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Global biodiversity decline of marine and freshwater fish: A cross-national analysis of economic, demographic, and ecological influences

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Abstract

We test competing hypotheses from political–economic and neo-liberal theories about the effects of economic growth and urbanization on a neglected, but important, indicator of environmental health: aquatic biodiversity. We analyze cross-national data on the number of threatened fish species within national territorial waters using negative binomial regression. We find that, counter to the expectations of neo-liberal theories, economic growth increases the likelihood of fish species becoming threatened within nations. Urbanization, however, appears to have no additional effect. The "environmental Kuznets curve" does not hold for aquatic biodiversity, suggesting that further economic growth in nations is likely to escalate the biodiversity crisis.

Keywords: Biodiversity; Endangered species; Aquatic ecosystems; Environmental Kuznets curve

1. Introduction

One of the primary concerns of the environmental social sciences is furthering our understanding of the social forces that lead to environmental change. One important debate centers on the effects of modernization[1] on environmental problems. Those coming from a neo-liberal perspective, such as ecological modernization theory in sociology and the environmental Kuznets curve in economics, argue that economic growth and modernization need not expand environmental problems and expect that the most affluent nations will be at the forefront of

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[1] Here we are referring to the material macro-structural aspects of modernization, especially economic growth, industrialization, and urbanization. The term *modernization* has different meanings in different contexts, and in some uses it refers to institutional and cultural change, particularly the adoption of a Western scientific worldview. Although changes in worldview and other non-material cultural processes have historically been connected with material structural processes, we do not directly examine them here. It should be noted that we do not use the term *modernization* to imply that the changes that have occurred in Western societies over the past few centuries represent an inevitable or "natural" course of development, nor to imply that societies that have not followed "modernization" processes are in any way "immature" or less "advanced" than so-called "modern" societies.

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environmental reform. Critical political economists, on the other hand, hold that the modernization process and economic growth in particular almost invariably lead to escalating environmental degradation. There is a growing body of empirical research addressing this debate, and findings differ across the types of environmental issues examined and the types of data, analytic procedures, and units of analysis used. Understanding how modernization influences various types of environmental conditions at various scales is clearly a necessary part of moving societies toward sustainability. Here, we help to further our understanding of how social forces affect the environment by empirically analyzing, at the cross-national-level, the effects of economic production and urbanization on an important, but neglected, indicator of environmental health: aquatic biodiversity.

Biodiversity loss has received particular attention in the natural sciences due to the increasing rate and scale of current species endangerment, although it has received scant attention by social scientists. The Millennium Ecosystem Assessment (2005: vi), compiled by 1400 scientists from 95 countries, states, "Changes in biodiversity due to human activity were more rapid in the past 50 years than at any time in human history." Based on published data from around the world, the Living Planet Index aggregates trends in the populations of 3000 wild species. The Index reports a consistent decline in average species abundance of about 40% between 1970 and 2000; inland water species declined by 50% over this same period, while marine and terrestrial species both declined by around 30% (World Wide Fund for Nature, UNEP World Conservation Monitoring Centre, Global Footprint Network, 2004). Although biodiversity loss is only one measure of overall environmental change, it is a key aspect of ecosystem integrity and widely considered by scientists to be one of the most serious ecological challenges facing humanity (Secretariat of the Convention of Biological Diversity, 2006). Given the significant impact of human populations on biodiversity, an interdisciplinary research program addressing underlying causes of species endangerment is clearly warranted.

Scholars have contributed to research on global biodiversity loss by introducing the relevance and context of threatened species to the interdisciplinary social science community (Hoffman, 2004a; Naidoo and Adamowicz, 2001; Czech et al., 2000). Due to the constraints of data availability and reliability, however, cross-national comparisons have to date primarily addressed only the loss of land-based species, such as birds and mammals. Although these studies provide sophisticated and relevant analyses, they only partially capture the cumulative effects of human activity on global biodiversity. A comprehensive analysis exploring the social factors affecting marine and freshwater biodiversity worldwide has not yet been conducted to our knowledge.

Our objective here is to incorporate new scientific data on fish biodiversity into the contemporary theoretical debate between the modernization and political economy perspectives with regards to the factors driving environmental degradation. We employ cross-national data for the number of threatened fish species in over 140 countries as an indicator of global fish biodiversity. After reviewing the social science debates over the anthropogenic drivers of environmental decline, we present a negative binomial regression model that operationalizes the theoretical constructs of each perspective. Drawing on contributions from environmental economics and modernization theories, the model is designed to test the environmental Kuznets curve (EKC) hypothesis, with regards to both the scale of economic production (Grossman and Krueger, 1995) and urbanization (Ehrhardt-Martinez et al., 2002).

2. Improved understanding of marine and freshwater ecosystems

Scientific understanding of marine and freshwater ecosystems has recently advanced in fish species identification and historical evaluation of fish stocks. In addition to improving our understanding of aquatic environments, accumulating research has contributed to the larger discussion of proximate factors influencing loss of fish biodiversity. First, collaborative research effort has improved the identification and taxonomic categorization of the world's fish species. The WorldFish Center, comprised of eight international agencies, has engaged in an ambitious effort to catalog global fish populations. This institution recently launched FishBase, a web-based resource (www.fishbase.org) that provides detailed information on 28,000 fish species representing 96% of those known to science.

Offering accessible fish species data to the larger research community allows for species-specific analyses of global fish populations. In particular, FishBase offers cross-national data on the numbers of endemic fish and introduced non-native invasive species, which are recognized as a "major cause of species extinction in freshwater systems" in the Millennium Ecosystem Assessment (2005: 51). Proximate factors that may affect freshwater species are fish capture, pollution, modification of water regimes, and physical habitat changes (Millennium Ecosystem Assessment, 2005). The FishBase data provide a foundation for exploring how human impacts may alter the native fish species in countries worldwide.

Exploitation and depletion of the ocean's top predators creates the ''need'' to fish for species lower in the food chain. Fisheries biologist Daniel Pauly refers to this as ''fishing down the food chain'' and explains how this process has masked the true ecological implications of overfishing for the oceans trophic structure (Pauly et al., 1998). Time-series data on the global fish catch indicate that the world passed ''peak fish''—a peak in the biomass of fish caught from the world's oceans—in the late 1980s. Since then, although there have been regional variations, the global fish production has gradually declined even as fishing effort increases. According to the Millennium Ecosystem Assessment, ''Fishing is the most direct anthropogenic force affecting the structure, function, and biodiversity of the oceans'' (2005: 61). In studying the effects of this overharvest, Myers and Worm (2003) found that only 10% of all large predatory fish (such as cod, tuna, swordfish, and salmon) remain in the world's oceans relative to their levels prior to the onset of industrial fishing.

Historical data on fish populations have contributed to research on species abundance and distribution and marine ecosystem metabolism. Most fisheries research is based on local field studies lasting only a few years, failing to encompass the life-spans of many ecologically important species and important environmental changes, such as those associated with El Nino. Using paleoecological, archaeological, and historical records, Jackson et al. (2001) have shown that fish stock reduction can lead to collapse of coastal marine ecosystems. The authors state, ''Evidence from retrospective records strongly suggests that major structural and functional changes due to overfishing occurred worldwide in coastal marine ecosystems over many centuries'' (2001:629). The research concluded that collapse of top predators in the marine food web is directly related to the collapse of coastal ecosystems such as coral reefs, kelp forests, and estuaries (Jackson et al., 2001).

The long duration of human history encompassed in the analysis of Jackson et al. (2001) makes these findings a particularly significant contribution to the understanding of human activities that impact fish populations and coastal ecosystems. The research confirms that loss of fish biodiversity makes aquatic ecosystems more vulnerable to other natural and human disturbances, such as eutrophication, climate change, and toxic blooms (Jackson et al., 2001). In addition, the research shows that these effects are synergistic so that the whole response can be greater than the sum of individual disturbances. Appreciating the complexity and interconnected relationships within aquatic ecosystems is crucial to understanding why fish species loss may contribute to ecosystem-wide collapse. The concept of ecological thresholds is important since it emphasizes how a sudden change in an ecosystem can be due to a smooth and continuous change in a causal factor. A fish population may continue to be depleted over time with little impact to an ecosystem, until a critical threshold is reached. At this point, the population cannot continue to reproduce at sustainable numbers and ecological discontinuities result. Muradian (2001) explains how prices are unable to detect when an ecological system is approaching a threshold; therefore, ''neither specialists nor consumers can predict exact ecological thresholds'' (2001: 20). Overharvest and ''fishing down the food chain'' are the manifested results of this disconnect between economic incentives and ecosystem services. As a consequence, fish biodiversity loss not only affects coastal ecosystems, but also the human communities which depend on them for livelihood and subsistence.

3. Fish biodiversity and human well-being

For millennia, harvesting fish from seas, lakes, and rivers has been a source of sustenance and a mainstay of many societies. Fishing remains a cornerstone of local employment in many communities and a key food source for millions of people. Ethical, aesthetic, and scientific considerations provide compelling justifications for attempting to understand and alleviate human impact on aquatic organisms. For the purposes of this paper, however, we provide a brief overview of the utilitarian role of fisheries in human well-being to highlight the importance of social science research about declining fish populations.

Fishing is an essential source of livelihood in many developing nations, particularly for low-income families in rural areas. It provides a lasting vestige of utilizing the resources of a global commons, which are often part of maintaining traditional and cultural customs. The UN Food and Agriculture Organization estimates that approximately 35 million people are directly engaged, either full- or part-time, in fishing practices. Over 95% of them live in developing countries, and most are small-scale fishers (FAO, 2002). Fisheries in industrialized nations, such as the United States, also provide livelihoods for commercial fishers, including those in small communities. Loss of fish biodiversity affects not only the fishers worldwide whose communities and livelihoods depend on the sustainable harvest of fishery resources, but also the many people who rely on fish as a food staple. Approximately one billion people, largely in developing nations, rely on fish as their primary animal protein source (FAO, 2002). Small island nations and sub-Saharan African nations are most dependent on fish for food security, many of which rely on fish for more than 50% of their animal protein (Kura et al., 2004). Although levels of fish consumption are to a large degree dependent on levels of affluence and cultural variation among nations (York and Gossard, 2004), there is little doubt that fisheries resources help meet the basic needs of people and communities worldwide. There are examples of sustainably managed subsistence and commercial fisheries, however these cases have not yet been systematically investigated. Here we focus on aggregate fisheries within a national context, many of which are heavily industrialized and focused on extraction for luxury food markets, but we recognize the need for complementary analyses of small-scale fisheries. The ecological and social importance of fish biodiversity validates the significance of research aimed at assessing the social forces leading to the endangerment of fish species.

4. Social theories of environmental impact

Can economic growth benefit the environment or does it typically lead to an escalation of environmental problems? Research within environmental sociology, environmental economics, ecological economics, and conservation biology has contributed to developing an answer to this question. Modernization and economic affluence are by no means exhaustive of the possible social drivers of environmental impact. The human ecology perspective offers a distinct contribution to understanding the human relationship to the environment, suggesting that demographic factors play a key role in explaining environmental impacts (Dunlap and Catton, 1983; Dietz and Rosa, 1994). While we focus on the debates about the effects of modernization and per capita economic growth on the environment, we also assess the role of population (which contributes to total scale of economic production and consumption) in the relationship between society and biodiversity.

Neo-classical economic theorists argue that environmental quality is a luxury good, and, therefore, only affluent societies are willing to heavily invest in environmental protection. The environmental Kuznets curve (EKC) is the statistical hypothesis that describes this expected relationship between affluence and environmental quality. The EKC hypothesis suggests that environmental problems follow an inverted U-shaped curve relative to affluence (typically measured as GDP per capita), where environmental problems escalate in the early stages of development, but eventually a tipping point is reached, after which further economic growth leads to improvements in environmental quality (Dinda, 2004; Grossman and Krueger, 1995). Findings from EKC research are mixed, but the EKC is typically found only for a few local environmental impacts, such as air and water pollution, but not for sources of global environmental problems, such as greenhouse gas emissions and resource consumption (Cavlovic et al., 2000; Dinda, 2004; York et al., 2003a,b).

In environmental sociology ecological modernization theory (EMT) parallels the EKC argument, although it is not so singularly focused on economic development. EMT suggests that, although nations may degrade the environment in the early stages of modernization, the later stages of modernization are accompanied by the emergence of "ecological rationality," where environmental concerns diffuse throughout society, leading to the restructuring of major political, economic, and social institutions along ecologically sustainable lines (Mol and Sonnenfeld, 1995). From the EMT perspective it is not economic development per se that leads to environmental reform, but rather the institutional changes that accompany modernization, such the development of scientific organizations and the ongoing "rationalization" of bureaucracies. Although the scale of economic production is one indicator of the modernization of institutions, some scholars suggest that urbanization is a particularly apt indicator of (and, perhaps, force behind) the institutional restructuring that is integral to the modernization process (Ehrhardt-Martinez, 1998; Ehrhardt-Martinez et al., 2002). This leads to the hypothesis that environmental impacts may follow an EKC relative to urbanization. Ehrhardt-Martinez et al. (2002) suggest that such a relationship may be especially likely to exist for direct impacts on the land, such as deforestation (and, by implication, species endangerment as well), because urbanization concentrates people in cities, reducing population density in natural habitats and the number of people who are dependent for their livelihoods on direct extraction of natural resources.

Counter to the views of EMT and the EKC, the critical political economy perspective suggests that economic growth and urbanization are key drivers of environmental degradation. Rather than reaching a "tipping point," as posited by the EKC hypothesis, the political economy perspective argues that continued economic growth amplifies environmental impact due to the profit maximization imperatives of modern economies and the relentless drive for growth at all costs (Foster, 1992; O'Connor, 1994, 1998; Schnaiberg, 1980; Schnaiberg and Gould, 1994). Political–economic theorists in this tradition argue that escalating levels of production will outstrip any gains in the efficiency of resource utilization. The failure of producers to internalize environmental costs creates inherent contradictions between growth-dependent production and environmental sustainability. The treadmill of production thesis (Schnaiberg, 1980), which argues that increased economic growth almost invariably leads to increased levels of environmental degradation, has received considerable empirical support (Cole and Neumayer, 2004; Shi, 2003; York et al., 2003a), although its breadth of applicability is questioned by some scholars (Mol and Spaargaren, 2005).

To date, the focus of most previous national-level research has been on the emissions of greenhouse gases and air pollution, although some studies have applied social theories of environmental impact to biodiversity decline. Hoffman (2004a) completed an analysis of social influences on mammal and bird species endangerment. His model tested the theoretical claims of the neo-Malthusian, ecological modernization, treadmill of production, and world-systems perspectives. Hoffman examined social drivers such as population, urbanization, land-use, economic growth, and world-system position with regards to the number of mammal and bird species threatened in each nation. Hoffman's (2004a) findings are consistent with an EKC for endangered species: "At low to medium per capita GDP, rates of endangered species follow a positive linear trend, but at high levels of per capital GDP this association flattens out and becomes negative" (2004a: 97). He contextualizes this finding by noting that the level at which the relationship turns negative is quite high (>$9000 per capita—a level well above most nations in the world), therefore giving credence to the concerns of treadmill of production perspective as well. It is important to note that Hoffman included energy consumption as a control variable, finding it to have a positive monotonic effect. Energy consumption is highly correlated with GDP and is an indicator of the same types of structural conditions as GDP (e.g., scale of production). Thus, the inclusion of energy consumption may have attenuated the estimated effects of GDP. We do not include energy consumption as a control variable here because it would reduce our sample by 37 cases (25% of the sample from model 3, presented below) and because it overlaps conceptually and statistically with GDP. Hoffman also found that nations with high population densities have higher rates of endangered species, although he did not find urbanization to have a significant effect (2004a: 98).

In a similar line of research, Naidoo and Adamowicz (2001) test the hypothesis that increasing per capita income results in conservation of biodiversity using cross-national data. They compare the total number of threatened plants, mammals, birds, amphibians, reptiles, fish, and invertebrate species with national per capita GNP. Land-use variables in their analysis included indicators of area under domestication, remaining original forest cover, and IUCN protected areas. In this study, threatened marine fish were excluded from fish totals, and no data were available for numbers of endemic fish species in each nation, thus their data on fish were much more limited than the newer, more comprehensive data we analyze here. Naidoo and Adamowicz (2001) found that within the range of per capita GNP observed in developed nations, the number of threatened plants, amphibians, reptiles, and invertebrates all increase with per capita GNP. In the model with all countries included, the authors report that, "the number of threatened…fishes… had a negative log (GNP) term and a positive quadratic term, indicating a general U-shaped functional relationship" (p. 1025). When the outlying nations were removed, however, per capita GNP did not significantly predict the number of threatened fish species and therefore the variable was eliminated from subsequent reduced models. For bird species, however, there was evidence of an EKC—potentially explained by income elasticity, institutional designs, and biological characteristics.[2]

[2] Czech et al. (1998) provide evidence to suggest that bird species receive special protection in the public policy realm due to focused efforts of the NGO community and the especially favorable public perception of birds as species worthy of protection. These results are based on a social construction/political will matrix that challenges the hypothesis that GDP and economic production are responsible for providing increased protection for threatened species.

Finally, Czech et al. (2000) contribute to the EKC debate by examining economic associations with species endangerment in the United States. In this taxonomically comprehensive study, the authors found evidence that species endangerment in the United States stems from the integration and growth of economic sectors. Their findings "support the theory and evidence that economic growth proceeds at the competitive exclusion of non-human species in the aggregate" (2000: 503). They predict that as the scale of the integrated economy within the United States grows the list of US threatened species will grow too.

These three studies significantly contribute to our understanding of social drivers of biodiversity loss, and form a foundational literature base from which our project extends. We hone in on the relevant discussion in each of these studies—the relationship between the scale of economic production and species decline—and offer an original analysis to further advance the discussion. We provide a cross-national comparison of the factors contributing to the number of threatened marine and freshwater fish. As we learn more about the fragility of our oceans, rivers, and lakes—and the important role they play in global metabolic interactions—the more the need to understand how human economic activity affects the biodiversity of the aquatic world becomes apparent.

5. Data

To indicate the level of impact on fish biodiversity, our dependent variable, we used the total number of threatened fish in each nation. We chose nation-level analysis for continuity with previous research, consistency of available data, and the macro-level of the social theories we test. We understand that employing nation-level data highlights only one aspect of the continuum of processes at work affecting biodiversity decline. By focusing on national data on fish biodiversity, we mix the impacts of both local forces and transnational scale forces that influence the nation-state. Cinner and McClanahan (2006) demonstrate how pockets of overexploitation of small-scale, artisanal coral reef fisheries in Papua New Guinea do not accumulate into nation-level fisheries depletion, however the local impacts remain substantial. In this case, our analysis would not capture the subtleties of local fisheries depletion. Similarly, our study does not address transnational impacts spurred by the mobility of global capital or the vulnerability of highly migratory fish stocks (e.g., tuna). International fleets targeting a specific marine species may cause depletion well beyond national borders. Our decision to use national-level data allows us to assess biodiversity decline on one scale—the level of the nation. Other types of analyses are necessary to assess the impacts that global processes impose on local environments and the effects of local processes on specific ecosystems.

The data on number of threatened fish species in each nation were acquired from the FishBase data base, and include both freshwater and marine species. FishBase classifies species as threatened according to the protocols of the IUCN Red List of Threatened Species (2004). The Red List is produced and updated every four years by a network of 7000 species experts from around the world. These biologists use standardized criteria to evaluate the extinction risk of species and subspecies based on biological factors including rate of decline, population size, and area of geographic distribution. Due to its consistent methodology and strong scientific base, the Red List is considered an authoritative guide to the status of global biodiversity. The Red List does not claim to represent all information on all species, since many taxa have yet to be described. In addition, some researchers debate the validity of species' Red List status over time since variation in scientific knowledge rather than environmental conditions may lead to a change in listing (Possingham et al., 2002; Gardenfors, 2001). For our analysis, we do not compare the number of threatened species in each nation over time, rather we use the most recent estimate of threatened fish species. Although incomplete and imperfect, the Red List offers the best available data on threatened species status.

Marine fish for each nation are categorized as those that are found within the 200-mile national continental shelf. Although some species are highly migratory, it is essential to use the best available data on threatened marine fish to account for the global capture industry's impacts. To accurately specify our model, a number of biophysical control variables are required to reflect the cross-national variability of fish species and aquatic ecosystems. The number of threatened fish species in each country is obviously related to the total number of fish species; therefore, this indicator must be included in the model. We used FishBase data to record total number of fish species and the percentage of this total that are freshwater species, since species from different ecosystems may face different threats. The amount of aquatic habitat in each country is another necessary biophysical control variable for our model. With data from the World Resources Institute's EarthTrends database, we summed the area of freshwater habitat and the area of the continental shelf for each nation. For further specification, we calculated the percent of freshwater habitat relative to all aquatic habitat to account for the prevalence of different types of ecosystems. Total land area in each country was also included to account for geographic context. Finally, the number of endemic fish in each nation is included in the model as a biophysical parameter. Endemics refer to the number of fish species that occur exclusively within national borders. Conservation biology suggests that levels of endemism within a region may influence the rate and scale of biodiversity loss due to the specific niches required for species resiliency (Noss and Cooperrider, 1994). High endemism may also reflect biodiversity hotspots, and therefore represents another indicator of cross-national variability that must be included in the model.

The drivers of fish biodiversity decline can be conceptualized as proximate and ultimate factors. Proximate factors include direct human endangerment of fish species or their habitat. Research in marine and freshwater ecology demonstrates that fish capture is a leading proximate factor affecting fish populations. To calculate cross-national fish capture effort over time, we used FishStat—a software package available from the UN Food and Agriculture Organization that records annual total capture fish production in millions of metric tons. We averaged data for every year from 1980 to 2000 in order to account for lag effects of previous harvest levels on species decline. Other proximate factors that affect freshwater species decline are water pollution, invasive species, and habitat alteration for freshwater species. Due to lack of data availability, these factors are not incorporated in our model, and these proximate factors are assumed to be driven by the anthropogenic factors we examine. Ultimate anthropogenic factors that drive fish species decline are the characteristics of social organization that lead to human exploitation of natural resources. As discussed above, social theory suggests that ultimate factors include national population size, level of urbanization, and the scale of economic production. World Development Indicators from the World Bank supplied data for each nation's total population, the percent of the population that lives in urban areas, and the GDP per capita. For each of these ultimate factors, we averaged data from 1980–2000 to incorporate lag effects of influence on fish biodiversity.[3]

6. Analysis

The number of threatened fish species in a country is a discrete count, not a continuous variable. Applying a linear OLS model to a count-dependent variable, such as this, results in inefficient, inconsistent, and biased estimates (Long, 1997; Hoffman, 2004b). Poisson regression and negative binomial regression are two models that overcome this problem. In a Poisson distribution, the outcome variable represents the number of times that an event has occurred, based on a critical assumption that the events are independent. The Poisson regression model rarely fits in practice since in most applications overdispersion exists—i.e., the conditional variance does not equal the conditional mean, violating the error assumption of the Poisson distribution. Overdispersion is due to heterogeneity within the sample causing events to lose independence (Hoffman, 2004b).

In the case of our count variable, the event of having one fish species become threatened is probably not independent from the status of other fish species. This may be due to the interconnected relationships among trophic levels of marine and freshwater species (e.g., big fish rely on 1 smaller fish as food source) and other ecosystem connections. Therefore, our response variable does not meet the requirements of the Poisson regression model. Since the variance is larger than the mean, signaling overdispersion, the negative binomial regression model is more appropriate (Hoffman, 2004b; Cameron and Trivedi, 1998; Long, 1997). The negative binomial regression model extends the Poisson model by adding a parameter that allows the conditional variance to exceed the conditional mean (Long, 1997). Given these considerations, we use the negative binomial regression model for our analysis.

Independent variables in cross-national datasets often have highly skewed distributions (Dietz et al., 1987). Outliers can often exert undue influence on model estimates, and many factors vary widely across nations. To scale our model accordingly, we follow Naidoo and Adamowicz (2001) by log-transforming (using the natural

[3] For 27 countries the GDP per capital was missing for all or part of the 1980s, so the average GDP per capita for these countries is based on only the years for which data are available. We estimated our models both with and without these countries with missing data, and the sign and significance of our independent variables remained unchanged.

Table 1
Negative binomial regression models of factors influencing the number of threatened marine and freshwater fish species in nations

Independent variable	Model 1	Model 2	Model 3	Model 4
	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)
Total number of fish species (log)	.630*** (.062)	.602*** (.052)	.597*** (.054)	.607*** (.055)
Percent fish species that are freshwater (log)	.093 (.053)	.086* (.043)	.039 (.046)	.039 (.047)
Number of non-endemic fish species (log)	.961 (1.80)	−3.768* (1.77)	−2.317 (1.75)	−2.215 (1.80)
Total water area (log)	.036 (.042)	−.023 (.042)	.017 (.042)	−.010 (.042)
Percent of water area that is fresh (log)	−.040 (.057)	−.061 (.049)	−.024 (.051)	−.047 (.051)
Total land area (log)	.005 (.036)	.033 (.031)	−.012 (.037)	−.005 (.037)
Average annual metric tons of fish harvested, 1980–2000 (log)		.025 (.023)	−.025 (.024)	−.012 (.025)
Average population 1980–2000 (log)			.129*** (.036)	.117 ** (.037)
Average annual GDP per capita 1980–2000 (log)			.119* (.049)	.063* (.029)
Average annual GDP per capita 1980–2000 $(\log)^2$			−.020 (.021)	
Average annual percent urbanization (log)			−.271 (.160)	
Average annual percent urbanization $(\log)^2$			−.324 (.170)	
Constant	−6.331 (8.462)	15.628 (8.287)	7.946 (8.318)	6.974 (8.546)
McFadden's Pseudo-R^2	.115	.158	.178	.170
AIC	6.785	6.574	6.559	6.573
N	186	160	147	148

* $p < .05$ (2-tailed tests).
** $p < .01$ (2-tailed tests).
*** $p < .001$ (2-tailed tests).

logarithm) all of the independent variables. This reduces the influence on model estimates of outliers on the independent variables (leverage cases). In addition to McFadden's (Pseudo) R^2, the Akaike's information criteria (AIC) statistic is used to compare the fit of competing models. The model with the smaller AIC is considered the better fitting model (Long, 1997).

7. Results

Four negative binomial regression models are designed to test the effects of social and ecological drivers on fish biodiversity. The results of these analyses are presented in Table 1. Model 1 is a simple baseline model of the biophysical parameters that control for species endangerment. We include variables for total fish species, percent of fish species that are freshwater species, total water area, percent of water area that is freshwater, total land area, and percent of fish that are non-endemic[4] in each country. The findings indicate that the number of marine and freshwater fish species threatened in each country is significantly influenced by the total number of fish species, although the other biophysical factors in the model do not have significant effects. Model 2 incorporates a proximate driver of fish species endangerment: fish capture. National capture fisheries production is added to the model to test the impact of marine harvest on overall species decline. While it is well understood in the scientific literature that capture fisheries have depleted many fish populations, the impacts estimated in our models are not significant. This may be explained by the fact that a dramatic reduction in the size of a fishery may undermine the economic viability of that fishery before it threatens the species with extinction. It is still crucial to include this as a control variable in the full model to avoid mis-specification.[5]

[4] The model uses the total number of *non*-endemic fish species to accommodate the log transformation of independent variables. There are several nations with no endemic species, and the log of zero is undefined.

[5] The World Resources Institute offers a measure of cross-national water pollution, specifically the organic pollutant emissions from industrial sources. Recognizing point-source pollution as an important proximate driver of freshwater habitat decline, we also estimated a model (not presented here) including the water pollution variable for exploratory purposes. A lack of available data decreased our sample size from 160 to 86, therefore reducing the overall confidence in the model. The sign and significance of the other variables in the model remained unchanged across the models with and without the water pollution indicator. Therefore, excluding water pollution from our proximate drivers model does not change the substantive interpretation of results. Thus, to retain the larger sample size, we do not include water pollution in the models presented here.

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Model 3 represents the full social structural model incorporating the key theorized anthropogenic factors behind species decline: average population (1980–2000), average GDP per capita (1980–2000), and average urbanization (1980–2000). Biophysical and proximate causes of species decline are included as control variables in the model. Average population is significant and positive, indicating that nations with large populations are likely to have more threatened fish species than nations with small populations. This is an expected outcome, following the logic that the more people in a nation, the greater the impact on the environment.

Model 3 is specifically designed to test the hypotheses derived from the neo-liberal and political economy perspectives outlined above. To test for an EKC, we use the quadratic of GDP per capita and the quadratic of percent urbanization to allow for a non-monotonic relationship, as predicted by EKC and ecological modernization theorists.[6] Finding that the quadratic of these variables has a significant negative relationship with threatened fish species would suggest a potentially inverted U-shaped curve—an EKC. This curve would indicate that after nations reach a certain level of economic prosperity (the "tipping point"), the expected number of threatened fish species would decline. However, we did not find evidence of a tipping point; the quadratic function of GDP per capita is not significant, while the linear term is positive and significant, indicating that no EKC exists for the relationship between the scale of economic production and fish species endangerment. Both the linear and quadratic versions of the percent urbanization variable are non-significant. Thus, the model suggests that economic growth increases the expected number of threatened fish species in a nation, but that the percent of the population living in urban areas does not have a significant effect on fish species endangerment.

Model 4 is a reduced version of Model 3, retaining only the ecological factors and the significant social structural drivers of fish biodiversity decline. Based on the results from Model 3, the quadratic terms are excluded as well as the variable representing urbanization.[7] The biophysical and proximate factor variables are left in as controls. The model demonstrates that population and GDP per capita are significant and positive indicators of the number of threatened marine and freshwater fish species at the national-level.

8. Discussion and conclusion

The goal of our paper has been to examine the influence of social structural factors on the number of threatened fish species in nations. Our models were informed by a contemporary debate in the social sciences, as well as by new data available in fisheries science. Our research informs the discussion on the relationship between modernization and environmental quality by revealing that increases in national economic affluence have deleterious effects on fish biodiversity. This result is contrary to the thesis put forth by ecological modernization theorists and adherents of the environmental Kuznets curve. The connection between economic production and loss of fish biodiversity conforms to the predictions of the political economy perspective, which argues that economic growth is ultimately unsustainable. However, urbanization appears to have no effect on fish biodiversity, suggesting that the scale of economic production is the best indicator of modernization's impacts on biodiversity.

A second finding of our research is that societies' impacts on fish species are influenced by human population size. Adding people to a nation's landscape appears to affect the aquatic habitat upon which fish species rely, as expected by human ecologists. Possible effects of increased population include loss of wetlands, modification of water regimes (for irrigation and energy), and discharge of pollution in coastal ecosystems. These results can be used to inform a discussion about the type of political, economic, and social organization that is required to create a society where human well-being and ecological integrity are maintained.

We offer two points to consider regarding the specification of our model. First, the indicator we have chosen—the number of threatened fish species within each nation—is not singularly affected by the social factors within the bounded parameters of each nation-state. For example, the world-systems perspective suggests that

[6] To generate the quadratics, each variable was centered by subtracting its cross-national mean before squaring, so as to reduce problems with collinearity between the linear and quadratic terms. This is a procedure recommended by Neter et al. (1990: 315–316), and it does not change the estimated shape of the relationship; it simply reduces the standard errors, allowing for more reliable significance tests.

[7] In a model including the urbanization variable, but excluding its quadratic, urbanization still has a non-significant effect.

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trade dependency relations between core and periphery nations may influence not only the scale of environmental impacts nations generate but also where they occur (Jorgenson and Burns, 2007). Wealthy nations may be able to somewhat curb the impacts on their own environments by importing natural resources (and thus ''exporting'' environmental impacts) or by moving polluting industries and hazardous waste to poorer nations (Frey, 1998; York et al., 2003a). Thus, the impacts in some nations may be largely driven by social and economic processes occurring elsewhere. Additionally, pollution may cross national boundaries, and global scale processes, such as climate change, may have substantial effects on fisheries. Similarly, highly migratory fish species do not abide by national boundaries and species such as tuna may suffer deleterious population effects beyond what is measured within a nation's EEZ. We also recognize that aggregate fish harvest data of a nation may overlook accomplishments of some small-scale fisheries in maintaining sustainable harvests.

Second, we have chosen to only investigate one measure of overall environmental impact—biodiversity loss—and we have narrowed that category down even further to include only fish species. We acknowledge the limitations of parceling out the concept of environmental impact in this manner, as nature typically does not act or respond strictly according to individual variables in isolation. Nonetheless, focusing on specific types of impacts is valuable, since social forces likely affect different aspects of the natural environment in heterogeneous ways. We recognize that one limitation of statistical modeling is sacrificing some realism in order to gain generality and precision. Even with these considerations in mind, however, we are hopeful that this research makes a significant contribution to interdisciplinary efforts aimed at understanding the relationship between human organization and environmental sustainability.

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