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**WORKING PAPER**
**07/2013**

# Species Imperilment on the Global Scale: Empirical evidences of economic causes

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Working Paper Series 2013:07
Uppsala 2013

ISSN 1401-4068
ISRN SLU-EKON-WPS-1307-SE

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*Abstract.* Economic factors contribute to biodiversity directly through activities such as pollution and land use, and indirectly by affecting preferences and institutional capabilities of implementing mitigation measures. This paper tests the explanatory power of these different mechanisms on threats to biodiversity on a global scale. Econometric analyses are performed with invasive species, land use, climate, economic prosperity, corruption, and spatial autocorrelation as explanatory variables. This is carried out for all taxonomic groups and separately for mammals, birds, plants, amphibians, and reptiles. Different models are tested and robust results appear for detrimental effects of invasive species, pollution, and high average temperature. Results also indicate that economic prosperity and institutional capacity do not act as curbing factors in isolation, but instead together which points out the need for sufficient levels of both prosperity and institutional capability in order to preserve biodiversity. These impacts are significant for all taxonomic groups but of different magnitude. Plants show the highest relative response to several factors and mammals the lowest.

*Key words*: threatened species, climate, land use, non-indigenous species, spatial autocorrelation, economic development, institutions, climate, econometrics

JEL: Q56, Q57

# 1. Introduction

The rate of biodiversity loss is alarming; it is estimated that the rate of extinction of species has increased by approximately 1000 times above the background rates (MEA, 2005). The major immediate threats to biodiversity listed by CBD (Convention on Biological Diversity), are overharvesting of species, habitat changes, pollution, invasive alien species, and climate change (CBD, 2013). The impact of these threats have been tested and confirmed in a large body of ecological literature (for reviews see Luck, 2007; Field et al., 2009), but it is also argued that the underlying causes for these threats are related to economic factors (e.g. Perrings and Mäler, 1997; Wood et al., 2000).

In principle, economic factors can act on the loss of biodiversity through three mechanisms; *i)* as causes of loss and spread through economic production and trade of products and services, *ii)* as contributors to formulation of preferences, and *iii)* as providers of institutional capabilities to halt the loss of biodiversity. Examples of the first mechanism are development of land for agricultural or forestry purposes, damages of habitat quality from pollutant emissions, and spread of alien species through trade of goods and services. Income level is shown to affect our environmental preferences and willingness to pay and act to preserve biodiversity. The third mechanism is related to a society's capacity to implement and enforce policies to better reflect the value of biodiversity and thereby mitigate further loss. The purpose of this study is to test the explanatory power of these three classes for biodiversity loss, which is carried out by econometric analyses on a cross country scale.

The empirical literature in economics on explanations for the loss of biodiversity has investigated the role of selected variables in each of the three classes (Kerrie and Currie, 1995; Naidoo and Adamowicz, 2001; Dietz and Adger, 2003; Pandit and Laband, 2007a, 2007b, 2009a, 2009b; Mills and Waite, 2009; Halkos and Tzemeres, 2010; Tevie et al., 2011). Commonly used explanatory variables in the first class are land use, pollution, and geographical characteristics such as island versus mainland nation. Invasive species and climate factors have listed by CBD, however, not been included. On the other hand, all studies account for economic prosperity, mainly represented as income per capita, and a few add the role of institutional factors. However, a common finding is that these two latter mechanisms seldom generate significant effects on threats to biodiversity. One reason could be their mutual dependency, a relatively rich country with low institutional capacity may fail to implement and enforce appropriate policies and vice versa. A specific contribution of this paper is the test of this hypothesis, i.e. whether economic prosperity and institutional capacity are complements in combatting biodiversity. In our view, other contributions are the inclusion of factors in the first class which have not been considered in other studies, i.e. invasive species and climate change. In addition, we account for dispersal of loss among countries by spatial auto correlations.

A few caveats are in order. The main weakness of this study, which we share with almost all other studies with similar purpose, is the reliance on a cross section data set with country level observations. The use of cross section data can be justified by the long term processes of the loss of biodiversity. A panel data set covering a few decades may not capture impacts of, for example, occurrence of NIS on threats of biodiversity. It can also be argued that a cross section of data reflect differences among countries with respect to long term adjustment to exposure to NIS, habitat fragmentation, climate change, and economic and institutional development during several decades and even centuries. Our specific interest in impacts of NIS brings another weakness into the analyses; the lack of data for different taxonomic groups.

However, in spite of these weaknesses with respect to data, two main robust results appeared for all model specifications. One was that two variables belonging to the first class of mechanisms, invasive species and relatively high temperature, contributed to threats of species. The other was that the other two classes of economic factors, economic prosperity and institutional capacity, had no significant impact on threats to species in isolation but their combined effect curbed the threat. The latter thus implies that our hypotheses on complementarity between the two classes cannot be rejected; impacts of threats to species on economic prosperity are positive for sufficient level of institutional capacity.

The paper is organised as follows. First, we give a brief review of the empirical economic literature on causes for loss of biodiversity. Secondly, data retrieval is presented, and Section 4 contains econometric analyses and discussion of results. The paper ends with a brief summary and concluding comments.

## 2. Brief literature review

The literature in economics is relatively recent and scant, and a common purpose of all studies is to estimate the impact of prosperity on biodiversity (Kerrie and Currie, 1995; Naidoo and Adamowicz, 2001; Dietz and Adger, 2003; McPherson and Nieswiadomy 2005; Pandit and Laband, 2007a, 2007b, 2009a, 2009b; Mills and Waite, 2009; Halkos and Tzemeres, 2010; Tevie et al. 2011). The underlying theory for the impact of economic prosperity is based on the so-called Environmental Kuznets Curve (EKC) hypothesis, which predicts that economic growth is associated with higher biodiversity loss at low income levels, but decreases at higher income levels due to changes towards environmental friendly preferences and ability to pay for conservation measures. A majority of the studies are summarized in Table 1, which is not exhaustive but presents representative studies published in international journals. They are classified in chronological order, and choices of explanatory variables within the three classes of economic causes are presented. Significant results are marked with sign on the variable within parentheses. For one variable, gross domestic product (GDP) per capita, two signs are shown which result from the quadratic formulation in order to test the EKC hypothesis.

**Table 1: Studies, dependent and independent variables, and type of data. (Signs within parentheses denote statistically significant results at min 10% level)**

| ***Authors, dependent variable*** | ***Independent variables; Land use, pollution*** | ***Prosperity*** | ***Institutional factors*** | ***Data and spatial resolution*** |
|---|---|---|---|---|
| Kerrie and Currie (1995), threatened mammal and birds | Crop land (+), protected areas, population (+), $CO_2$ | GDP/capita (- mammals) | | Cross section with 90 countries |
| Naidoo and Adamowicz (2001), several threatened taxa [1] | Forest, protected areas | GDP/capita in quadratic form (+,- for birds) | | Cross section with 152 countries |
| Dietz and Adger (2003), species richness in forests | Forest area (+), population | GDP/capita (+) | Democracy (-) | Panel , 35 tropical countries [3] |
| McPherson and Nieswiadomy (2005), threatened mammals and birds | Endemic species (+), population (+), island (+) spatial correlation (+) | GDP/capita in quadratic form (+,-) | Civil or muslim law, comm-unism (+), demonsrations | Cross section, 113 countries |
| Pandit and Laban (2007b), several threatened taxa[2] | Endemic species population, island, spatial correlation (+) | GDP/capita (+ for birds) | | Cross section 117-173 countries |
| Mills and Waite (2009), species richness in forests | Forest , population, spatial correlation (+) | GDP/capita in quadratic form | Democracy | Data from Dietz and Adger (2003) |
| Pandit and Laban (2009a) several threatened taxa[2] | population, island, transboundary dispersion (+) | | Economic freedom (+), corruption (-) | Cross section 152 countries |
| Pandit and Laban (2009b) all and different threatened taxa[2] | Endemic species (+), population (+), island, spatial correlation (+) | GDP/capita (-) | Income inequality (- all threatened species) | Cross section with 133 countries |
| Halkos and Tzemeres (2010), biodiversity index | Protected areas, $CO_2$, population (-) | GDP/capita (-, +) | Income inequality (-) | Cross section with 71 countries |
| Tevie et al. (2011), index of biodiversity at risk | Population, land area, spatial correlation (+) | GDP/capita | Policy makers' environmental voting[4] | Cross section with 48 states in US |

1)plants, mammals, birds, amphibians, reptiles, fish, invertebrates ; 2) birds, mammals, vascular plants, reptiles, amphibians; 3) constructed time series data on forest biodiversity; 4) Number of times a senator or representative vote for environmental protection in the US congress and House of representatives

When looking at the choice of dependent variable, it can be noticed that the majority of studies use threatened species for different taxonomic groups. A common data source is then the IUCN (the International Union for the Conservation of Nature and Natural Resources) red list of threatened species. With respect to the first class of economic causes, all studies rest on findings from the ecological literature by including independent variables reflecting habitat fragmentation or quality but in different ways. The most commonly used explanatory variable is then human population, but the estimated impact on biodiversity is seldom significant. The two studies with significant results show diverse impacts. Different measurements of land use do, in general, not show significant effects. This is in contrast with the spatial autocorrelation variable which shows significant and positive effect on species threat or biodiversity loss in all studies where it is included. Since ecosystems usually don't share the same borders as nations this is expected when the spatial variable refers to countries' shared borders (McPherson and Nieswiadomy, 2005; Pandit and Laband, 2007a,b, 2009a,b) or to distances between centroid points in the countries (Mills and Wait, 2009).

Turning to our second class of economic influences, economic prosperity presented in the third column in Table 1, the studies show mixed results. A few studies report results that are in line with the EKC hypotheses, but most often not for all included taxa. It can also be seen that an equal number of studies do not obtain significant impacts of economic prosperity, and the estimated sign differ when results are significant. The third class, institutional capacity, show even more diversity both with respect to choice of explanatory variable and associated result. One variable, income inequality turns out to contribute to species threat in one study (Pandit and Laban, 2009b) and to have the opposite effect in another (Halkos and Tzemeres, 2010).

Based on results from the studies presented in Table 1 we can thus conclude that no clear pattern emerges on which factors are most important for species threat, except for the relevance of spatial autocorrelation. It can be argued that the summary of studies is not exhaustive, which is correct, but it includes those which are relatively easy to access. This, in turn reflects the low number of economic studies compared with the large body of literature in ecology developed during of approximately 200 years (see reviews in Hawkins et al., 2003; Field et al., 2009).

Ecological research identifies three main causes of biodiversity loss; climate conditions, habitat loss and fragmentation, and NIS exposure. The impact of climate conditions on biodiversity has its roots in the large research on taxonomic richness, which was initiated already in the beginning of 1900s century (e.g. Hawkins et al., 2003; Field et al., 2009). Habitat loss and degradation through changes in land use is regarded as the single most serious threat to biodiversity (Baille et al., 2004; Luck, 2007). Factors such as agriculture, urbanization, water development, and forestry practices are found to be important agents of habitat change. With respect to harmful impacts of NIS on species richness, several mechanisms have been suggested in the ecological literature (Wilcove et al., 1998; Owens and Bennet, 2000; Clavero et al., 2009; Spear and Chown, 2009). There might be *direct* effects, through increased predation and competition, and *indirect* effects, such as NIS-borne pests that introduce new diseases to the natural floras and faunas. However, none of the listed economic studies has included all these three factors, but instead focused on variables reflecting habitat degradation and fragmentation.

## 3. Description of data

The choice of explanatory variables in the regression equations is based on the brief reviews in Section 2, which includes economic development, institutional strengths, and habitat degradation. We add climate conditions and occurrences of non-indigenous species (NIS) as explanatory variables. However, one of the main challenges is to find a relevant measurement of the dependent variable, biodiversity loss, given the limitation of one of our explanatory variables NIS without taxa classification which is described below. One of the most known indexes within ecology is the Shannon's or Simpson's index, which requires data on species richness and abundance typically not available on the global scale. As shown in Section 2, the most used response variables are therefore species richness or its inverse, species threat, which are found at the WRI (World Resources Institute) and IUCN data bases. These are, in turn, measured at a taxa level, mostly mammals, birds, and plants, or totally. Data on species richness for a large number of countries are found no later than 2004, and the IUCN data on species threat is available for later years. In this paper we will use the data on species threat provided by IUCN due to its more recent update.

Data on NIS exposure, one of explanatory variables classified in the first class of economic causes, are recorded by ISSG (Invasive Species Specialist Group) (2012). This database shares a disadvantage with the IUCN data on threatened species with respect to the lack of time dimension of reported biodiversity threat and occurrences of NIS. Further, there is no classification of the NIS in different taxonomic groups. As measurements of climate conditions we use average and variability in temperature in the countries (Weatherbase, 2012). Different land use variables are introduced as measurements of habitat conditions; arable and forest land, protected areas, and population density (CIA, 2013). Protected areas may be regarded as a response to species threat and is then at risk of being an endogenous variable. In order to account for this we use data on shares of protected areas for 1990 as independent variable. This implies a 20 years period between the establishment of these areas and species threat in 2010 (IUCN and UNEP, 2012).

Following previous economics studies surveyed in Section 2, we include GDP/capita as a measurement of economic prosperity (UN, 2012a). A corruption index is introduced as a variable reflecting the institutional ability to implement and enforce policies promoting biodiversity (CIA, 2013). Countries are indexed from 1 to 10 where a higher number denotes less corruption. Corruption indexes for different countries are frequently used as measurements of institutional capacity (e.g. Aidt et al., 2008).

We introduce a spatial lag model where a spatial correlation variable is constructed as $S=\boldsymbol{W}y$, where $\boldsymbol{W}$ is a matrix of weights among countries and $y$ is a vector with the dependent variable. A commonly applied weight matrix is where each cell in the matrix corresponds to the length of borders to neighbouring countries (e.g. McPherson and Nieswiadomy, 2005; Pandit and Laband, 2007a,b). We also test for the impact of weights reflecting imports of goods and services from trading countries. For both these expressions of spatial correlation weights are calculated which sum to one, and the number in each cell is the share of total borders to the surrounding countries or share of total imports from trading partners.

Table 2 lists all dependent and independent variables and associated abbreviations, and Table 3 presents descriptive statistics.

**Table 2: Abbreviations, description of variables and data sources**

| | |
|---|---|
| ***Dependent variables***: | |
| $Taxa_j$ | number of threatened species, where j=total, mammals, birds amphibians, reptiles, plants (IUCN, 2012) |
| ***Explanatory variables***: | |
| GDP/capita | gross domestic product per capita in 1000 international dollars (adjusted by purchasing power parity index) per year (UNa, 2012) |
| Corru | corruption index (lower value corresponds to higher corruption), (Transparency International, 2012) |
| NIS | number of invasive species (ISSG, 2012) |
| $SO_2$ | thousand tons of $SO_2$ emissions (WRI, 2012) |
| Popdens | population/total area in 1000/km$^2$, (CIA, 2012) |
| Ara | arable land/total area, (CIA, 2011) |
| Prot90 | protected areas/total area in 1990 (IUCN and UNEP, 2012) |
| $S_{TRAj}$ | spatial variable with import shares as weights where j=total, mammals, birds, amphibians, reptiles, and plants (UN, 2012b) |
| $S_{BOj}$ | spatial variable with length of borders as weights where j=total, mammals, birds, amphibians, reptiles, and plants (Nationmaster, 2012) |
| Avtemp | average annual temperature in capitals (Weatherbase, 2012) |

**Table 3: Summary statistics**

| *Variables* | *N* | *Mean* | *Std. Dev* | *Minimum* | *Maximum* |
|---|---|---|---|---|---|
| *Dependent variables:* | | | | | |
| Total | 192 | 172.613 | 263.092 | 2 | 2255 |
| Mammals | 190 | 15.405 | 20.876 | 1 | 183 |
| Birds | 183 | 16.743 | 20.615 | 1 | 123 |
| Amphibians | 191 | 11.424 | 29.936 | 0 | 213 |
| Reptiles | 191 | 6.602 | 10.084 | 0 | 94 |
| Plants | 167 | 65.072 | 170.053 | 0 | 1837 |
| *Explanatory variables:* | | | | | |
| NIS | 192 | 65.088 | 59.541 | 3 | 499 |
| GDP/capita | 192 | 14.671 | 16.965 | 0.351 | 88.75 |
| Corru | 166 | 4.007 | 2.129 | 1.000 | 9.30 |
| Corrgdpc | 165 | 70.135 | 106.918 | 0.581 | 501.752 |
| Popdens | 192 | 278 | 1310 | 0.033 | 16075 |
| Aras | 191 | 0.135 | 0.131 | 0 | 0.607 |
| $SO_2$ | 186 | 764.224 | 2995.945 | 0 | 34205 |
| Prot90 | 188 | 0.071 | 0.084 | 0 | 0.411 |
| $S_{Bototal}$ | 192 | 170.265 | 242.934 | 0 | 1180 |
| $S_{BOmammals}$ | 192 | 18.197 | 25.602 | 0 | 183 |
| $S_{BObirds}$ | 183 | 18.708 | 27.225 | 0 | 150 |
| $S_{BOamphibians}$ | 191 | 13.079 | 26.683 | 0 | 143 |
| $S_{BOreptiles}$ | 191 | 6.401 | 10.825 | 0 | 88 |
| $S_{Boplants}$ | 167 | 60.909 | 115.011 | 0 | 692 |
| $S_{TRAtotal}$ | 192 | 414.895 | 250.710 | 1 | 1098 |
| $S_{TRAmammals}$ | 190 | 28.036 | 16.568 | 1 | 88 |
| $S_{TRAbirds}$ | 183 | 35.021 | 21.692 | 1 | 105 |
| $S_{TRAamphibians}$ | 191 | 26.906 | 21.676 | 1 | 99 |
| $S_{TRAreptiles}$ | 191 | 14.307 | 9.349 | 1 | 40 |
| $S_{TRAplants}$ | 167 | 124.406 | 87.109 | 1 | 425 |
| Avtemp | 185 | 19.828 | 7.373 | -1 | 30 |

The number of reported threatened plants is far higher than that of the other species, and we find the largest number in Ecuador (1837). The largest amount of reported threatened birds is also found in South America, in Brazil (123). The highest number of reptiles and mammals occurs in Mexico (94) and Indonesia (183). The largest amount of NIS is found in USA (499), Australia (318) and New Zeeland (242).

## 4. Econometric model specifications and results

Investigation of the variables presented in Table 2 shows that several of them are highly skewed; $Taxa_I$, *NIS, Gdpc, Corr,* $SO_2$, and *Popdens.* One way of dealing with this is to transform them into logarithms, which are renamed to *NISlog*, *Gdpclog, Corrlog,* $SO_2log$ and *Popdenslog*. The response variable can be treated in two ways; one is to interpret it as a count variable and the other is to transform it into logarithm. The choice of treatment requires different estimation methods, which will be carried out in this paper.

When the response variable, $Taxa_{ij}$, is characterised as an event count, i.e. the realisation of a non-negative positive integers, OLS (ordinary least square) method gives rise to biased and inefficient estimates (Cameron and Trivedi, 1998). Nonlinear models have therefore been developed that are based on Poisson or negative binomial distributions (e.g. Long, 1997). A Poisson distribution is a discrete probability distribution where the probability that an event occurs in a given time interval is independent from the occurrence of the last event but at a known average rate, implying that the mean equals the variance. Thus the number of occurrences fluctuates around its mean. Since the variance in the response variable is considerably larger than the mean (see Table 2), the dispersion parameter is statistically significant and we therefore apply a negative binomial regression model, which is written with the dependent variables, $Taxa_j$, as a random variable and $Taxa_{ij}$ number of occurrences

$$\Pr ob(Taxa_j = Taxa_{ij}) = \frac{e^{-u_{ij}} \mu_{ij}^{Taxa_{ji}}}{Taxa_{ij}!} \quad (1)$$

and $$\ln \mu_{ij} = x_{ij} \beta_j' + \varepsilon_{ij} \quad (2)$$

where $\mu_i$ is the average frequency of the dependent variable, $x_i$ is a vector of explanatory variables, $\beta$ is a vector of estimated coefficients, and $e^{\mu_i}$ is a Gamma distribution with mean 1 and variance $\alpha$, which is a measure of dispersion. When $\alpha=0$ the probability distribution is a Poisson. We therefore display likelihood ratio tests of $\alpha=0$ when presenting the regression estimates.

In addition to the count data model we estimate OLS with transformed response variable into logarithm, $Taxalog_{ij}$. However, we may expect problems with endogeneity in models including *Gdpclog* and *NISlog*. Many studies have pointed at the importance of corruption as a barrier for economic growth (e.g. Aidt et al., 2008), which implies that *Gdpclog* depends on *Corrlog*. However, since we are particularly interested in the impacts on species threat from each of these variables we follow studies that account for this by introducing an interaction term, which in our case is defined as *Corrgdpc=Gdpclog*Corrlog* (e.g. Gren and Campos, 2011). This variable has an interesting interpretation since it informs about the impact on biodiversity threat from a change in either economic prosperity or institutional variables while keeping the other at a certain level. If the estimated coefficient is negative there is complementarity and if it is negative substitutability. Recall that higher level of *Corrlog* implies less corruption. Thus, complementarity implies enforcement in mitigation of biodiversity threat by the two variables; a higher level of *Gdpclog* implies more impact from a marginal change in *Corrlog* and vice versa. Substitutability implies the opposite; the two variables then replace each other where lax mitigation of biodiversity loss because of a higher level of corruption is compensated by more efforts due to higher income. There are no á priori expectations on the sign of this interaction term. An empirical evidence is suggested by Gren and Campos (2011) who points at complementarity in development and institutional capability for the occurrences of invasive species on the global scale.

Several studies have shown that the occurrence of invasive species is determined by similar variables as species threat (Dalmazzone, 2000; Vila and Pujadas, 2001; Gren et al., 2011; Gren and Campos, 2011). If so, ordinary least square (OLS) will not give consistent estimates. We will therefore use both OLS and instrumental variable (IV) method with dummy for island nation, and two lagged spatial variables with borders and import share as weights. Several studies have shown that these variables have significant impacts on the occurrences of NIS (Dalmazzone, 2000; Vila and Pujadas, 2001; Gren et al., 2011; Gren and Campos, 2011).

The linear model specification used for all regressions is then written as

$$Y_{ji} = a_j + \alpha_{1j}\,Nislog_i + \alpha_{2j}Gdpclog_j + \alpha_{3j}\,Corrlog_i + \alpha_{4j}\,Corrgdpc_i + \alpha_{5j}\,SO_2log_i + \alpha_{6j}\,Aras_i + \alpha_{7j}\,Prot90_i + \alpha_{8j}\,Popdenslog_i + \alpha_{9j}\,Spatra_{ji} + \alpha_{10j}\,Spabord_{ji,} + \alpha_{11j}\,Avtemp_j +, \varepsilon_{ij} \quad (3)$$

where $Y_{ij} = Taxa_{ij}$ for the count data model and $Y_{ij}$=$Taxalog_{ij}$ for the OLS and instrumental variable estimators, and $i$ is country, $j$ taxonomic group, and $\varepsilon_{ij}$ error term.

### *4.1. Regression estimates with all threated species*

Results from the estimators when the dependent variable is $Taxalog_{total}$ for the OLS and instrumental variable methods or $Taxa_{total}$ for the negative binomial count data model are presented in Table 4.

**Table 4: Results from regression analyses of all threatened species and different robust estimators, N=156**

| | ***OLS*** | | ***Instrumental variable method*** | | ***Negative binomial count data model*** | |
|---|---|---|---|---|---|---|
| | ***Coeff*** | ***p*** | ***Coeff*** | ***p*** | ***Coeff.*** | ***p*** |
| NISlog | 0.836 | 0.000 | 1.065 | 0.000 | 0.842 | 0.000 |
| Gdpclog | 0.304 | 0.252 | 0.319 | 0.166 | 0.347 | 0.162 |
| Corrlog | 0.290 | 0.446 | 0.253 | 0.527 | 0.033 | 0.944 |
| CorrGdpc | -0.282 | 0.046 | -0.302 | 0.032 | -0.279 | 0.057 |
| $SO_2$log | 0.120 | 0.000 | 0.092 | 0.040 | 0.102 | 0.001 |
| Aras | -1.544 | 0.000 | -1.754 | 0.002 | -1.886 | 0.000 |
| Prot90 | -0.007 | 0.342 | -0.005 | 0.481 | -0.004 | 0.664 |
| Popdenslog | 0.034 | 0.516 | 0.024 | 0.637 | 0.033 | 0.562 |
| $S_{TRAI}$ | 4.900-4 | 0.122 | 2.487-4 | 0.544 | 6.146-4 | 0.070 |
| $S_{Bototal}$ | 2.857-4 | 0.298 | 2.390-4 | 0.391 | 3.688-4 | 0.203 |
| Avtemp | 0.063 | 0.000 | 0.070 | 0.000 | 0.050 | 0.000 |
| Intercept | -0.617 | 0.341 | -1.238 | 0.210 | 0.169 | 0.814 |
| Adj. $R^2$ | 0.62 | | 0.61 | | 0.09 (pseudo $R^2$) | |
| Log likelihood | 153.91 | | 191.19 ( 11) | | 892.11 (LR 172.97) | |
| Likelihood-ratio test of alpha | | | | | p=0.000 | |

Despite different estimation methods, the results show quite similar results with respect to sign and significance of the estimated coefficients. This makes the choice among the estimators relatively easy when these two criteria are of importance. We also tested for endogeneity in the IV model, with an augmented Hausmann tests where *NISlog* was regressed on a variable on total export and import as share of GDP, a dummy for island nation, and lagged GDP/capita. Several studies have shown that these variables have significant impacts on the occurrences of NIS (Dalmazzone, 2000; Vila and Pujadas, 2001; Gren et al., 2011; Gren and Campos, 2011). However, the test did not reveal presence of endogeneity. Similarly, tests did not show existence of problems with heteroscedasticity.

Common to all three estimators is the significant contribution to species threat by invasive species, pollution, and high average temperature. Curbing mechanisms are the combined impact of economic prosperity and low degree of corruption. With respect to the last observation we can thus conclude that our estimates point at complementarity; economic wellbeing must thus be accompanied with low corruption level for a successful mitigation of species threat. The results do not give indications of significant separate effects of these variables, which support several of the studies listed in Table 1.

The positive effect of spatial autocorrelation also supports results from other studies, but the lack of significance does not. The estimated coefficient for the spatial variable with import shares as weights is positive in all models, showing that countries with relatively much trade with other countries face relatively high species threat. This result is in line with that of McPehrson and Nieswiadomy (2005) and Pandit and Laban (2007a,b), who applied different formulations of the spatial structure among countries (simple adjacency, centroid-to-centroid distance, length of borders) and found a positive impact of spatial variables on imperilment of species. The lack of significance can be explained by the fact that dispersal among countries is captured by *NISlog* since occurrences of invasive species are highly determined by countries' trade and openness (Dalmazzone, 2000; Vila and Pujadas, 2001; Gren et al., 2011; Gren and Campos, 2011). The positive sign of the estimated coefficient of *Avtemp* indicates that species threat is larger in countries with higher average temperature, which is expected (see reviews in Luck, 2007; Field et al., 2009).

Estimated impacts of the land use variables *Ara, Prot90* and *Popdenslog* show robust results with respect to sign of estimated coefficients but not with respect to significance for protected areas and population density. The negative sign of the coefficient of *Prot90* is expected, as well as the positive sign of *Popdenslog*. However, the negative effect of *Aras* is more surprising. We would expect countries with large shares of arable land to have relatively much threatened species because of the fragmentation and destruction of habitats. An explanation for the negative effect can be that land subjected to regular harvesting strengthens the competiveness of native species and makes them less susceptible to threats from invasive species.

### *4.2 Different taxonomic groups*

When estimating the regression equations for the five taxonomic groups we may experience another statistical problem in addition to those associated with endogenity and heteroscedasticity. Since the dependent variables, one for each of the taxonomic groups, are regressed on several common independent variables there is a risk for contemporaneous correlation which creates inefficient OLS estimates of separate regressions. We therefore use the method of seemingly unrelated regressions (e.g Zellner, 1962). Results from this method are presented in Table 5. Table A1 in appendix shows regression results from separate regression equation with the IV method.

**Table 5: Regression results for different taxonomic groups using seemingly unrelated regression estimation method, N=138**

| | *Mammalslog* | *Birdslog* | *Amphilog* | *Plantslog* | *Reptileslog* |
|---|---|---|---|---|---|
| NISlog | 0.389*** | 0.498*** | 0.967*** | 1.167*** | 0.847*** |
| Gdpclog | 0.163 | 0.086 | 0.952*** | 0.707* | 0.663*** |
| Corrlog | 0.316 | 0.336 | 1.256* | 0.786 | 0.688 |
| CorrGdplog | -0.265** | -0.232* | -0.700*** | -0.537** | -0.492*** |
| SO2log | 0.171*** | 0.139*** | 0.061 | 0.057 | 0.062** |
| Aras | -0.841** | -1.560*** | -2.225*** | -2.673*** | -1.409*** |
| Prot90 | -0.012** | -0.005 | 0.008 | 0.008 | -0.023*** |
| Popdenslog | -0.072* | 0.017 | 0.071 | 0.083 | 0.090* |
| $Spa_I$ | 6.674-4*** | 0.005*** | 0.007** | 0.180*** | 0.015*** |
| $Spa_{BO}$ | 7.682-4** | 0.011*** | 0.019*** | 0.001 | 0.016*** |
| Avtemp | 0.037*** | 0.014* | 0.046*** | 0.094*** | 0.060*** |
| Intercept | -0.287 | -0.503 | -5.708*** | -5.243*** | -4.226*** |
| Pseudo-$R^2$ | 0.668 | 0.659 | 0.550 | 0.523 | 0.651 |
| Chi-square | 298.48 | 288.03 | 180.90 | 154.50 | 277.78 |
| Breusch-Pagan test of residual correlation | p=0.0000 | | | | |

*,**,***: statistical significance at the 10, 5 and 1 per cent level respectively

The Breusch-Pagan test of residual correlation clearly shows the existence of contemporaneous correlation, which justifies the choice of estimation method. All regressions show relatively good statistical fit with relatively high values of pseudo-$R^2$ and Chi-square.

Most of the results obtained in Section 4.1 for all threatened species are transferred to the taxonomic groups; significant estimates of the coefficients of *NISlog, CorrGdpc, Aras,* and *Avtemp*. These coefficients can be interpreted as elasticities, and it is of interest to test whether they show significant differences among taxonomic groups. For example, the coefficient of *NISlog* in the equation for *Mammalslog* is approximately one third of that for *Plantslog*. Chi-square tests of differences between pairs of equations with respect to *NISlog* show that significant differences at the 5% level occur between *Mammalslog* and *Plantslog* and between these two and the other taxa. The impact of *NISlog* is thus significantly higher on plants than on the other taxonomic groups. Similarly, the effects on mammals are significantly lower. This result supports the finding by Spear and Chow (2009) who observed that invasive ungulates have particular effects on plants species through rooting and digging and facilitating introductions of invasive plant species. Similar results are obtained by Wilcove et al. (1998) who showed that the percentage of plants imperilled by alien species is more than twice as large as the share of threatened mammals in the US.

The main difference in results between all and different threatened species is the significant effect of spatial autocorrelation in the latter case, in particular of $Spa_i$. This finding points at the importance of imports for threat of species in all taxonomic group. Another difference is the significance of protected areas for certain taxonomic groups, Mammal and Reptiles, which were not significant for any estimator when using all threatened species as dependent variable. These results together with the differences in the magnitude of estimated coefficient necessitate a need for taxa specific analyses.

## 5. Summary and conclusions

The main purpose of this paper has been to test the explanatory power of three different classes of economic mechanisms for biodiversity threat; *i)* production activities including land use, pollution, NIS exposure, climate, and spatial autocorrelation, *ii)* economic prosperity affecting preferences and affordability, and *iii)* institutional aspects reflecting ability to implement and enforce mitigation policies. A specific interest in our study was to test the hypotheses on interaction between the two last mechanisms, i.e. whether it is sufficient to have high levels of either prosperity or institutional capacities, or if both needed for promoting halting of biodiversity loss. The hypothesis emerges from the lack of significant findings in the literature on the impact of each of the mechanisms. Similar to most other studies, we used cross section data at the country level for the regression analyses, and different estimators were applied. Further, regressions were made for all threatened species as dependent variable and for different taxonomic groups.

The results showed robust and significant impact on all species and taxonomic groups of several factors classified into the first type of mechanism; land use, NIS exposure, and climate. NIS exposure adds to threat of all species, in particular of plants. Plants are also relatively vulnerable to climate as measured by average temperature. An unexpected result was the negative impact on species threat of share of arable land. One speculation is that native species relying on land subjected to regular harvesting develop relative strength and are more able to withstand NIS exposure and degraded environmental quality from pollution. Another finding common to all taxonomic groups is that spatial autocorrelation, in particular exposure to trade, contributes to specie threat.

With respect to the two other classes of mechanisms we did not find any significant evidence on species threat from any of them when treated separately. On the other hand, our hypothesis on combined effect of both mechanisms could not be rejected since the interaction term turned out to have significant mitigation effects for all estimators and taxonomic groups. This means that economic prosperity or institutional in isolation is not sufficient for a successful mitigation policy. Instead, halting of biodiversity loss is likely to require sufficient levels of both prosperity and institutional capability. Although this may not come as a surprise it has not been shown before in the literature on factors driving biodiversity loss. Instead the focus has been on prosperity and then whether increases in prosperity have different effects depending on the level of economic development in the country, the so-called environmental Kuznets (EKS) hypothesis. Our findings indicate that threatened species increase for two taxonomic groups, mammals and reptiles, in all countries and does not support the EKC hypothesis.

In a policy context, our results underline the need for existing international cooperation and commitments, such as the international agreement in 2010 on protecting 17 per cent of terrestrial land and 10 per cent of coastal and marine areas at the latest in 2020 (CBD, 2013b). This is revealed through three channels; the significance of spatial autocorrelation pointing at the importance of trade for dispersal of biodiversity threat. This mechanism acts as a single device through e.g. habitat degradation caused by tourism, but also together with NIS exposure where frequent trade facilitates intentional and unintentional dispersal of invasive species. The results also encourage current practice of compensation payments in many countries but add the need for caution with respect to outcome depending on institutional capacity in the country. This in turn, calls for institutional capacity as a criterion for selecting suitable areas for habitat support and not only actual or potential biodiversity richness which has been the common selection criterion in most countries (e.g. TEEB, 2013).

However, the reliance on cross section data without time perspective calls for careful interpretation of results. It is quite likely that it takes some time for several of the independent variables to impact species threat. For example, the establishment of NIS and associated damage to biodiversity is likely to be associated with different types of time lags, and with the potential for irreversibilities if native species adapt to the introduction e.g. through changes in feeding or other behavior (Crooks and Soulé, 1999). Another reason for careful interpretation of results is the limited coverage of NIS in different taxonomic groups. ISSG data sources cover only a fraction of all NIS in the countries, and the results in this study are then affected if an enlargement of included species implies relative changes in the occurrence of NIS and species threat among countries. Nevertheless, robust results in the paper point at the need for managing international threats to biodiversity, such as regulation of trade related spread of NIS (IMO, 2012), and to pay attention to both economic prosperity and institutional capacity if the strategy suggested by CBD (2013b) to improve biodiversity by protecting, constructing and restoring habitats is to be successful.

## Appendix: Table

**Table A1: Regression results for different taxonomic groups using IV estimates**

| | *Mammalslog N=153* | *Birdslog N=153* | *Amphilog N=154* | *Plantslog N=139* | *Reptileslog, N=154* |
|---|---|---|---|---|---|
| NISlog | 0.326** | 0.626*** | 1.363*** | 1.696*** | 0.885*** |
| Gdpclog | 0.106 | 0.136 | 0.897** | 0.722 | 0.702*** |
| Corrlog | 0.361 | 0.363 | 1.089 | 0.706 | 0.879* |
| CorrGdplog | -0.242* | -0.266** | -0.684*** | -0.579** | -0.534*** |
| SO2log | 0.199*** | 0.133*** | 0.018 | -0.024 | 0.076* |
| Aras | -0.930** | -1.753*** | -2.472*** | -3.064*** | -1.567*** |
| Prot90 | -0.011* | -0.003 | 0.013 | 0.010 | -0.022*** |
| Popdenslog | -0.066 | -0.003 | 0.063 | 0.08 | 0.089* |
| $Spa_I$ | 7.216-4* | 7.367-4** | 0.011 | -0.001 | 0.011 |
| $Spa_{BO}$ | 6.062-4*** | 3.304-4* | 0.009** | 0.225*** | 0.011** |
| Avtemp | 0.040*** | 0.022** | 0.056*** | 0.104*** | 0.067*** |
| Intercept | -0.277 | -0.922 | -6.747*** | -6.766*** | -4.686*** |
| Adj. $R^2$ | 0.653 | 0.640 | 0.495 | 0.453 | 0.620 |

*,**,***: statistical significance at the 10, 5 and 1 per cent level respectively

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