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Using Multiple Linear Regression Models to Identify Factors Underlying Avian Species Imperilment in Sub-Saharan Africa and Europe

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1. Introduction

Determining what factors influence the threats faced by the world's flora and fauna is of key importance to conservation biologists (Cardillo et al., 2008; Davies et al., 2006; Smith et al., 2003; see Spangenberg, 2002). A plethora of research has been directed at this effort and has looked extensively at biological and anthropogenic factors, including social and socio-economic conditions (e.g. Holland et al., 2009; Huby et al., 2006; Kerr & Currie, 1995; Lenzen et al., 2009; McKee et al., 2003). This chapter intends to supplement the existing literature by utilizing updated data to address this issue from a primarily socio-economic perspective for birds in a selection of sub-Saharan African and European countries. We generate several models using multiple linear regression to test the explanatory power of a host of variables, including human population density (HPD) per km^2, Corruption Perception Index (CPI) score (as a proxy for governance), GDP per capita, and the average degrees from the equator. In addition, the results are considered in light of projected changes to HPD levels for the year 2050 (United Nations [UN], 2008).

Bird species are currently being impacted by several threats, resulting in the need for conservationists to address a wide range of issues (Brooke et al., 2008). These include land-use change, habitat destruction, invasive species, unsustainable exploitation, climate change, and insufficient governance (Brooke et al., 2008; Butchart, 2008; Lemoine et al., 2007; Lenzen et al., 2009; Reif et al., 2008; Smith et al., 2003; Thomas et al., 2004). These threats have the potential to impact the quality or quantity of available resources, directly impact the population, or change the conditions that a species may face. In addition, while these threats exist in isolation, many are correlated or exist in a cascading fashion (for example climate change can lead to habitat destruction). While these threats, and others, can be enumerated, the underlying drivers of these pressures are often rooted in socio-economic conditions, including corruption, HPD, and poverty level (Kerr & Currie, 1995; Pandit & Laband, 2009; Pellegrini & Gerlagh, 2004).

Understanding how these socioeconomic factors influence conservation agendas has been the focus of several authors, occasionally with contradictory results. While correlation can often be observed, the exact causal influence of these factors on the species of interest is typically a matter for interpretation. Corruption has been speculated to influence the availability of resources that are necessary to implement and enforce conservation efforts (Smith & Walpole, 2005). While corruption may potentially positively affect conservation efforts by minimizing the economic development of a country, it may at the same time jeapordize conservation efforts by compromising the support structure necessary for conservation efforts to be successful (Laurance, 2004). HPD has also been shown to be an essential factor to consider when implementing biodiversity conservation strategies (Kerr & Currie, 1995). While a relationship between HPD and species richness clearly exists, the mechanism(s) by which HPD influences biodiversity is less clear; the extent to which HPD influences biodiversity through habitat loss or use patterns is unresolved (Chown et al., 2003, Kerr & Currie, 1995). Similarly, while it is accepted that biodiversity loss and poverty are linked, the relationship between the two is not universally agreed upon (Adams et al., 2004). However, it has been suggested that poverty may hamper efforts by encouraging both violation of protected areas and minimizing ability to dedicate funds for conservation.

These threats are not unique to bird species and, according to the Millennium Ecosystem Assessment [MEA] (2005), biodiversity and the ecosystems that support it are in many cases imperiled. However, specific to birds, it has been suggested that extinctions per million species per year (E/MSY; a unit used to describe relative extinction rates [Pimm et al., 1995]) are occurring at 1000 - 10 000 times above background rates; more conservative estimates are 100 - 1000 times above background rates (see Brooke et al., 2008; Pimm et al., 2006).

While current research suggests that conservation efforts are successful at reducing the amount of extinctions being experienced, existing efforts are still lacking to successfully protect the world's biodiversity (Brooke et al., 2008; Pimm et al., 2006). In order for these conservation methods to be successful, they must not only deal with the flora and fauna that are being threatened but must address the underlying drivers for the pressures exerting the threats; it is essential that conservation measures are considered for management of people in addition to nature (Luck, 2007). According to the Millennium Ecosystem Assessment, effective ecosystem management "requires substantial changes in institutions and governance, economic policies and incentives, social and behavior factors, technology, and knowledge" (MEA, 2005).

2. Methods

2.1 Country selection

We first considered all countries from sub-Saharan Africa and Europe for our study. However, countries of either region were omitted from the analyses if data was not available for at least one of the variables under consideration. Our final list includes 73 countries, 42 from sub-Saharan Africa and 31 from Europe (see *Fig. 1 & 2*).

2.2 Data acquisition

Data was acquired for the variables utilized in the model through an internet search. Data for each of the variables was freely available from online datasets provided through the respective sources. As the dependent variable, the proportion of threatened bird species as a percentage of total bird species per country was utilized. This value was derived by dividing the number of threatened bird species (International Union for Conservation of Nature and Natural Resources [IUCN] designations critically endangered [CR], endangered

sub-Saharan Africa (n = 42; *Fig. 1*): Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Cote d'Ivoire, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Malawi, Mali, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe.

Fig. 1. Map of sub-Saharan countries included in regression analyses (dark gray shaded countries) (Base map source: CIA, n.d.).

[EN], and vulnerable [VU]) in each country as listed in the 2009.1 IUCN Red List database (http://www.iucnredlist.org; International Union for Conservation of Nature and Natural Resources [IUCN], 2009) by the total number of bird species recorded in each country (United Nations Environment Programme-World Conservation Monitoring Centre, 2008) and multiplying by 100%.

Europe (n = 31; *Fig. 2*): Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, The former Yugoslav Republic of Macedonia, United Kingdom.

Fig. 2. Map of European countries included in regression analyses (dark gray shaded countries) (Base map source: CIA, n.d.).

Four independent variables were considered in our study. These included HPD per km^2 (UN, 2005), CPI score (Transparency International, 2007), GDP per capita (medium variant in Current International Dollars [CID]) (UN, 2006), and average distance from the equator based on the approximate geographic center for each country (see www.cia.gov for an explanation of how geographic center is determined; Central Intelligence Agency (CIA) n.d.). This last latitudinal variable was added to control for the trend towards higher species richness closer to the equator and associated differences in variance between the size of country bird lists. While HPD and GDP per capita (as a proxy for poverty level) are utilized in other similar research, CPI score is intended to illustrate the relative national level of governance (e.g. Kerr & Currie, 1995; McKee et al., 2003; Smith et al., 2003). CPI score is based on a ten point scale with 10 being the highest score, indicating the presence of less corrupt governance (for more information, consult http://transparency.org).

2.3 Model generation and manipulation

SPSS (ver. 16.0) software was utilized to generate the models under consideration. Within the program, the built in Regression-Linear option was performed. This function output an equation of the form:

$$\text{Proportion of threatened bird species (\%)} = \text{constant} + a\,(\text{HPD per km}^2) + b\,(\text{CPI score}) + c\,(\text{GDP per capita}) + d\,(\text{degrees from the equator})$$

Equations were derived for each model performed using a different set of explanatory variables.

Two datasets, comprised of the countries listed for sub-Saharan Africa and Europe, were run through the regression function utilizing the four independent variables. In addition to the original models containing all independent variables, a second set was generated excluding the GDP per capita variable for both country groups, as it showed strong co-linearity to CPI score. A final set of models were run for Africa and Europe, which included only CPI score and CPI score and HPD per km^2, respectively.

The results from the models run with all variables except GDP per capita were used to illustrate the effects of a theoretical shift in the HPD per km^2 independent variable to reflect projected HPD per km^2 in the year 2050. Projections were taken from the 2008 Revision of the World Population Prospects generated by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (UN, 2008). The projections include values for three variants (low, medium, and high) and current fertility rate to reflect the range of plausible population scenarios for both sub-Saharan Africa and Europe. For more information consult http://esa.un.org/unpp.

3. Results

The mean proportion of threatened bird species for the sub-Saharan African countries considered is significantly lower than that for the European countries ($t = -6.26$; $P = 0.000$; mean = 1.88 ± 0.86 and 3.10 ± 0.76, respectively). Models generated using all four independent variables for Europe and sub-Saharan Africa showed a disparity in level of significance and explanatory power ($P = 0.002$ and 0.129; adjusted $R^2 = 0.384$ and 0.082; $F = 5.673$ and 1.912, respectively). Despite the difference in level of significance, there was a high degree of correlation between CPI score and GDP per capita for both Europe and sub-Saharan Africa (Pearson correlations of 0.914 and 0.550, respectively) (*Fig. 3*). Removing GDP per capita from the independent variables considered improved the significance and explanatory power of the Europe and Africa models ($P = 0.001$ and 0.069; adjusted $R^2 = 0.397$ and 0.103; $F = 7.571$ and 2.563, respectively). Using a paired down set of independent variables returned an improvement in the Africa model (CPI score only; $P = 0.009$; adjusted $R^2 = 0.136$; $F = 7.454$) and an impairment in the European model (HPD per km^2 and CPI score; $P = 0.006$; adjusted $R^2 = 0.258$; $F = 6.221$).

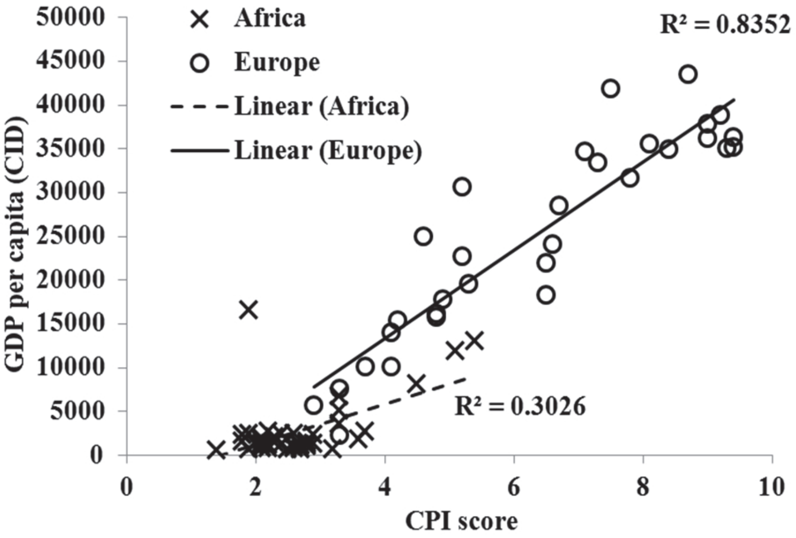

Fig. 3. Scatterplot of GDP per capita and CPI Score with linear trend line. sub-Saharan Africa n = 42; Europe n = 31.

Within the models, not all independent variables considered were significant (*Table 1*). For the African models, no single variable was significant for either the model containing all four independent variables or the model with GDP per capita removed. In both instances, CPI score was the closest to being significant (P = 0.075 and 0.057, respectively). In the African model considering only CPI score, CPI score became a significant predictor (P = 0.009). For the European models containing all four and all but GDP per capita, the only significant individual variable was degrees from the equator (P = 0.010 and 0.011, respectively). In the model generated using just HPD per km^2 and CPI score, CPI score was significant and HPD was nearly significant (P = 0.004 and 0.053, respectively).

Figure 4 shows the relationships between HPD per km^2, CPI score, and degrees from the equator and proportion of threatened bird species when plotted individually against one another. For all three independent variables, the trends are opposite for the two country groups *(Fig. 4).*

For Europe, increasing HPD per km^2 and decreasing CPI score and degrees from equator correspond to an increasing proportion of threatened bird species. For Africa, the opposite is true; decreasing HPD per km^2 and increasing CPI score and degrees from equator correspond to an increasing proportion of threatened species. Of these trends, degrees from equator is the variable with the strongest relationship for Europe followed by CPI score (R^2 = 0.44 and 0.21, respectively). For Africa, CPI score is the strongest followed by degrees from the equator (R^2 = 0.16 and 0.08, respectively). For Europe and Africa, HPD per km^2 has the weakest correlation to proportion of threatened species (R^2 = 0.06 and 0.004, respectively).

Variable	**sub-Saharan Africa**				**Europe**			
	Coeff.	**SE**	***P***	**Mean**	**Coeff.**	**SE**	***P***	**Mean**
Model 1								
Constant	0.769	0.465	0.106		5.996	0.849	0	
HPD	$-5.21E^{-4}$	0.002	0.798	58.75	$1.31E^{-3}$	$1.35\ E^{-3}$	0.343	113.08
CPI	0.393	0.214	0.075	2.67	0.030	0.145	0.839	6.35
GDP	$-0.17E^{-4}$	$0.46E^{-4}$	0.717	2772.45	$-0.16E^{-4}$	$0.24E^{-4}$	0.511	25231.84
Degrees	0.012	0.021	0.580	11.63	-0.057	0.021	0.010	49.96
Model 2								
Constant	0.813	0.443	0.075		6.024	0.840	0	
HPD	$-3.16E^{-4}$	$1.92E^{-3}$	0.870	58.75	$1.22E^{-3}$	$1.33E^{-3}$	0.368	113.08
CPI	0.351	0.179	0.057	2.67	-0.054	0.070	0.442	6.35
Degrees	0.012	0.021	0.547	11.63	-0.054	0.020	0.011	49.96
Model 3								
Constant	0.785	0.419	0.068		3.945	0.388	0.000	
HPD	-	-	-	-	0.003	0.001	0.053	113.08
CPI	0.409	0.150	0.009	2.67	-0.182	0.057	0.004	6.35

Table 1. Model coefficients (Coeff.) with standard error (SE) and significance values *(P)* generated using the Regression-Linear function and associated current mean values for independent variables considered. Model 1: all four independent variables; Model 2: all but GDP; Model 3: CPI score only for sub-Saharan Africa and HPD per km^2 and CPI score for Europe. HPD = HPD per km^2, CPI = CPI score, GDP = GDP per capita (CID), and Degrees = average degrees from equator. sub-Saharan Africa n = 42; Europe n = 31.

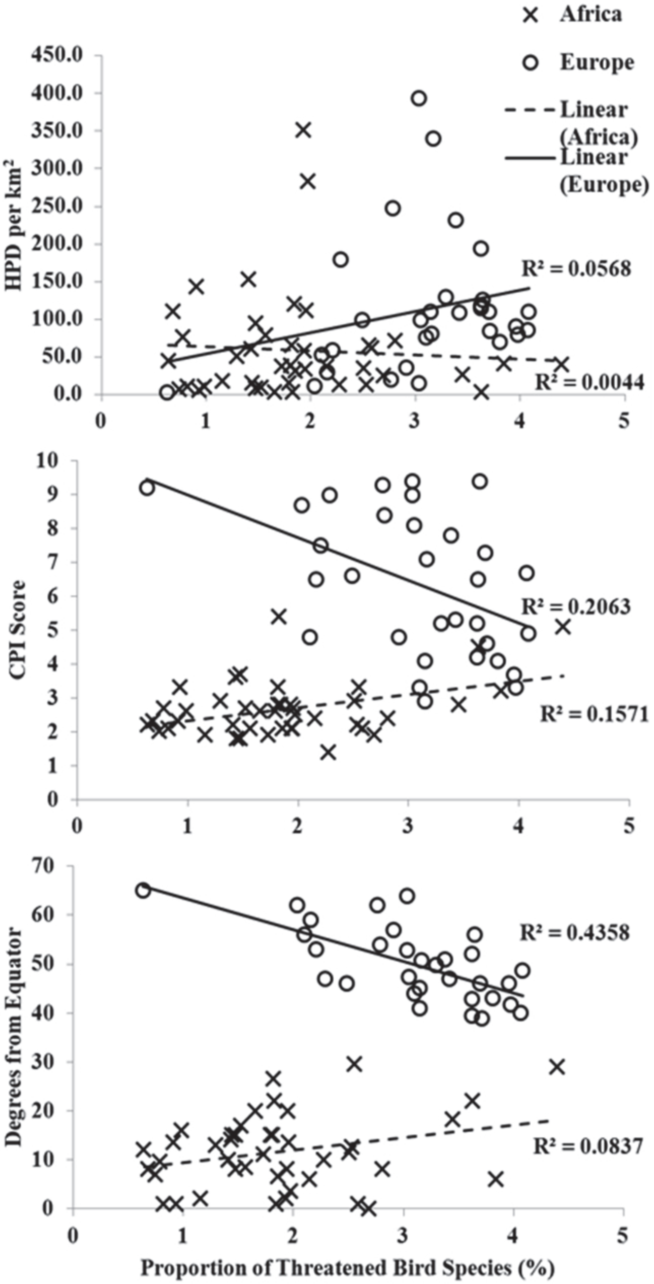

Fig. 4. Scatterplots of HPD per km², CPI score, and degrees from equator plotted against proportion of threatened bird species (%). sub-Saharan Africa n = 42; Europe n = 31.

Using the results from the models generated with all variables except GDP per capita, HPD per km^2 projections for the year 2050 (UN, 2008; *Table 2*) were utilized to predict the impact of future population projections on the proportion of threatened bird species. For both the European and African models, the HPD coefficients were small and not significant (*Table 1*). However, the African model resulted in a negative relationship, while the European model contained a positive one (*Fig. 4*). As a result of the small coefficient values, these manipulations resulted in modest to no changes to the proportion of threatened bird species for all scenarios despite the difference between projected HPD changes in Africa and Europe (*Table 2*).

Scenario	**sub-Saharan Africa**				**Europe**			
	Value	**Change**	**Prop.**	**Change**	**Value**	**Change**	**Prop.**	**Change**
Current	58.75	-	1.88	-	113.08	-	3.09	-
Low	116.31	1.98	1.86	0.99	100.61	0.89	3.08	1.00
Medium	132.90	2.26	1.85	0.99	113.94	1.01	3.10	1.00
High	150.60	2.56	1.85	0.98	128.55	1.14	3.11	1.01
Constant	199.71	3.40	1.83	0.98	109.71	0.97	3.09	1.00

Table 2. Values for current and projected HPD per km^2 levels and corresponding modeled proportion of threatened bird species (Prop.) (%) based on the Model 2 scenario (without GDP per capita independent variable included). Projected values are based on manipulation of HPD per km^2 to reflect 2050 projections for Low Variant (Low), Medium Variant (Medium), High Variant (high), and current fertility rate (constant) scenarios (derived from UN, 2008 data). Change is categorized in relation to current values. sub-Saharan Africa n = 42; Europe n = 31.

4. Discussion

It is clear that conservation efforts are criticially important to protect biodiversity from the increasing multitude of threats that species are presented with. These threats are both direct and indirect and primarily driven by anthropogenic activities. However, the threats that these species face (e.g. land-use change/habitat destruction, overexploitation, invasive species, climate change) are in many cases symptoms of underlying social conditions rooted in politics and economics. The research conducted within this project helps to further the analysis of what factors influence the threatened status of bird species. Without suggesting causation, these models represent a plausible set of proxies which can significantly explain up to 13.6% and 39.7% of the variation in the sub-Saharan African and European countries examined, respectively. While it was possible to develop a significant model for both country groups, there were disparities in the amount of variation explained within each model and the relative impact and significance of the individual parameters considered. In terms of significance, the only parameter to register as significant (at $P < 0.05$) for both country sets was CPI score in the Model 3 scenario. In the other two model scenarios, sub-

Saharan Africa had no significant individual parameters, and for Europe, only degrees from the equator was significant.

The lack of significance in the Model 1 and Model 2 scenarios for the three socio-economic variables (HPD per km^2, CPI score, and GDP per capita) for both Europe and sub-Saharan Africa provides an interesting perspective on their relative importance within these models. However, more interesting is the opposite trends observed between the two country groups. In the Model 2 scenario, all three variables considered had opposite influence between country groups. This can also be seen in the scatterplots in Figure 4, which show that the trends in the existing data are inverted between country groups. While the significance of these variables in the Model 2 scenario makes comparison difficult, Model 3 suggests that CPI score is an important, significant factor for both the African and European country groups. However, this model suggests that improving governance in Europe decreases the proportion of threatened species, while in Africa improving governance increases the proportion of threatened species. While this model does not suggest reasons to why this is the case, it highlights the importance of creating models that are specific to the region within question. For similar models to be useful in providing insight into conservation issues and strategies, it is important that regionally specific conditions are considered in model generation.

Furthermore, comparison between the sub-Saharan African and European data highlights the fact that these models are reliant on abundant and accurate data for creating reasonable forecasts, which can be a problem in areas with insufficient data (problems of this nature were encountered when searching for historic data for sub-Saharan Africa). Indeed, national level data may also be too coarse to tease out confounding factors contributing to species imperilment and, for example, may ignore potentially vast differences in HPD *within* countries, which may have significantly greater effects on birds than what our models indicated. Brown & Laband (2006), for example, utilized state-level data to evaluate correlations between species imperilment and the level and spatial distribution of human settlement and infrastructure development in the United States. It was only at this scale that they were able to identify that the number of people and households, incidence of roads, and intensity of nighttime lights were all significantly correlated with the ecological imperilment of species. Additionally, Pandit & Laband (2007) point out that modeling the determinants of threats to species using country-level data may also be complicated by the fact that factors that influence species imperilment may extend or operate beyond arbitrary political boundaries. Therefore, they advise controlling for spatial autocorrelation in models focusing on imperilment of flora and fauna. As data becomes more abundant at finer resolutions, and more easily accessible, we expect that better, more functional models are likely to be produced.

HPD has been shown to have very little impact on the proportion of threatened species in both the African and European countries considered due to the extremely small coefficients within the models. This outcome is surprising given the potential increase in HPD values in the 2050 projections and contradictory to assumptions based on existing theory, which suggest that increasing HPD should have a negative impact on species. The violation of the exisitng assumption is especially true in regard to the sub-Saharan Africa countries correlation, which has an inverse relationship between HPD and proportion of threatened bird species. While HPD and the other variables are not significant individually in all models, the trends observed in the models provide an interesting insight into potential conservation issues. These trends suggest that in order to develop effective conservation strategies in Europe, a set of goals must be pursued including decreasing HPD and increasing CPI and GDP. In Africa, the exact opposite is the case.

Developing an understanding of the relationships between socioeconomic drivers and the threats faced by avian and other species worldwide is essential for developing a functional conservation strategy. Understanding the regional specific trends allows for a more focused application of effort to maxamize the conservation outcome. However, these trends are purely correlational, and understanding the cause of these relationships requires interpretation of the data and a detailed understanding of the sociopolitical dynamics of the region in question. To this end, the trends observed in this study are perplexing and counter intuitive to what would be expected from existing theory. In particular, CPI score as a metric of governance suggests that in Europe strong governance and lack of corruption are beneficial while in sub-Saharan Africa the opposite relationship exists. This model suggests that corruption may function to protect bird species under certain conditions. It may be the case that in under-developed regions, corruption and poor governance obstruct development, with the effect that even while human populations remain mired in poverty, wildlife habitat is left intact. Conversely, in highly developed areas a great deal of governance effort is required to protect what habitat remains. While this is an interesting idea, given that CPI and GDP are colinear, suggesting that lower CPI will benefit birds has significant social implications for the nations concerned. These postulates concerning the disparate effects of corruption and governance across our regions were not tested in our analyses, but they are interesting and would be worthy of continued research effort, on both regional and national scales.

5. Conclusion

The determination of what factors influence the threat status of the world's flora and fauna is of key interest to conservation biologists worldwide. While these models do not suggest causation and it is likely that the independent variables suggested represent proxies for the pressures rather than the actual pressures themselves, the models generated within this research have significant explanatory power. Given that these models are built on a combination of anthropogenic and non-anthropogenic variables, they highlight the interdependent nature of humans and the environment for conservation purposes. Finally, given the disparities in the results between geographic regions, these models suggest that accurate data reflecting regionally specific differences must be taken into account when considering which pressures and conservation strategies are most applicable to the area in question.

It is evident that these models, though significant, explain only a fraction of the variability in threat status faced by bird species in these regions. Additionally, these models result in a plethora of questions that are of critical importance for conservation strategies. While correlations are presented, these models do not present either a mechanism or answers to why regional differences exist. There is no reason why any of these factors independent of their causal effects should threaten biodiversity. Therefore it is essential to develop a better understanding of what the cascading effects of these socio-economic factors might be, and it is equally important to recognize that the same socioeconomic condition may result in a very different outcome in different regions as demonstrated by these models. Furthermore, what factors are influencing the remaining variability is left unresolved.

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