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BIODIVERSITY LOSS AND ECONOMIC GROWTH: A CROSS-COUNTRY ANALYSIS

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This paper empirically examines the relationship between biodiversity loss and economic growth in light of the current debate on the effects of economic growth on environmental quality. The basic premise of the paper is that biodiversity belongs to a special class of environmental degradation because it involves complex ecosystems the loss of which cannot be recovered by technological advances. The main finding is that while economic growth has an expected adverse effect on biodiversity, the composition of economic output can also be significant particularly in low-income countries. The study highlights the need to develop appropriate institutions and macroeconomic policies that allow biodiversity values to be internalized in decision-making processes. (*JEL* Q22, Q23, Q28)

I. INTRODUCTION

Biodiversity loss is among the most serious environmental problems facing the world today. Natural habitats in the moist tropical regions, which harbour the majority of the world's flora and fauna, are being lost at an alarming rate. It is estimated that in tropical rain forests alone the rate of loss of entire species (not merely genetic varieties or subspecies) is now a minimum of about 27,000 per year, or three per hour, and the rate is increasing. This rate of decline is believed to be at least 1,000 times the 'ordinary' (i.e., background) rate of extinction (Wilson, 1992). There are many who believe that we are facing a biodiversity crisis and others have gone as far as to suggest that we are slipping into a rate of extinction that may well rival that which resulted in the demise of the dinosaurs some 65 million years ago.

Within the last decade, there has been a resurgence of the debate about the effects of economic growth on environmental quality. This particular debate has been fuelled by studies carried out in the early 1990s that showed that there is an inverted U-shaped relationship between certain indicators of environmental degradation and economic growth (e.g., see

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Grossman and Krueger, 1991, 1995; Antle and Heidebrink, 1995; Shafik and Bandyopadhyay, 1992; Selden and Song, 1994). This relationship is now widely known as the *Environmental Kuznets Curve (EKC)*. The EKC hypothesis suggests that environmental effects are initially low at low levels of economic growth. However, as development proceeds, the rate of pollution increases. At higher levels of economic development, countries are able through structural change to substitute towards industrial and agricultural technologies that are less harmful to the environment. A typical feature of the EKC is the inverted U shape, which suggests that the level of pollution reaches a maximum level with respect to income, after which it begins to decline.

The EKC debate is of considerable national and international importance. The existence of such a relationship would lend support to the view that as countries develop they will experience a cleaner environment (Beckerman, 1992; Bartlett, 1994). A corollary of this view is that pollution is a necessary evil for countries at an early stage of development and that economic growth is the key to solving environmental problems.

This paper considers the issue of biodiversity loss in the context of the current debate on economic growth and environmental quality. The EKC debate has given rise to a rapidly expanding literature, part of which is reviewed in the next section. However, the majority of these studies focus on aspects of environmental degradation such as air/water pollution and deforestation. The basic premise of this paper is that biodiversity belongs to a special class of environmental degradation because it involves complex ecosystems the loss of which cannot be recovered by technological advances. As such they differ from other types of environmental degradation such as pollution and deforestation for which improvements are possible to some extent. Furthermore, biodiversity levels are not related to energy use unlike pollutants commonly used in EKC studies. Thus, at the global level, there cannot be a turning point in the relationship as income increases. Rather than estimating an EKC relationship, here we endeavour to investigate the determinants of biodiversity loss and offer suggestions for policy. The main finding of the study is that while economic growth has an expected adverse effect on biodiversity, the composition of output can be important particularly in low-income countries. For some aspects of biodiversity such as mammal and bird species, the results indicate that there is some scope for using appropriate institutional and macroeconomic policies to reduce the rate of species decline.

The remainder of the paper is organised as follows. Section II briefly reviews the current literature on EKC relationships and biodiversity loss. Section III discusses the data and methodology, while Section IV reports the empirical results for four indicators of biodiversity. The final section evaluates the empirical findings and discusses the policy implications.

II. LITERATURE REVIEW

The term 'environmental Kuznets curve' was first used by Selden and Song (1994) when they suggested that the environment-income relationship might be similar to the one proposed by Kuznets (1955) for income inequality in relation to development, namely an 'inverted-U' shape. To date, the empirical evidence in support of the EKC has been mixed. Earlier studies (e.g., Shafik and Bandyopadhyay, 1992; Panayotou 1993, 1995; Grossman and Krueger, 1995) found an EKC relationship for sulphur dioxide (SO_2), suspended particulate matter, and carbon dioxide at incomes below US$8,000 per capita. However, more recent research casts doubt on an EKC for SO_2 (Stern and Common, 2001) and other air pollutants (Harbaugh et al., 2000). Even when the EKC appears to be valid, there are doubts about the stability and hence the reliability of the turning points. For example, in Cropper and Griffith (1994), the per capita income levels of most of the African and Latin American countries in the sample were below the EKC turning points.

In their study which used a much larger sample of countries over a longer period of time than previous sulfur EKC studies, Stern and Common (2001) found that the turning point estimates were sensitive to sample choice. For example, using a sample of 23 OECD countries and a random effects model, they obtained an inverted-U shape with a turning point of US$9,239 which was well within the sample. However, using a global sample, they obtained a very high turning point of US$101,166, implying that the EKC is effectively a monotonic function of income. This finding is consistent with that of List and Gallet (1999) who also found a very high turning point for sulphur for US states when they used a long time series (1929-1994) and a wide income range (US$1,162-US$22,462).

Harbaugh et al. (2000) re-examined the empirical evidence for the EKC for SO_2, smoke, and total suspended particulates using data from World Bank (1992) and Grossman and Krueger (1995), with the benefit of an additional ten years of data. They also tested the sensitivity of the EKC relationship to different functional forms and econometric specifications, to the inclusion of additional covariates besides income and to the nations, cities and years sampled. They found that the location of the turning points, as well as their very existence, was sensitive to both slight variations in the data and to the econometric specification. For example, merely cleaning up or updating the original data caused the inverted-U shape to disappear. On the basis of these results, they concluded that there is little if any empirical support for the existence of an EKC for these pollutants.

A major shortcoming of EKC studies is their focus on a range of air and water pollutants, ignoring important ecological aspects of the environment. Indicators such as protected areas expressed as a percentage of total land area and threatened species of mammals and birds as a percentage of all such species in a country have been identified by MacGillivray (1993) as two important indicators of biodiversity which should be included in any examination of environmental performance.

The *Global Biodiversity Strategy* defines biodiversity as the totality of genes, species and ecosystems in a region (WRI/WCU/UNEP, 1992). The ecosystem level is related to the spatial scale and pattern of species combination, while the genetic and species levels deal with the numbers of species and variations amongst them. In addition to the standard definition above, it has been suggested that landscape diversity should also be also be considered when defining biodiversity (Noss and Cooperrider, 1994). Biodiversity benefits humans in a variety of ways. First, there are direct uses such as the discovery of wild relatives of agricultural crops such as corn and potato that have disease-resistant properties. Secondly, there are other benefits including discoveries for the advancement of medicine and understanding of the life sciences, as well as provision of services such as stabilisation of hydrological cycles on larger landscape scales. In this regard, biodiversity has insurance and information value.

Whereas some progress has been made in recent years towards collecting information to aid environmental management, scientists still have only a limited understanding of the earth's biodiversity resources. This is due to gaps in knowledge about species and the complex nature of ecosystem interactions. For example, of the 13 to 14 million species on earth, only 1.75 million (13 percent) have been scientifically described. The status of the 1.75 million described species have never been fully assessed (UNEP, 1995). There is also uncertainty about the rates of species extinction. It is estimated that about 500 animal species have become extinct since 1600 (Smith et. al, 1993). The majority of these extinctions have occurred among vertebrates, which constitute only a small fraction of the world's species. Therefore, it is possible that many more extinctions among small-bodied organisms such as insects have escaped our attention.

Although environmental factors such as climate contribute to biodiversity decline, by far the major causes are conversion and degradation of natural habitats. Habitat loss affects all three of the principal levels of biodiversity (i.e., genetic, species and ecosystem biodiversity). 'Conversion' refers to the transformation of a natural form of a resource into another form suitable for human use. This can occur in various ways. For example, conversion occurs when an excessive amount of the main constituents of an ecosystem is withdrawn (e.g., clear felling of a forest). Another instance is when too much of an introduced element (artificial or natural) is added to the ecosystem. Conversion occurs mainly to supply the needs of a growing human population. One of the consequences of conversion is that the available habitat becomes fragmented. Over time, the isolated fragments are unable to support the remnants, resulting in species loss.

Vitousek et al. (1986) estimate that the human species uses about 40 percent of potential terrestrial net primary product based on an estimate of 5 billion people (1990 population) and a daily consumption of 2,500 calories per capita. The UN predicts that world population growth would rise to 10 billion people by 2050 (UN, 1993). Given the projected increase in the world's population, it will be a major challenge to avoid a staggering loss of biodiversity in the future.

Given that biodiversity is a public good whose benefits cannot be appropriated by individuals, the rate of conversion and thus the rate of biodiversity decline is higher than is socially desirable (Krautkraemer, 1995). The decline of biodiversity resources is also due to the fact that the value of these resources is underestimated or ignored in decision-making processes. Another unique feature of biodiversity compared to other public goods is that whereas the costs are borne locally, the benefits accrue globally. Therefore, the incentive to supply (or conserve) biodiversity may be lesser than for other public goods. Although government policies are supposed to correct the market failure associated with biodiversity, there are numerous cases in which government policies have actually promoted biodiversity decline. Examples include the pricing of logs in tropical forests, and subsidization of land clearing and export commodities.

In the following section the framework for modeling biodiversity decline is discussed together with the econometric specification of the relationship between biodiversity and various socioeconomic variables.

III. METHODOLOGY

A. Measuring Biodiversity

Biodiversity is a complex variable that is difficult to capture with a single indicator. A naïve model of biodiversity is based on the ecological theory of island biogeography (MacArthur and Wilson, 1967) which represents the number of species (*S*) as a function of area (*A*) as follows:

(1) $$S = CA^z$$

where *C* and *z* are positive parameters, with *z* ranging from 0.10 to 0.35 (Wilson, 1992). If, say, *z* = 0.25, then at the margin, a 1 percent increase in area results in a 0.25 percent increase in the number of species. Thus, it can be seen that equation (1) is non-linear in both the parameters and variables. The following model was therefore specified:

(2) $$ln S = ln C(X) + z\ ln(A)$$

where *X* is the vector of variables whose impact on biodiversity we wish to investigate.

Due to lack of data indicators of species diversity were used as proxies for biodiversity. These were as follows: (1) number of known mammal species/10,000 sq km (*MAMMALS*); (2) number of known bird species/10,000 sq km (*BIRDS*); (3) number of known higher plant species/10,000 sq km (*PLANTS*); (4) percentage of bird and mammal species threatened with extinction (*PBMT*); and (4) average annual percentage change in the number of known mammal species for the period 1989/1999 (*PCMAM*). The last indicator was only obtained for mammals due to insufficient data for the other species. The above indicators are problematic because many countries have already lost significant numbers of species in the past. Thus, information on past species decline may not be a good reflection of current actions taken by humans. Notwithstanding the problems, we are compelled to use these indicators for lack of better alternatives.

B. Factors Affecting Biodiversity Loss

Building on the above model, it is hypothesized that biodiversity is directly affected by the size of habitat, population pressure, climate, the level of income and composition of output of a country, as well as by institutional factors such as the level of economic freedom and the macroeconomic policy environment. Each of these factors is briefly discussed below.

Habitat size

As indicated above, habitat loss is a crucial factor affecting biodiversity decline. Most forms of economic activity require more physical space, implying loss of species habitat and therefore loss of biodiversity. The main cause of habitat destruction is the clearing of vegetation for agricultural and other purposes. It has been suggested that one of the devastating effects on biodiversity is the fragmentation of habitat into 'islands' separated by artificial vegetation (e.g., see Robbins, 1980). In this study, the percentage of land developed for agriculture and other uses (*PDLAND*) and the percentage of protected land area (*PPLAND*) were used as proxies for habitat size. It is expected that the percentage of protected land area will be positively related to biodiversity levels, while the percentage of land developed for agriculture and other uses will be negatively related to biodiversity levels.

Population pressure

Population growth increases the demand for food, shelter and other services that require increased conversion of habitat. It has been shown that high population densities can lead to excessive deforestation and hence loss of biodiversity (e.g., see Cropper and Griffiths, 1994). While the rate of habitat conversion may not necessarily be proportional to population size, it is quite clear that unchecked population growth will have adverse effects on biodiversity levels unless resource use per capita declines. Available statistics indicate that much of the growth in population is from the high rate of urbanization. According to the World Bank, developing country cities as a group will grow by 160 percent by 2030, whereas rural populations will grow by only 10 percent (World Bank, 1992). Population density (*POPDENS*) and urban population growth (*UPOPGRO*) were used as measures of population pressure. It is expected that both measures will be negatively related to biodiversity levels. Population density was used for Indicators 1 through 3 (i.e., number of species per 10,000 sq km), while population growth was deemed to be more appropriate for Indicators 4 and 5.

Climate

It is a well-known fact that species diversity increases as one moves from the polar areas towards the equator. Studies suggest that phenomena such as ozone depletion and CO_2 emissions that contribute to global warming may indirectly increase biodiversity loss. For example, Holm-Hansen et al. (1993) found that ozone depletion reduced productivity in the Antarctic ocean by less than 5 percent, while Termura et al. (1990) found that ultra-violet radiation reduces the rate of CO_2 assimilation by land plants. Dummy variables for climate were used to account for climatic effects on biodiversity. For this purpose, the countries in the sample were divided into three climatic groups: (1) cold and cold temperate countries; (2) sub-tropical and dry countries; and (3) wet tropical countries. It is expected that the coefficient on climate will be positively related to biodiversity levels.

Income

Income (represented by GDP per capita) is expected to affect the level of biodiversity because it is related to the level of economic output. The higher the level of economic output, the higher is the rate of habitat conversion in order to produce material goods and services, resulting in a higher level of biodiversity decline. In addition, it is hypothesized that biodiversity decline is not only affected by the level of economic activity but also by the composition of economic output. Countries with agriculture forming a high proportion of their total output will experience faster biodiversity decline due to more rapid conversion of habitat for agricultural purposes. Thus, agricultural value added as a percentage of GDP (*AGRICPC*) is included as a regressor in the model.

Level of institutional development

It is hypothesized that the development of a country will be accompanied by the development of economic, social and political institutions that help to internalise the value of biodiversity into decision-making processes of the state and individuals. For example, a fully developed market system offers opportunities to use market mechanisms and fiscal policies (e.g., pollution taxes and taxes on land conversions) to achieve certain environmental objectives. Furthermore, the market system provides scope for the creation of markets for environmental goods (e.g., markets in rights for environmental use). The institutional proxy used in this study is the level of economic freedom in a country. It is hypothesized that increased economic freedom is associated with improvement in the functioning of the market system, which enables economic agents to better take into account the environmental costs of economic growth. Also, it may be argued that greater economic (and political) freedom allows individuals and groups to lobby the government for provision of a cleaner environment.

The particular version of the index of economic freedom used in this study is published by the Fraser Institute (Gwartney and Lawson, 1997). It was chosen over other indices of economic freedoms (e.g., Messick, 1996; Holmes et al., 1997) because it is focused principally on economic freedoms as distinct from broader social freedoms such as freedom of speech, freedom to assemble, freedom from torture and so on. The index (*FREE*) ranges from 0 (most free) to 20 (least free). It is expected that a negative relationship will exist between the degree of economic freedom and biodiversity level.

Macroeconomic policy environment

It is expected that macroeconomic policies will affect the level of environmental degradation, which in turn will affect biodiversity resources. In this study, the black market premium on foreign exchange is used as a proxy for exchange rate and trade policies, which in turn reflect the overall macroeconomic environment. For example, a high black market exchange rate indicates a restrictive trade policy stance and overvaluation of the domestic currency. The net effect of exchange rate and trade policies on biodiversity decline cannot be determined *a priori*. It is possible, for example, that currency overvaluation could negatively affect private rents from timber exports. However, on the other hand it could also discourage development of non-timber forest product industries. The measure of the black market premium on exchange rates used here (*FOREX*) is based on a scale of 0 to10, with 0 representing a black market exchange rate premium of 210 percent or more and 10 representing a premium of 0 percent.

C. Econometric Model and Data

For Indicators 1 through 3 the following econometric model was estimated:

$$(3) \qquad ln\mathrm{E}_{ij} = \alpha_0 + \alpha_1 ln\mathrm{GDP}_i + \alpha_2 ln\mathrm{AGRICPC} + \alpha_3 ln\mathrm{FREE}_i + \alpha_4 ln\mathrm{FOREX}_i + \alpha_5 ln\mathrm{POPDENS}_i + \alpha_6 ln\mathrm{PDLAND}_i + \alpha_7 ln\mathrm{PPLAND} + \alpha_8 ln\mathrm{CLIMATE}_i + \varepsilon_i$$

For indicators 4 and 5 the following econometric model was estimated:[2]

$$(4) \qquad \mathrm{E}_{ij} = \alpha_0 + \alpha_1 ln\mathrm{GDP}_i + \alpha_2 ln\mathrm{AGRICPC} + \alpha_3 ln\mathrm{FREE}_i + \alpha_4 ln\mathrm{FOREX}_i + \alpha_5 ln\mathrm{UPOPGRO} + \alpha_6 ln\mathrm{PDLAND}_i + \alpha_7 ln\mathrm{PPLAND} + \alpha_8 ln\mathrm{CLIMATE}_i + \varepsilon_i$$

where E_{ij} is an indicator of biodiversity level, j = 1 (mammals), 2 = (birds), 3 = (plants), 4 = (pbmt) and 5 (pcmam); ε_i is a random error term; and all the other variables are as previously defined.

Cross sectional data on the above variables were obtained for 100 countries, including 50 low-income, 25 middle-income and 25 high-income countries. The use of panel data was restricted with many indicators only being reported for the 1990's. GDP per capita (in PPP terms, 1995 International $) was used as a proxy for income. Data on GDP per capita, the Index of Economic Freedom, and the black market exchange rate premium were obtained from Gwartney and Lawson (1997), while data on population density and the percentage of agricultural value added in GDP were taken from World Bank (1999). Data on the remaining variables were obtained from *World Resources* (WRI, 1990, 1999). The list of countries included in the sample is given in the Appendix.

IV. EMPIRICAL RESULTS

Figure 1 presents plots of the income-biodiversity relationship using the first four indicators (i.e., numbers of known mammal, bird and higher plant species per 10,000 sq km and the percentage of birds and mammals threatened with extinction).

[Figure 1]

For each indicator, the plots show wide variations in species diversity especially for countries in the less than US$10,000 category. However, ignoring the outliers in the samples, it can be seen that there is an overall negative relationship between income and biodiversity levels for the numbers of known mammal, bird and higher plant species, and a positive relationship between income and the percentage of birds and mammals threatened with extinction.

The countries in the sample were grouped into the following three per capita income categories: (1) low-income (<US$5000), (2) middle-income (US$5000-14500), and (3) high-income (>US$14500). Table 1 shows the breakdown of the biodiversity indicators computed for each of the three categories.

[Table 1]

The figures for mammals decrease from 61.4 per 10,000 sq km for low-income countries to 31.3 per 10,000 sq km for high-income countries. A similar pattern is observed for birds, with numbers declining from 164.2 per 10,000 sq km for low-income countries to 85.6 per 10,000 sq km for high-income countries. These results support the trends observed in the graphical analysis. However, in the case of higher plants, the mean number of birds per 10,000 sq km increases from 1755 for low-income countries to 2565 for middle-income countries, before declining to 1120 for high-income countries.

A. Regression Results

To quantify these relationships more precisely and examine the impact of economic growth on biodiversity, equations (3) and (4) were estimated using ordinary least squares (OLS). As pointed out by Stern et al. (1996), data used in EKC studies are subject to the problem of heteroskedasticity and therefore OLS estimation would yield unbiased but inefficient parameter estimates. Initial diagnostic tests on the models revealed the presence of significant heteroscedasticity and therefore White's heteroskedasticity consistent covariance matrix estimator was used (White, 1980). Table 2 reports the results for known species of mammals, birds, and higher plants per 10,000 sq km and the average annual percentage change in species numbers for mammals. The equation for the percentage of birds and mammals threatened with extinction is not reported due to the poor fit.

[Table 2]

We begin the discussion with the effects of the economic output variables (*GDP* and *AGRICPC*) on biodiversity. The level of economic activity represented by income has a significant negative effect on species density for mammals and birds but not for higher plants. It also appears to have an adverse effect on the average annual percentage change in the number of known mammal species. The proxy for the composition of economic output (*AGRICPC*) is highly significant for the average annual percentage change in the number of known mammal species. This result provides some justification for the view that it is not only the level of economic output *per se* which is injurious to biodiversity, but also the composition of that output. This confirms the fact that conversion of habitat for agricultural and other purposes is one of the major threats to biodiversity conservation.

The coefficient on economic freedom (*FREE*) is negative and statistically significant for the average annual percentage change in the number of known mammal species. This result indicates that to some extent, there are better prospects for developing institutional responses for dealing with biodiversity concerns the greater is the level of economic freedom in a country. In general this is consistent with earlier findings that: (i) insecure property rights and government instability are associated with increased deforestation (Deacon, 1994), and (ii) increase in civil and political freedoms improves environmental quality (Torras and Boyce, 1998; Barrett and Graddy, 1998). The black market exchange rate premium (*FOREX*) is positive and statistically significant for mammals and higher plants, with the effect being relatively stronger for the latter. This particular variable is an indicator of distortions in the economy and the implication here is that removal of such distortions could lead to an improvement in not only the economy but also aspects of the environment.

Turning now to the indicators of population pressure, it can be seen that, as expected, population density has a highly significant negative effect on biodiversity loss in general. Urban population growth has a negative effect on the average annual percentage change in the number of known mammal species, although this is not statistically significant. Of the habitat size variables, the percentage of protected land area (*PPLAND*) is significant for all the three indicators of species density, while the percentage of land developed for agriculture and other uses (*PDLAND*) is significant for the average annual percentage change in the number of known mammal species. These results lend empirical support for the view that space is a limiting factor to biodiversity protection and provide a justification for the policy of setting aside nature conservation areas. According to Peter Vitousek of Stanford University, 40 percent of the earth's land surface has already been transformed for direct human use and over half of all accessible surface freshwater is in use. Finally, the results in the last row of Table 2 indicate that climatic differences significantly explain biodiversity loss.

The next stage of the analysis was to estimate models that allow interaction of low and high-income dummy variables with the other right-hand side variables. Such models allow for the possibility that the impact of these variables may be different in low-income and high-income countries. Torras and Boyce (1998) tested this type of hypothesis for various pollutants. Following Torras and Boyce (1998), we use US$5,000 per capita income as the cut-off between high and low-income countries. Approximately half of the sample fell into the low-income category after this division. The results (Table 3) indicate that the negative effects of agricultural expansion on mammal and bird species densities are significant for low-income countries but not for high-income countries.

[Table 3]

The effect on the average annual percentage change in the number of known mammal species is significant for both income groups, but is more pronounced in low-income countries. These results can be explained in two ways. First, agriculture tends to form a higher component of economic output in low-income countries compared to high-income countries. Secondly, harmful agricultural practices such as slash-and-burn cultivation and uncontrolled use of insecticides and pesticides are more prevalent in low-income countries. For example, slash-and-burn agriculture has been identified as the main source of deforestation in countries such as Columbia, Ecuador, Peru, Bolivia, Ivory Coast, Nigeria, Zaire, India, Sri Lanka, Thailand, Indonesia and the Philippines (Myers, 1992; FAO, 1992; Grainger, 1993). It is also a contributory factor in Mexico, Brazil, Myanmar and Vietnam.

The variable for economic freedoms is significant for low-income countries but not for high-income countries in the case of the average annual percentage change in mammal species numbers. Likewise, the variable representing the macroeconomic environment (*FOREX*) is significant for low-income countries but not for high-income countries in the case of higher plants. The effect of population density on mammalian species density is approximately similar for both low and high-income countries, although the effects on bird and higher plant species densities are slightly higher for high-income countries.

Although not statistically significant, the rate of urban population growth (*UPOPGRO*) appears to have a relatively greater effect on the average annual percentage change in mammal species numbers in low-income countries than in high-income countries. A similar differential impact can be observed in the case of percentage of protected land area (*PPLAND*) where the effects are significant in low-income countries for mammals, birds and higher plants but not in high-income countries. Finally, for all four indicators of biodiversity loss, climatic effects are relatively more significant in low-income countries. This particular result could partly be explained by the fact that countries in the colder regions, which tend to be the richer countries, have already lost a large amount of biodiversity and are now experiencing a slower decline. Another possibility is that species in these countries have become more resistant or better adapted and therefore decline at a lower rate.

V. CONCLUSION AND POLICY IMPLICATIONS

Biodiversity loss ranks among the major global environmental problems confronting the world. It is a form of environmental degradation that has not been well highlighted in the current debate on the effects of economic growth on the environment. Biodiversity loss belongs to a special category of environmental degradation because it involves the irreversible loss of valuable ecosystems. Thus, in this case policy implications associated with EKC-type studies are inappropriate. In this paper an attempt has been made to empirically examine the relationship between biodiversity and economic growth using indicators of species diversity and income per capita as proxies for biodiversity and economic growth, respectively. The main finding is that while economic growth has an adverse effect on biodiversity, the type or composition of this growth can also be significant for biodiversity loss. In particular, it was shown that countries with a higher component of agricultural output in total output, which tend to be the low-income countries, experience relatively greater biodiversity decline. Although farmers in these countries tend to use low-level agrotechnology which is environmentally benign, inappropriate farming practices such as slash-and-burn cultivation is a major cause of deforestation and hence biodiversity loss. There is therefore the need to address the underlying causes of biodiversity loss in these countries which include poverty, lack of property rights and tenure regimes, lack of inadequate rural infrastructure, health and education services, and lack of employment opportunities.

The institutional proxy used in the study was an indicator of economic freedoms that is more narrowly defined than those used in previous studies. This indicator is based mainly on economic freedoms while the others have been based on broad social freedoms. The study results indicate that while improvement in economic freedoms can be associated with improvement in mammal and bird species numbers, the effect on biodiversity is much stronger in low-income countries compared to high-income countries. The main implication here is that there is a need to develop appropriate institutional and macroeconomic policies that allow biodiversity values to be internalised in decision-making processes at the individual and national levels. However, a major obstacle to achieving this objective is that biodiversity is a global public good, and as such individuals and countries have no incentive to invest in the stocks of such resources. Thus, there is the need for more international initiatives such as the Global Environmental Facility that aim to promote the management of biodiversity resources.

In conclusion, a number of caveats are in order. Given that the measurement of biodiversity loss is imprecise and there are omitted variables in the model, the magnitudes of the estimated coefficients are also uncertain. Nevertheless, the negative effects of economic growth on biodiversity appear to be quite robust. There is the need for more studies of this kind to enhance our understanding of the relationship between biodiversity loss and economic growth. In particular, there is the need for country specific studies. Unfortunately, the availability of good quality time series environmental data remains a major obstacle to this type of analysis. In many countries, time series data on environmental indicators prior to 1989 is unavailable or so poorly reported that its use would be detrimental to any study. Finally, there is a need to investigate the role of additional socioeconomic and institutional factors in the income-biodiversity relationship.

REFERENCES

Antle, J.M., and G. Heidebrink. "Environment and Development: Theory and International Evidence." *Economic Development and Cultural Change*, 43(3), 1995, 603-625.

Barrett, S., and K. Graddy. "Freedom, Growth and the Environment." Unpublished paper, London Business School, 1998.

Bartlett, B. "The High Cost of Turning Green." *Wall Street Journal,* September 14, 1994, p.18.

Beckerman, W. "Economic Growth and the Environment: Whose Growth." *World Development*, 20, 1992, 481-496.

Cavlovic, T., K.H. Baker, R.P. Berrens, and K. Gawande. "A Meta-Analysis of Environmental Kuznets Studies." *Agricultural and Resource Economics Review*, 29(1), 2000, 32-42.

Cropper, M., and C. Griffiths. "The Interaction of Population Growth and Environmental Quality." *American Economic Review*, 84, 1994, 250-254.

Deacon, R.T. "Deforestation and the Rule of Law in a Cross-Section of Countries." *Land Economics*, 70, 1994, 414-30.

Food and Agriculture Organisation, FAO. *Third Interim Report on the State of Tropical Forests*. Forest Resources Assessment 1990 Project, Food and Agriculture Organisation, Rome, 1992.

Grainger, A. *Controlling Tropical Deforestation*. London: Earthscan Publications, 1993.

Grossman, G.M., and A.B. Krueger. "Environmental Impacts of a North American Free Trade Agreement." National Bureau of Economic Research Working Paper No.3914, 1991.

______. "Economic Growth and the Environment." *Quarterly Journal of Economics*, 2, 1995, 353-375.

Gwartney J. D., and R. A. Lawson. *Economic Freedom of the World: 1997 Annual Report*. The Fraser Institute, Vancouver, Canada, 1997.

Harbaugh, W., A. Levinson, and D. Wilson. "Re-examining the Evidence for an Environmental Kuznets Curve." NBER Working Paper No. 7711, 2000.

Holm-Hansen, O., E.W. Helbling, and D. Lubin. "Ultraviolet Radiation in Antartica: Inhibition of Primary Production." *Photochemistry and Photobiology*, 58, 1993, 567-570.

Holmes, K.R., B.T. Johnson, and M. Kirkpatrick. *Index of Economic Freedom*. The Heritage Foundation and the Wall Street Journal, 1997.

Krautkraemer, J.A. "Incentives, Development and Population: A Growth-Theoretic Perspective," in *The Economics and Ecology of Biodiversity Decline: The Forces Driving Global Change*, edited by T.M. Swanson. Cambridge: Cambridge University Press, 1995.

Kuznets, S. "Economic Growth and Income Inequality." *American Economic Review*, 45(1), 1995, 1-28.

List, A.J., and C.A. Gallet. "The Environmental Kuznets Curve: Does One Size Fit All?" *Ecological Economics,* 31, 1999, 409-423.

MacArthur, R.H., and E.O. Wilson. *The Theory of Island Biogeography.* Princeton, NJ: Princeton University Press, 1967.

MacGillivray, A. *A Green League of Nations: Relative Environmental Performance in OECD Countries*. London: New Economics Foundation, 1993.

Messick, R.E. *World Survey of Economic Freedom: 1995-1996*. New Brunswick: Transaction Publishers, 1996.

Myers, N. *The Primary Source: Tropical Forests and Our Future*. New York: W.W. Norton, 1992.

Noss, R.F. and A.Y. Cooperrider. *Saving Nature's Legacy: Protecting and Restoring Biodiversity*. Washington, D.C.: Island Press, 1994.

Panayotou, T. "Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development." Working Paper No. WP238. Technology and Employment Programme, ILO, Geneva, 1993.

______. "Environmental Degradation at Different Stages of Economic Development" in *Beyond Rio: The Environmental Crisis and Sustainable Livelihoods in the Third World*, edited by I. Ahmed, and J.A. Doeleman. London: Macmillan, 1995.

Robbins, C.S. "Effect of Forest Fragmentation on Bird Populations in the Piedmont of the Mid-Atlantic Region." *American Naturalist*, 33, 1980, 31-36.

Selden, T.M., and D. Song. "Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions?" *Journal of Environmental Economics and Management*, 27, 1994, 147-162.

Shafik, N., and S. Bandyopadhyay. "Economic Growth and Environmental Quality: Time Series and Cross Country Evidence." Background Paper for *World Development Report*. WPS, Washington D.C.: The World Bank, 1992.

Smith, F.D.M., R.W. May, R. Pellew, T.H. Johnson, and K.R. Walter. "How Much Do We Know About the Current Extinction Rate?" *Ecology and Evolution*, 8, 1993, 375-378.

Stern, D.I. "Progress on the Environmental Kuznets Curve?" *Environment and Development Economics*, 3(1), 1998, 73-196.

Stern, D.I., and M.S. Common. "Is there an Environmental Kuznets Curve for Sulphur?" *Journal of Environmental Economics and Management*, 41, 2001, 162-178

Stern, D.I., M.S. Common, and E.B. Barbier. "Economic Growth and Environmental Degradation: The Environmental Kuznets Curve and Sustainable Development." *World Development*, 24(7), 1996, 1151-1160.

Temura, A.H., J.H. Sullivan, and L.H. Ziska, "Interaction of Elevated UV-B Radiation and Carbon Dioxide on Productivity and Photosynthetic Characteristics in Wheat, Rice, and Soybean." *Plant Physiology*, 94, 1990, 470-475.

Torras, M., and J.K. Boyce. "Income, Inequality, and Pollution: A Reassessment of the Environmental Kuznets Curve." *Ecological Economics*, 25, 1998, 147-160.

United Nations Environmental Programme, UNEP. *Global Biodiversity Assessment.* Cambridge: Cambridge University Press, 1995.

United Nations Population Division. *Long Range World Population Projections: Two Centuries of Population Growth, 1950-2150*. New York: United Nations, 1993.

Vitousek, P., P.R. Ehrlich, A.H Ehrlich, and P.A. Matson. "Human Appropriation of the Products of Photosynthesis." *BioScience*, 36, 1986, 368-373.

White, H. "A Heteroskedasticity-Consistent Covariance Matrix and a Direct Test for Heteroskedasticity." *Econometrica*, 48, 1980, 817–838.

Wilson, E.O. *The Diversity of Life*. Cambridge, M.A.: Harvard University Press, 1992.

World Bank. *World Development Report 1992*. New York: Oxford University Press, 1992.

______. *World Development Indicators 1999*. CD-ROM version, Washington, D.C.: World Bank, 1999.

World Resources Institute, WRI. *World Resources 1990-1991*. New York: Oxford University Press, 1990.

______. *World Resources 1999-2000*. New York: Oxford University Press, 1999.

World Resources Institute, The World Conservation Union (WCU) and United Nations Environment Program (UNEP). *Global Biodiversity Strategy*. Washington, D.C.: World Resources Institute, 1992.

FOOTNOTES

1. Special issues of two environment-related journals, *Environment and Development Economics* in November 1997 and *Ecological Economics* in May 1998, were devoted to EKC studies. Excellent reviews can be found in Stern (1998) and Cavlovic et al. (2000).

2. The choice of this specification is necessitated by the fact that for variable 5, average percentage change in numbers of mammal species, some of the observations are negative and therefore cannot be logged.

ABBREVIATIONS

CO_2: Carbon Dioxide
EKC: Environmental Kuznets Curve
FAO: Food and Agriculture Organization
GDP: Gross Domestic Product
OECD: Organization for Economic Cooperation and Development
OLS: Ordinary Least Squares
SO_2: Sulfur Dioxide
UN: United Nations
UNEP: United Nations Environment Program
WCU: World Conservation Union
WRI: World Resources Institute

APPENDIX

List of Countries Included in the Sample

United States of America
Switzerland
Singapore
Norway
Kuwait
Denmark
Japan
Canada
Belgium
Austria
France
Iceland
Italy
Germany
Netherlands
Australia
Sweden
United Kingdom
Finland
Ireland
New Zealand
Spain
Mauritius
Portugal
Greece
Korea
Chile
Trinidad and Tobago
Malaysia
Oman
Argentina
Venezuela
Thailand
Mexico
Uruguay
Hungary
Colombia
Panama
Fiji
Costa Rica
Syria
Belize
Algeria
Turkey
Iran
Brazil
Poland
Tunisia
South Africa
Jamaica
Bulgaria
Ecuador
Romania
Estonia
Namibia
Jordan
Lithuania
Paraguay
Gabon
Indonesia
Egypt
Morocco
Peru
Latvia
Dominican Republic
Guatemala
Sri Lanka
China
El Salvador
Papua New Guinea
Ukraine
Nicaragua
Cameroon
Pakistan
Zimbabwe
Ghana
Honduras
Senegal
Cote d'Ivoire
Benin
Uganda
Nigeria
Kenya
India
Bangladesh
Togo
Nepal
Central African Republic
Zambia
Philippines
Malawi
Niger
Chad
Madagascar
Burundi
Sierra Leone
Mali
Rwanda
Congo
Guinea-Bissau

FIGURE 1

Graphical Plots for the Relationship Between Income and Biodiversity Levels

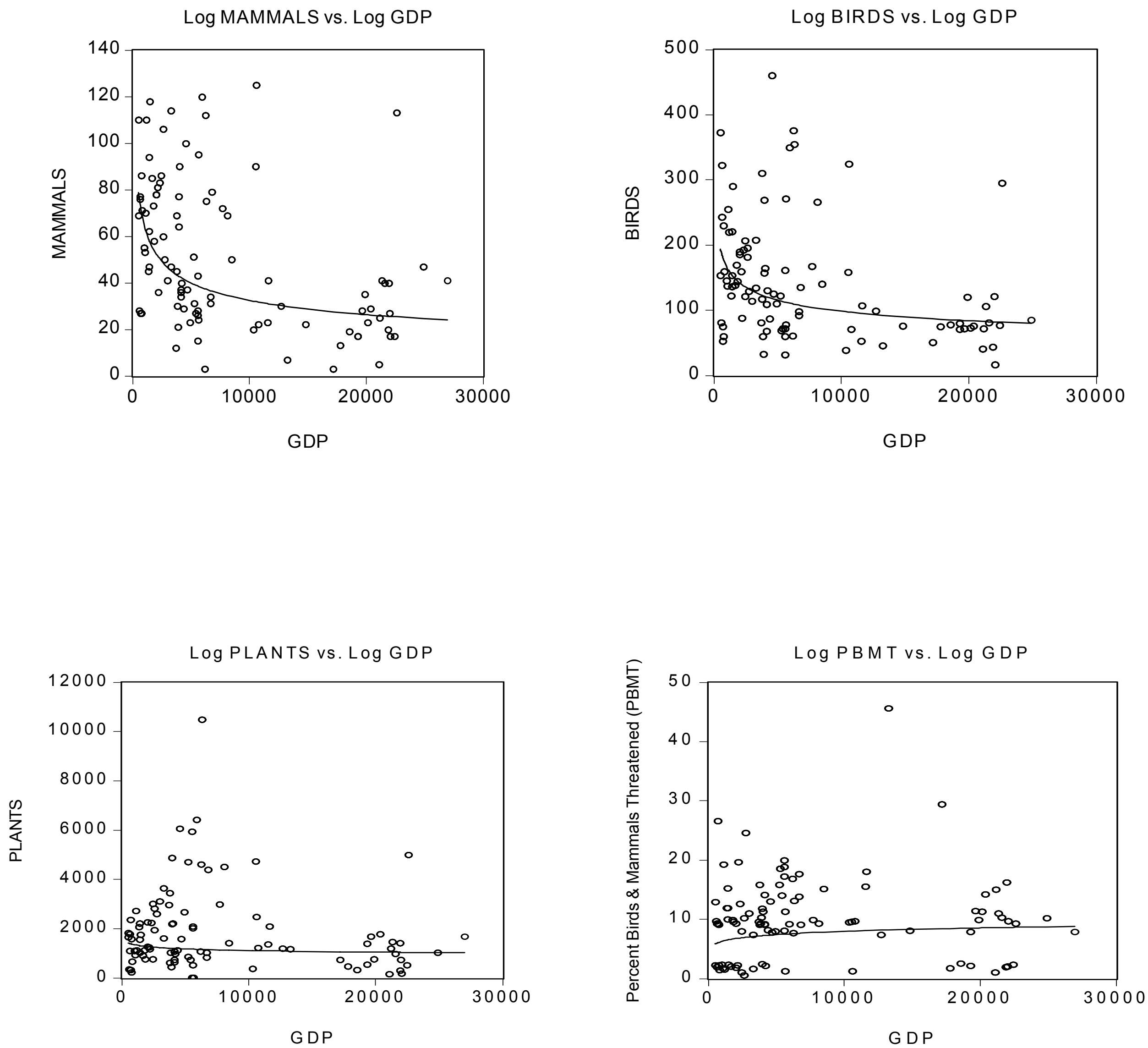

TABLE 1
Breakdown of Means of Biodiversity Indicators by Income Categories[a]

Variable	Low Income (<US$5000)	Middle Income (US$5000-14500)	High Income (>US$14,500)	Full Sample
Number of mammals/10,000 sq km	61.4 (27.8)	51.4 (34.6)	31.3 (29.2)	51.8 (32.1)
Number of birds/10,000 sq km	164.2 (84.4)	147.3 (106.8)	85.6 (53.10	142.5 (90.5)
Number of higher plants/10,000 sq km	1754.6 (1148.2)	2564.8 (2472.1)	1120 (1027.6)	1847.8 (1658.4)
Percentage of birds and mammals threatened	3.7 (4.8)	3.9 (4.8)	6.7 (8.4)	5.3 (6.3)
Average percentage change in mammals 1989-1999	0.9 (2.9)	1.1 (6.1)	-1.8 (-35.1)	0.4 (4.0)

[a] Standard deviations are in parentheses.

TABLE 2
Regression Estimates for Determinants of Biodiversity

Variable	No. of mammals /10,000 sq km[a]		No. of birds /10,000 sq km[a]		No. of higher plants/10,000 sq km[a]		Average % change in No. of mammals 89-99[b]	
	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
Intercept	6.00***	2.98	4.02***	3.22	3.51*	1.45	22.88**	2.14
*ln*GDP	-0.28**	-2.26	-0.04*	-1.37	0.11	0.56	-1.40*	-1.51
*ln*AGRICPC	-0.08	-0.60	0.09	0.94	-0.11	-0.63	-2.70***	-2.65
*ln*FREE	-0.10	-0.41	0.08	0.43	0.27	0.70	-1.91*	-1.30
*ln*FOREX	0.01*	1.87	0.02	0.84	0.30***	6.01	-0.06	-0.20
*ln*POPDENS	-0.10**	-1.99	-0.11***	-2.85	-0.20***	-2.61	-	-
*ln*UPOPGRO	-	-	-	-	-	-	-0.02	-0.05
*ln*PPLAND	0.11***	2.31	0.12***	2.91	0.10*	1.35	-0.12	-0.39
*ln*PDLAND	0.02	0.30	0.03	0.49	0.19	1.22	-1.04**	-2.04
*ln*CLIMATE	0.54***	2.64	0.48***	3.25	1.39***	4.88	5.85***	3.64
R^2	0.34		0.35		0.44		0.28	
Adjusted R^2	0.29		0.29		0.39		0.18	
Std error	0.64		0.53		1.02		3.63	
F-statistic	5.95***		5.89***		8.63***		2.91***	
N	99		98		98		71	

[a] The dependent variable is the logarithm of number/10,000 sq km.
[b] The dependent variable is the logarithm of the average annual percentage change in the number of known mammal species from 1989 to 1999.
***, **, and, * indicate statistical significance at the 1%, 5% and 10% level, respectively, for a one-tailed test.

TABLE 3

Regression Estimates for Determinants of Biodiversity – Low and High Income Countries

Variable	No. of mammals /10,000 sq km[a]		No. of birds /10,000 sq km[a]		No. of higher plants /10,000 sq km[a]		Average % change in No. of mammals 89-99[b]	
	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
Intercept	5.00**	2.42	4.24***	2.44	3.10	1.06	24.50**	1.67
*Ln*GDP	-0.19*	-1.31	-0.06	-0.39	-0.14	-0.57	-0.97	-0.76
*ln*AGRICPC-LOW	-0.10**	-1.75	-0.12*	-1.33	-0.02	-0.12	-3.47***	-2.92
*ln*AGRICPC-HIGH	-0.01	-0.04	0.001	0.01	-0.17	-0.49	-2.28**	-1.32
*ln*FREE-LOW	-0.12	-0.39	0.09	0.35	0.10	0.23	-3.37*	-1.49
*ln*FREE-HIGH	0.02	0.07	0.08	0.33	0.72	1.75	-2.36	-1.04
*ln*FOREX-LOW	0.001	0.01	0.02	0.69	0.47***	7.74	-0.67	-0.45
*ln*FOREX-HIGH	0.01	0.25	0.02	0.50	0.06	0.85	-0.07	-0.25
*ln*POPDENS-LOW	-0.09*	-1.45	-0.12**	-2.09	-0.14*	-1.48	-	-
*ln*POPDENS-HIGH	-0.10*	-1.35	-0.11*	-1.77	-0.23**	-2.13	-	-
*ln*UPOPGRO-LOW	-	-	-	-	-	-	-0.39	-0.65
*ln*UPOPGRO- HIGH	-	-	-	-	-	-	-0.03	-0.05
*ln*PPLAND-LOW	0.16***	2.36	0.16***	2.74	0.15*	1.55	-0.55	-1.17
*ln*PPLAND-HIGH	0.04	0.48	0.05	0.84	-0.03	-0.25	0.55	0.85
*ln*PDLAND-LOW	0.02	0.16	-0.02	-0.17	0.14	0.83	-0.92	-1.14
*ln*PDLAND-HIGH	0.001	-0.03	0.12	1.17	0.24	0.37	-1.38	-1.23
*ln*CLIMATE-LOW	0.64***	2.85	0.49***	2.54	1.61***	5.00	6.81***	3.40
*ln*CLIMATE-HIGH	0.47*	1.42	0.52**	2.02	1.07***	2.43	0.93	0.23
R^2	0.36		0.37		0.57		0.33	
Adjusted R^2	0.25		0.25		0.49		0.14	
Std error	0.66		0.55		0.93		3.71	
F-statistic	3.17***		3.14***		7.26***		1.87*	
N	99		98		98		71	

[a] The dependent variable is the logarithm of number/10,000 sq km.
[b] The dependent variable is the logarithm of the average annual percentage change in the number of known mammal species from 1989 to 1999.
***, **, and, * indicate statistical significance at the 1%, 5% and 10% level, respectively, for a one-tailed test.