, 2009). Several questions must yet be answered before biodiversity can be systematically considered in the formulation of economic policy.

The key ecological principle suggesting a conflict between economic growth and biodiversity conservation is competitive exclusion (Gause's Law) whereby one species is successful (i.e., becomes more prominent in an ecosystem) by out-competing species with overlapping niches (Hardin, 1960). Pursuant to this principle, an increasing prominence of *Homo sapiens*, either via increasing population or increasing per capita consumption of natural resources, should result in the decline of other species. Trophic theory may also be invoked, with the human economy portrayed as the highest trophic level in the economy of nature (Figure 1, A). Growth of the human economy is then perceived as a compression of the lower trophic levels, which are comprised of non-human species (Figure 1, B).

Thus far, the primary empirical evidence for a conflict between economic growth and biodiversity conservation has been found in the causes of species endangerment (Czech *et al*., 2000; Rose, 2005). With few exceptions, the causes of endangerment are economic activities (e.g., logging), infrastructure (e.g., roads), byproducts (pollutants, primarily), or incidental effects. The last category includes increasingly important threats to native species, such as climate change and invasive species. Climate change is a partial function of greenhouse gas emissions, which in turn are a function of economic growth because the global economy is approximately 95% fossil-fueled (Chow *et al*., 2003). Non-native species invasions are a function of regional and international trade (Jenkins, 1996) which, *ceteris paribus*, increases with economic growth (Ericson, 2005). The proliferation of these economic activities, infrastructure, byproducts, and incidental effects reflects an expanding human niche and presumably results in additional competitive exclusion.

However, some posit that the concurrence of biodiversity decline with economic growth is not the result of a causal

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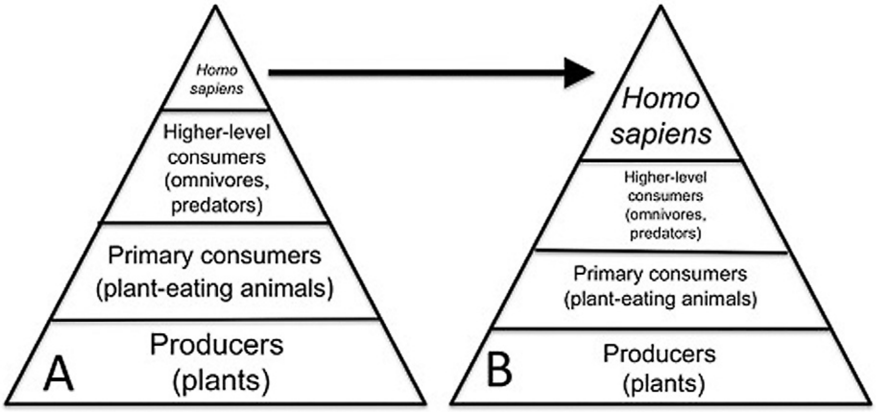

Figure 1. Trophic structure of the economy of nature, with font sizes indicating relative prominence of organisms.
Source: Authors' elaboration.
Note: (A) *Homo sapiens* occupying the highest trophic level; (B) growth of the human economy resulting in trophic compression and competitive exclusion of non-human species.

relationship, and that other factors have instead led to the decline of biodiversity. They argue that these factors, most notably poverty, could be alleviated by economic growth (Lomborg, 2001), alleviating biodiversity decline in the process. This argument entails defining economic growth as increasing per capita wealth or income (Geddes, 2004), indicated by increasing per capita GDP, rather than increasing wealth or income in the aggregate (indicated by GDP). The argument is a variant of the "environmental Kuznets curve" hypothesis (Stern, 2004) as applied to biodiversity, but researchers who have attempted to detect a biodiversity Kuznets curve (McPherson and Nieswiadomy, 2005; Clausen and York, 2008; Mills and Waite, 2009; Naidoo and Adamowicz, 2001), have found, at best, equivocal support for a Kuznets curve. In general, the evidence from these studies reinforces the case for a conflict between economic growth and biodiversity conservation.

Others acknowledge that economic activities have imperiled many species, but argue that the conflict between economic growth and biodiversity conservation may be alleviated with technological progress. Theoretically, more output of goods and services could occur with a non-increasing input of natural resources and a non-increasing output of pollution (Wils, 2001), stabilizing a growing economy's ecological footprint (Dietz *et al.*, 2007). Historically, though, more efficient use of natural resources has been accompanied by higher extraction rates of the same resources (Alcott, 2005). That trend might be expected to continue to the extent that economic growth is prioritized, because simultaneously increasing efficiency and extraction results in a higher rate of economic growth than increasing either variable alone. Furthermore, technological progress is a function of research and development finances availed in proportion to economic growth at existing levels of technology (Czech, 2008). This finding suggests that technological progress cannot reconcile the conflict between economic growth and biodiversity conservation, although it may lessen the rate of biodiversity loss in the process of economic growth.

Despite the strong theoretical evidence for a fundamental conflict between economic growth and biodiversity conservation, there remains the urgent task of analyzing the empirical evidence with statistical rigor. Such evidence and rigor are required to establish widespread recognition of the conflict by scholars, the public, and policymakers, and to drive a policy response conducive to biodiversity conservation.

If there is a conflict between economic growth and biodiversity conservation, the number of threatened, endangered, and extinct species (T&E species) should be correlated with GDP. In the US as a whole, GDP is strongly correlated with species endangerment ($R^2 = 0.99$) (Czech *et al.*, 2005). However, virtually any variable that has increased steadily during US history would be correlated with GDP. Furthermore, the aggregation entailed by a nationwide correlation could mask the real relationship between economic growth and biodiversity conservation. For example, consistent with the environmental Kuznets curve, most of the species endangerment could occur in poorer states with low GDP, while the wealthier states with high GDP could be conserving their flora and fauna with well-financed conservation programs. Developing a better understanding of the relationship between economic growth and biodiversity conservation requires an assessment of multiple areas and their respective economies and species.

2. Methods

2.1. Modeling species endangerment

Using state-level, time-series data ("panel data") from the United States, we built a set of models to examine the relationships between species endangerment and the drivers of competitive exclusion, namely: (1) human population; (2) GDP, and; (3) per capita GDP (Figure 2). We also accounted for three secondary independent variables in all models: (1) species richness, or the number of species in a state; (2) endemism, or the number of species found only in the state, and; (3) spatial extent (area) of the state. We thought it important to account for these variables because, respectively: (1) more species in an area afford more endangerment scenarios; (2) endemic species are more prone to endangerment because of their limited ranges, and; (3) compressing a given level of economic activity into a smaller area would intensify the effects on the species therein (though states with larger areas could also be expected to have more species, by virtue of the species-area relationship).

2.2. *The drivers of competitive exclusion*

At the state level, we might expect human population to be the most obvious contributor to competitive exclusion; people populating a state would presumably have more physical and biological impact within that state than elsewhere. GDP should also serve as an indicator of competitive exclusion, as it gauges the collective scale of economic activities, infrastructure, byproducts, and incidental effects that cause the endangerment of species (Czech *et al*., 2000; Rose, 2005). However, the correlation between GDP and species threat may be weakened somewhat by cross-border capital flows. For instance, income generated within one state may be dependent upon the use of landscapes and natural resources from other states.

Unfortunately, the relationships among species endangerment, human population, and GDP are further complicated by the fact that, for US states, human population and GDP are very strongly correlated. Using per capita GDP as a driver of competitive exclusion avoids the statistical consequences of multi-collinearity among independent variables. We anticipated that per capita GDP would be less strongly correlated with species threat than either population or GDP, because there may be a degree of merit to the environmental Kuznets curve hypothesis. A wealthier (per capita) polity may indeed be more likely to expend more income on conservation projects, overcoming the negative effects on biodiversity resulting from the economic activity required to produce the income for conservation expenditures.

2.3. *Basic multivariate model and data*

Drawing on a recent study (Brown and Laband, 2006), we developed a set of multivariate statistical models to examine these relationships. From a modeling perspective, the most transparent way to evaluate the biodiversity effects of economic activity levels was to include separate control variables for human population and total economic output (GDP):

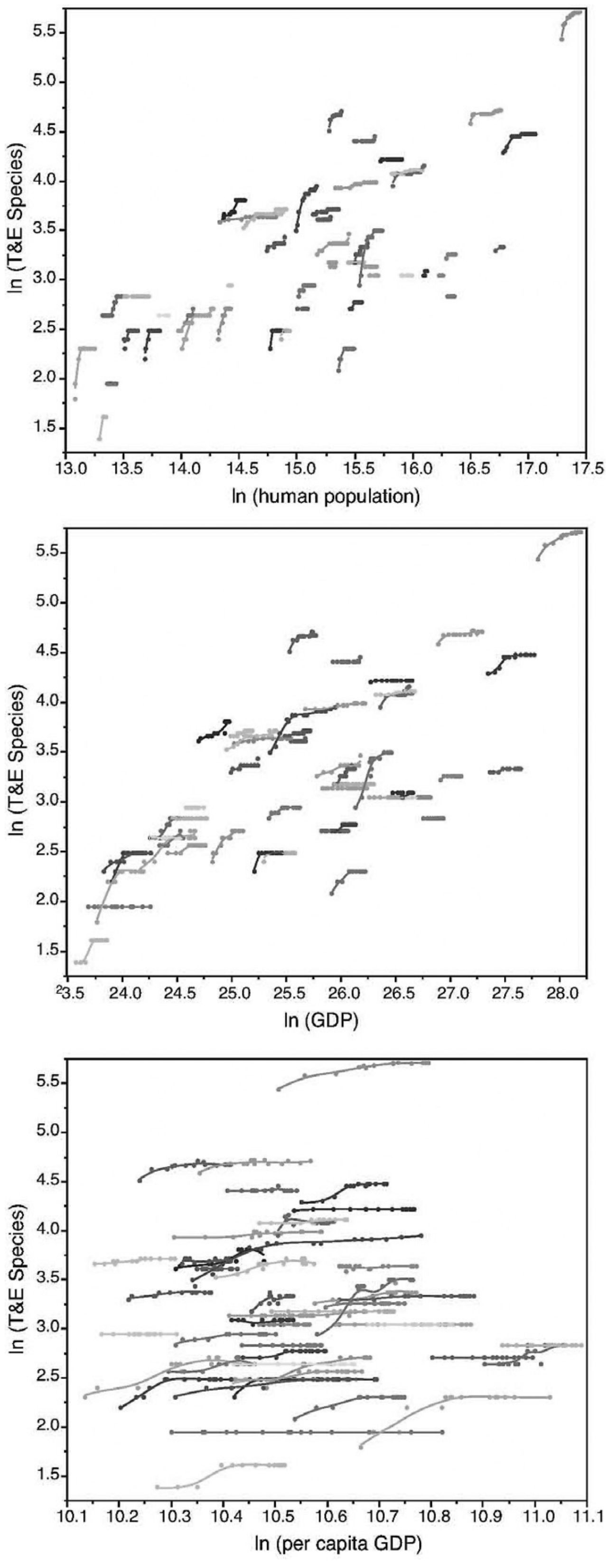

Figure 2. Relationships between species endangerment and drivers of competitive exclusion.
Source: Authors' elaboration.
Note: Each state's time series (1997-2011) is represented with a different symbol.

Table 1. Descriptive statistics for regression variables

Variable	Mean	Standard deviation	Maximum	Minimum
Number of threatened and endangered species	36	44	303	4
Number of species	3,354	957	6,717	1,835
Number of endemic species	69	191	1,296	1
Area of state ($km^2 \times 10^3$)	187	222	1,481	3
Human population ($\times 10^3$)	5,915	6,430	37,692	480
GDP ($\$ \times 10^9$)	241	285	1,763	17
Per capita GDP ($)	39,594	7,674	65,476	25,200

Source: Authors' elaboration.

$$\text{T \& E species} = f\,(\text{species richness, endemism, area, population, GDP}) \quad (1)$$

We derived an empirical model (Model 1) from our theoretical equation (1). We included in the model random intercepts for each state, to control for state-specific characteristics and to account for non-independence among repeated measures. Following the methodology of Mills & Waite (2009), we also incorporated a spatial filtering variable, derived from a state-to-state distance matrix, to account for spatial autocorrelation (Griffith & Peres-Neto, 2006); however, this variable was not significant in the models and was subsequently eliminated. Finally, yearly dummy variables were added to control for time series differences in biodiversity threats, as is standard when cross-section data are available for more than one time period (Greene, 2000).

To ascertain values for the T&E variable, we obtained counts of species listed as threatened or endangered by the US Fish and Wildlife Service pursuant to the Endangered Species Act (ESA), and we added extinct species. We used the Environmental Conservation Online System (http://ecos.fws.gov) to obtain state-by-state listings. We excluded Hawaii because of the complicating factors of island biogeography, most notably the pronounced manifestation of the species-area curve and the rapid immigration and emigration rates of island species (MacArthur and Wilson, 1967), and because the causes of endangerment on Hawaii are uniquely dominated by invasive species (Czech *et al*., 2000; Brown and Laband, 2006).

Laband and Nieswiadomy (2006) found that the average proportion of a state's species listed as "at risk" by the non-profit conservation organization, NatureServe, was roughly seven times greater than the proportion listed by the Fish and Wildlife Service. Despite this discrepancy, the same study found little evidence to support political bias in the T&E listings and concluded that there is "in some measure, a legitimate scientific basis" behind Fish and Wildlife listings (Laband and Nieswiadomy, 2006:167). Czech and Krausman (2001) described the relatively consistent, systematic approach taken by the Fish and Wildlife Service in the listing process, with inconsistencies being primarily chronological (e.g., the congressional moratorium listing activities from 1995-1996) and not taxonomic or geographic.

Data on species richness and endemism were obtained from NatureServe (Stein, 2002). Because some states have no endemic species, we added one to all endemism values to enable us to log-transform the data. The US Census Bureau reports data for states' areas and also maintains annual estimates of states' population levels. Finally, the Bureau of Economic Analysis, a branch of the US Department of Commerce, annually estimates states' real gross domestic product (GDP) and real per capita GDP using the NAICS industrial classifications.

Consistently measured data for the set of state-level cross-section variables were available for a period of fifteen years (1997 to 2011) allowing us to devise a panel data model with yearly dummy variables. We used a time series beginning in 1997 because the Bureau of Economic Analysis changed its reporting methods in 1997 and we wanted our time series to exclude the 1995-1996 listing moratorium noted above. Summary statistics for the dependent variable (species ENDANGERMENT) and the six primary independent variables (species RICHNESS, ENDEMIC species, EXTINCT species, AREA, POPULATION, and GDP) are provided in Table 1. Because of substantial skewness in the data (largely driven by California), the independent variable and each of the primary independent variables was log-transformed.

3. Results and corrected models

Model 1 shows that species richness and endemism were strong, positive predictors of species endangerment, while area was a strong negative predictor ($p < 0.05$ for all three; Table 2). The independent variable human population is statistically insignificant. State GDP is statistically significant at the 99% confidence level with a coefficient estimate of 0.2967. Since each model in this analysis was estimated in double-log form, coefficient estimates may be interpreted as elasticities. In other words, the coefficient estimate for GDP implies that the number of T&E species would increase on average by 0.2967% for every 1% increase in state-level GDP, holding other factors constant.

Table 2. Regression results from Model 1 estimating the number of nationally listed threatened, endangered, and extinct species across U.S. states from 1997 to 2011

Variables	Coefficient estimate	SE	p-value
Intercept	−11.6543**	2.5300	0.0000
species RICHNESS	1.0770**	0.3494	0.0035
ENDEMIC species	0.2042**	0.0508	0.0002
AREA of state	−0.1081*	0.0506	0.0380
human POPULATION	−0.0512	0.0596	0.3902
state GDP	0.2967**	0.0441	0.0000
Model R^2	0.8165		
Model AIC	−1973.279		

Source: Authors' elaboration.
Notes: Model expressed in double-log form so that coefficient estimates may be interpreted as elasticities. For example, the coefficient estimate for GDP is 0.2967, meaning that a 1% increase in real GDP across states is associated on average with a 0.2967% increase in US FW service listings of threatened and endangered species.
Results for 14 year-to-year dummy variables and random intercepts for each of 49 states excluded from table.
* statistical significance at the 99% confidence level.
** statistical significance at the 95% confidence level.

As noted above, however, POPULATION and GDP are highly correlated (r = 0.9893). When two (or more) independent variables are highly correlated, the statistical consequences can be severe, including very high standard errors, low significance levels (and p-values) despite relatively high model R^2 values, and coefficients with "wrong" or implausible magnitudes (Greene, 2000). With the population and GDP variables so highly correlated, hypothesis tests on these coefficient estimates from Model 1 present major multi-collinearity problems.

Several strategies are proposed for dealing with multi-collinearity problems: (1) obtain more data; (2) omit one or more of the highly correlated variables; or (3) transform two or more of the independent variables (Greene, 2000). The first strategy is generally not possible or practical except for future research projects. The second strategy is the one most often employed, but it is not without its drawbacks, particularly if theory or *a priori* evidence indicates that both (or all) highly correlated variables truly belong in the model. If variables are dropped that actually belong in the model, then estimates of the remaining coefficients will be biased, potentially severely. The exercise may be useful nonetheless. In Model 1, POPULATION is plausibly identified as the "offending" independent variable because it (rather than GDP) is statistically least significant. Omitting the population variable yields one alternate corrected model:

$$\text{T \& E species} = \text{f (species richness, endemism, area, GDP)} \quad (2)$$

Following this corrective strategy, we are led to make the guarded assumption that the coefficient estimate for the omitted variable (POPULATION) is equivalent to zero (i.e., statistically zero effect on the dependent variable, species endangerment). Results from Model 2 reveal that GDP is statistically significant well beyond the 99% confidence level with a coefficient estimate of 0.2705 (Table 3). For comparison purposes, a similar model (Model 3) is shown with GDP omitted instead of POPULATION.

As both Models 2 and 3 may still suffer from omitted variable bias, the best strategy in this case is to transform GDP and POPULATION into a substitute measure of economic activity, per capita GDP (PC-GDP):

$$\text{T \& E species} = \text{f (species richness, endemism, area, GDP/population, population)} \quad (3)$$

This strategy preserves the theoretical integrity of the original model by holding constant the effects of both population and economic output, albeit in a transformed way. Although per capita GDP exhibits a much weaker correlation with species threat than does either population or aggregate GDP (Table 4), this model has the added benefit of allowing us to examine the impacts of per capita wealth. Including population in this model allows us to capture total scale effects as well.

We find that the transformed variable PC-GDP is highly statistically significant ($p < 0.01$) (Table 3). The coefficient estimate for PC-GDP is 0.2671, implying that for every 1% increase in per capita economic output across states, the number of T&E species increases by 0.2671%. The coefficient estimate for population is also significant ($p < 0.01$), but has a smaller coefficient (0.2338). As in all previous models, species richness and endemism are statistically significant and positive predictors of species endangerment, while state area is negatively and significantly correlated with species endangerment.

4. Discussion and conclusions

Our results are consistent with the expectations described above. Population and GDP are highly (positively) correlated with species threat (Table 4). In the overall data, per capita GDP is weakly (negatively) correlated with species endangerment. However, when the time-series nature of the data is accounted for in the regression model, we find that per capita GDP is a highly significant predictor of species threat (Table 3).

These results suggest that the conflict between economic growth and biodiversity conservation is fundamental in the following sense: If the strong correlation of species endangerment with GDP could be relegated to the fact that GDP is a function of population growth (with which species endangerment is highly correlated), one could argue that the threat to biodiversity is fundamentally an issue of human population growth, not economic growth. To the contrary, the results indicate that the conflict between economic

Table 3. Results of regression models estimating the number of threatened, endangered, and extinct species across U.S. states, 1997-2011

Variable	Model 2: GDP			Model 3: population			Model 4: per capita GDP		
	Coefficient estimate	Standard error	p-value	Coefficient estimate	Standard error	p-value	Coefficient estimate	Standard error	p-value
Intercept	−10.9287	2.3897	0.0000	−8.4232	2.4568	0.0006	−11.4827	2.5282	0.0000
RICHNESS	0.9706	0.3274	0.0048	1.1079	0.3473	0.0026	1.1194	0.3486	0.0024
ENDEMIC	0.2117	0.0502	0.0001	0.2027	0.0502	0.0002	0.2016	0.0506	0.0002
AREA	−0.1070	0.0507	0.0402	−0.1148	0.0499	0.0261	−0.1095	0.0504	0.0351
POPULATION	—	—	—	0.2261	0.0437	0.0000	0.2338	0.0431	0.0000
GDP	0.2705	0.0318	0.0000	—	—	—	—	—	—
PC-GDP	—	—	—	—	—	—	0.2671	0.0447	0.0000
Model R^2	0.8152			0.8210			0.8178		
Model AIC	−1978.344			−1935.954			−1964.336		

Source: Authors' elaboration.
Note: The model is expressed in double-log form so that coefficient estimates may be interpreted as elasticities. Temporal dummy variables and state intercepts are omitted. All variables are significant at the 95% level.

growth and biodiversity conservation is manifested via per capita production and consumption, regardless of population.

The results indicate that macroeconomic policies designed to promote economic growth, whether via population or per capita production and consumption, will result in a continued loss of biodiversity. Conversely, the stabilization of the economy at a certain size would be conducive to equilibrium with the economy of nature. An adjustment to macroeconomic trends, either through changes in policy directives or by non-policy means, may therefore be a prerequisite for biodiversity conservation.

For purposes of macroeconomic adjustments, our coefficient estimates provide some guidance. Our results suggest that the number of T&E species increases by approximately 0.2671% for every 1% increase in per capita GDP. Thus, for Tennessee which had 82 T&E species for most of the time series, a 5% increase in per capita GDP would, *ceteris paribus*, be associated with the endangerment of approximately one additional species ($5 \times 0.2671\% \times 82 = 1.095$). Likewise, for the 49 continental states, a 5% increase in per capita GDP would, *ceteris paribus*, be associated with the endangerment of approximately 12 additional species ($5 \times 0.2671\% \times 902 = 12.046$).

Theoretically, the endangerment coefficient could decrease with research and development focused on end-use efficiency. However, given the tight linkage between technological progress and economic growth at pre-existing levels of technology (Czech, 2008), the coefficient is unlikely to decrease dramatically. It is also possible that technological progress would be outweighed by ecological threshold effects and that the endangerment coefficient could increase even concurrently with technological progress.

One might also apply the model "backwards" from current levels of endangerment. For example, the average number of T&E species in each of the 49 continental states is 36; *ceteris paribus*, to de-list an average of three species per state would require a 29% reduction in per capita economic output across states ($3 \div 36 \div 0.2934\% = 28.403$). However, this may be overly optimistic; once the habitat of a species has been eliminated or degraded by an economic sector or infrastructure, the habitat (and attendant species) may not recover if sector activity slows or the infrastructure is used less intensively.

In all of these cases, the qualifier *ceteris paribus* is important to note because other factors complicate the relationship between per capita GDP and species endangerment. Population, for example, continues to grow. Less obviously, the endangerment of some species by economic activity may lead to the endangerment of other species as a function of trophic interactions, resulting in a multiplier effect of economic growth on species endangerment. In the very long run, rates of biodiversity loss would decline, regardless of the drivers, if the species

Table 4. Correlation matrix for regression variables (Pearson r)

Variables	T&E species[a]	RICHNESS	ENDEMIC	AREA	POPULATION	GDP	PC-GDP
T&E species[a]	1						
RICHNESS	0.7965	1					
ENDEMIC	0.9189	0.7168	1				
AREA	0.1470	0.1544	0.2447	1			
POPULATION	0.7559	0.6887	0.7320	0.1028	1		
GDP	0.7382	0.6541	0.7296	0.1112	0.9893	1	
PC-GDP	–0.0171	–0.1602	0.0535	0.2581	0.1327	0.2177	1

Source: Authors' elaboration.
[a] Threatened, endangered, and extinct species, dependent variable.

pool became so depleted that relatively few species were "available" to endangerment.

Our results provide empirical evidence in support of a conflict between economic growth and biodiversity conservation. In adding to the well-developed theoretical basis for this conflict, these empirical results underscore the need to evaluate and reform macroeconomic policy if biodiversity is a concurrent policy goal.

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