# Toward Measuring the Impact of Ecological Disintegrity on Human Health

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Ecological integrity refers to the ability of environmental life-support systems to sustain themselves in the face of human-induced impacts. We used a correlational, aggregate-data study design to explore whether life expectancy, as a general measure of population health, is linked to large-scale declines in ecological integrity. Most of the data were obtained from World Resources Institute publications. Selected surrogate measures of ecological integrity and gross domestic product (GDP) per capita (as a socioeconomic confounder) were modeled, for the first time, using linear regression techniques with life expectancy as the health outcome. We found a modest relation between ecological integrity and life expectancy, but the direction of the association was inconsistent. When GDP per capita was controlled, the relation between ecological integrity and life expectancy was lost. GDP per capita was the overwhelming predictor of health. Any relation between ecological integrity and health may be mediated by socioeconomic factors. The effect of declines in ecological integrity may be cushioned by the exploitation of ecological capital, preventing a direct association between measures of exposure and outcome. In addition, life expectancy may be too insensitive a measure of health impacts related to ecological decline, and more sensitive measures may need to be developed. (Epidemiology 2001;12:28–32)

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Concern over the health effects of diminishing ecological integrity (EI) has arisen alongside the realization that humans are reshaping all regions of the globe and that this change has unknown health consequences. The aim of this study is to link indicators of EI with indicators of population health.

EI has been defined as "the property of coherent wholeness, health, and internal well-being that characterizes intact, adaptive, self-regulating, and self-repairing systems."[1,p.217] Loucks provided a more specific definition of EI: "An ecological system has integrity when it supports and maintains a balanced, integrated, adaptive biological system having the full range of living elements (genes, species, and assemblages) and processes (mutation, demography, biotic interactions, nutrient and energy dynamics, and metapopulation processes) expected in the natural habitat of a region" (O Loucks, JR Karr, P Crabbe, L Westra, WE Rees, C Solskolne. Definition of ecological integrity. Presented at the Global Ecological Integrity Project Workshop, Social Sciences and Humanities Research Council of Canada, 1997, Cortona, Italy. Personal communication). Some functional measures of EI have been developed (for example, the Index of Mean Functional Integrity[3] and the Index of Biological Integrity[4]) but have not yet been sufficiently widely implemented to be of use in this study. Instead, a surrogate of this functional definition called "original integrity" is used to define a prehuman, or at least preagricultural, starting point.[5] Choosing a preagricultural starting point is useful, because we know that this environment was suitable for diverse life forms (including human life) and, owing to the absence of industrial-scale human intervention, it changed slowly on a geologic time scale. Thus, original integrity provides a baseline at which we can assume, with some confidence, that functional EI was the global norm. Given this, we define EI operationally in terms of deviations from original integrity.

Many researchers have provided evidence that EI is rapidly decreasing. McMichael's[6] overview, given its health-based approach, is most useful for the epidemiologist. More recently, the Organization for Economic Cooperation and Development,[7] the World Bank,[8] the

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World Resources Institute,[9,10] and the World Health Organization[11] have recognized the possible human health consequences of decreasing EI. Some authors[12,13] have suggested that humanity has as little as two generations before EI has diminished to the point at which adaptive strategies will not be optional but necessary for survival.

Despite these supposed threats to human health, the classic indicators of human health have been showing improvements for several decades. Concern about present and future possible negative human health impacts from the degradation of environmental life-support systems motivated this study.

Like the present study, the 1998–1999 edition of the biennial World Resources (WR) report[10] focuses on linking environmental change and human health data. Unlike our study, however, no specific framework was specified as a theoretical basis for the choice of indicators. WR provided new indicators that attempt to summarize some of the specific characteristics of the environment (such as air quality and access to clean water). In the present study, we used the EI concept to unify environmental health indicators and transcend the usual piecemeal approach to environmental threats, thereby focusing on broader issues. We hoped that this approach would help to clarify the complex relation between declining EI and improving human health.

Our focus on ecological processes and broader ideas such as EI has been informed by Shy[14] and others.[15–19] They have called for epidemiologists to broaden rather than to narrow the focus of their studies, such as by measuring the effects of larger, system-level characteristics or "exposures" on entire populations. Although this perspective does not free one from concerns about individual health effects, it does provide a rationale for our study of EI as a population health determinant (Sander Greenland, 2000. Ecologic *vs* individual level sources of bias in ecologic estimates of contextual health effects, submitted for publication).

## Subjects and Methods

We used available aggregate data to explore possible relations between life expectancy and the large-scale deterioration of EI. In addition to indicators of EI as exposure metrics, we also considered gross domestic product (GDP) per capita as a surrogate for socioeconomic confounding.

### Data Sources

We abstracted all data from WR 1994–1995,[20] WR 1996–1997,[9] and the associated database diskettes. In total, we included 203 countries in the merged dataset.

### Choice of Ecological Integrity Indicators

We chose several indicators of EI from the World Resources Institute database as proximate measures of EI in all countries for which such measures were available. Unfortunately, there is no standard set of proxies for EI. Therefore, in accordance with the operational definition of EI given above, we chose exposures according to their face validity as measures of ecosystem pristineness. The appropriateness of these variables cannot be objectively quantified. Nevertheless, members of the Global Ecological Integrity Project confirmed our selection (Global Ecological Integrity Project meeting, 1998).

We included the percentage of land highly disturbed by human activity as one of our EI variables. We chose percentage of threatened species (standardized to a 10,000-km$^2$ species-area curve) as a surrogate for biodiversity. Although this measure is admittedly crude, it was the best available variable with global coverage.

It has been recommended that biodiversity could be better preserved by the protection of landscapes than by protecting individual species. Therefore, we also included the percentage of a country's land mass totally or partially protected. Because forests are important ecosystems and forest data are readily available, we included two related forest variables: the percentage of forest remaining since preagricultural times and the average annual change in forest cover.

### Choice of Potential Confounders

We considered that "development" would be an important confounder of any EI-health relation. Because richer countries are healthier than poorer countries, we wanted to isolate the positive influence of development on health from the negative influences of concurrent environmental degradation. Toward this end, we used GDP per capita [standardized by purchasing power parity (PPP) to 1985 international dollars] as a surrogate variable to control for potential socioeconomic confounding. PPP is the number of units of a country's currency required to buy the same amount as $1 would buy in the "average" country.[10] Thus, this variable takes cost of living into account.

### Choice of Health Outcome

Although the aspects of health affected by declining EI can depend on determinants of individual health outcomes, they also depend on determinants of population health outcomes. From this perspective, it is appropriate to explore the association between holistic measures of the state of the environment, namely EI, and aggregate health outcomes of entire populations. Because of the uncertainty surrounding which specific health outcomes are either most relevant or important and because of the unavailability of more sensitive and specific indicators or individual-level data to use in multilevel models, we have made use of a well established indicator of general population health.

One well accepted indicator of the general health status of a population is life expectancy. This measure has at least two major advantages for this study:[21] (1) life expectancies implicitly account for changes in the age structure and therefore do not require age standardization (this is especially useful when dealing with data from developing countries where age strata may not be reliably defined), and (2) life expectancies are longitu-

**TABLE 1. Descriptive Statistics of Variables for Both the Full Dataset and the Final Model Dataset (See Appendix 1 for List of Countries in Final Model)**

| | Full Set | | | | Final Model Set (n = 47) | | |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Range | n | Mean | SD | Range |
| % high disturbance | 40.7 | 31.2 | 0–100 | 135 | 45.8 | 29.5 | 1.39–100 |
| $Log_{10}$(% species threatened) | −1.26 | 0.588 | −2.26–0.233 | 85 | −1.22 | 0.564 | −2.26–0.233 |
| $Log_{10}$(% IUCN IV–V protected) | 0.256 | 0.763 | −2.59–1.50 | 134 | 0.345 | 0.716 | −1.57–1.46 |
| $Log_{10}$(% IUCN I–III protected) | 0.192 | 0.736 | −1.87–1.93 | 145 | 0.327 | 0.720 | −1.86–1.25 |
| % forest remaining | 28.9 | 28.6 | 0–97.4 | 150 | 38.7 | 29.5 | 0–95.7 |
| % annual change in forest | −0.378 | 1.32 | −5.08–7.78 | 136 | −0.632 | 1.13 | −2.82–1.97 |
| $Log_{10}$(GDP per capita) (Int $) | 3.49 | 0.50 | 2.61–4.25 | 91 | 3.54 | 0.423 | 2.70–4.25 |
| Life expectancy (years) | 65.0 | 10.3 | 39.0–79.5 | 176 | 68.0 | 8.31 | 44.9–79.5 |

% high disturbance = percentage of land highly disturbed by human activity; % species threatened = percentage of threatened species; % International Union for the Conservation of Nature IV–V protected = percentage of a country's land mass partially protected; % International Union for the Conservation of Nature I–III protected = percentage of a country's land mass totally protected; % forest remaining = percentage of forest remaining since preagricultural times; % annual change in forest = average annual change in forest cover; Int $ = international dollars.

dinal in nature. That is, on average, they reflect all of the known and unknown factors that have influenced longevity over a lifetime.

In addition to life expectancy, we studied infant mortality and incidence of low birth weight in live newborns, although they are not discussed in this paper (see Sieswerda[22]). Other considerations, besides face validity, in choosing variables included broad global coverage and a collection date in the period 1990–1996.

### Statistical Method

Most of the data analysis was performed using Stata.[23] We examined scatter plots of each of the predictors against life expectancy to determine functional form; in every case, either a transformation was not required or, if needed, a $\log_{10}$ transformation was deemed appropriate.

We conducted multivariate analysis by constructing a causal diagram wherein each group of variables was related to the others using multiple linear regression. The EI variables formed a block, and its relation to life expectancy was determined both with and without GDP per capita in the regression model. We considered only main effects.

## Results

### Descriptive Statistics

Table 1 describes the characteristics of both the full dataset and that of the much reduced set of countries (see Appendix 1) having data for each of the variables in the final model. These countries represent a cross-section of low-, middle-, and high-income economies. This table reveals a surprising concordance between the full dataset and the final model dataset for most variables. Most variables did not differ by more than 5% of their full range. Percentage of forest remaining since preagricultural times differed by approximately 10%, and life expectancy differed by approximately 7%, however.

### Multivariate Analysis: Life Expectancy as Outcome

Because our primary objective was to relate EI and life expectancy, we first regressed our block of EI variables on life expectancy as shown in Model 1 of Table 2. These results show a moderate relation between the block of EI variables (that is, percentage of land highly disturbed by human activity, percentage of threatened species, percentage of a country's land mass partially or totally protected, percentage of forest remaining since preagricultural times, and average annual change in forest cover) and life expectancy. A closer look at the individual variables within Model 1 suggests conflicting hypotheses. Based on the hypothesis that decreasing EI should result in poorer health outcomes, the asterisked coefficients indicate those associations that have a direction opposite that predicted by the hypothesis.

In Model 1, we show the relation between the block of ecological predictors and life expectancy. Analogously, in Model 2 of Table 2, we show the bivariate relation between GDP per capita and life expectancy. This strong relation [regression coefficient = 17.3 years of life expectancy gained per unit $\log_{10}$ (GDP per capita, international dollars)] is well supported in the literature.[24]

Model 3 of Table 2 describes the relation between the block of ecological variables and life expectancy with

**TABLE 2. Coefficients of Three Models Predicting Life Expectancy (n = 47)**

| Variable | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| % high disturbance | 0.127 | | 0.027 |
| % forest remaining | 0.143 | | 0.013 |
| % annual change in forest | 1.16 | | −1.27 |
| $Log_{10}$(% species threatened) | 2.67 | | 0.596 |
| $Log_{10}$(% IUCN I–III protected) | 0.424 | | −0.434 |
| $Log_{10}$(% IUCN IV–V protected) | 1.40 | | −0.618 |
| $Log_{10}$(GDP per capita) (Int $) | | 17.3 | 18.2 |
| Constant | 59.8 | 6.61 | 1.93 |
| $R^2$ | 0.333 | 0.779 | 0.807 |

% high disturbance = percentage of land highly disturbed by human activity; % forest remaining = percentage of forest remaining since preagricultural times; % annual change in forest = average annual change in forest cover; % species threatened = percentage of threatened species; % International Union for the Conservation of Nature I–III protected = percentage of a country's land mass totally protected; % International Union for the Conservation of Nature IV–V protected = percentage of a country's land mass partially protected; Int $ = international dollars.

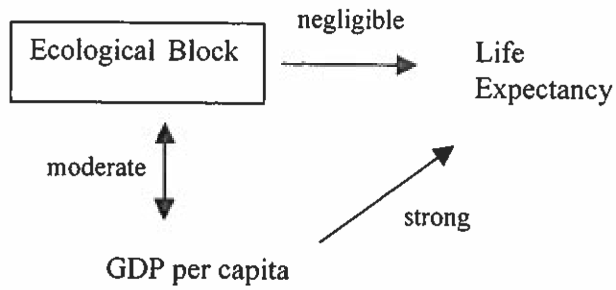


**FIGURE 1.** Causal diagram describing the relationships among the EI variables, GDP per capita, and life expectancy. The relation of the ecological block and GDP per capita is described as moderate because the correlations of all of the variables in the ecological block to GDP per capita are small to moderate in size (not shown). We characterize the relation between GDP per capita and life expectancy as strong because an increase of 1 unit of GDP per capita (international dollars) on a $\log_{10}$ scale leads to an increase in life expectancy of 18.2 years (Table 2, Model 3). The relation between the ecological block and life expectancy in this model is described as negligible because the ecological block has trivially sized coefficients in the prediction of life expectancy (Table 2, Models 1 and 3).

the inclusion of GDP per capita as a confounder in the model. We see that the addition of GDP per capita to the model causes the ecological coefficients to drop very close to zero or to reverse direction.

A diagram summarizing the information from Table 2 is presented in Figure 1. Each arrow represents a linear regression between a predictor and an outcome. To each arrow is attached a description of the strength of the relation.

## Discussion

The apparent relation in Model 1 between our indicators of EI and life expectancy is, in fact, spurious. Once we control for socioeconomic status, as represented by GDP per capita, the relation between EI and life expectancy all but disappears. This change is noteworthy because all of the underlying constructs that the indicators supposedly represent (for example, biodiversity, land protection, and species conservation) are cornerstones of the environmental movement. Nevertheless, rather than hastily concluding that EI has no effect on life expectancy, there may be several explanations for our findings.

First, the relation between declining EI and human health is undoubtedly highly complex and mediated by many interrelated social, political, and economic factors that we were unable to consider. Second, it is likely that our measures of EI are insufficiently representative of the true ecological situation. The concept of EI is relatively new, and measures of EI are still being formulated and are very much in the "trial-and-error" phase.

From a theoretical point of view, one may ask whether we should have attempted to control for confounding by GDP per capita at all. If we are to consider GDP per capita to be a confounder, it has to be causally related to the outcome in question and be unaffected by the other covariates in the model. If the other covariates in the model are causally related to GDP per capita, however, then it may be inappropriate to control for GDP per capita, because if GDP per capita is in the causal pathway, controlling it will adjust away part of the effect under study and may create confounding.[25] It is most likely, however, that there are multiple causal pathways from our covariates to our outcomes. Some pathways probably go through GDP per capita whereas others do not. In this situation, controlling for GDP per capita would reveal the relation directly from the covariates to the outcome, provided we can assume that controlling GDP per capita does not create confounding.

Leaving GDP per capita completely out of the model would render a slope representing a mix of associations, some of which mediate through GDP per capita and some of which do not. An additional complication is that we do not know whether GDP per capita should be in the causal pathway between the other covariates and the outcome or whether the other covariates should be between GDP per capita and the outcome. In fact, there may be complex feedback loops among all of the variables, further complicating the situation.

In this study, we have used all of the countries of the world as our starting point; that is, we have used the entire world population, not a random sample. Instead, the "sample" that we have used is based on whether we had appropriate data available. This sample is not random but rather is likely to reflect conditions such as not having adequate infrastructure to collect data, being in an area too war-ravaged to collect data, or, paradoxically, not being rich enough to collect one's own data but not being poor enough to warrant special attention by United Nations agencies. All of these possibilities are, in turn, potentially in the causal pathways to health.

### General Interpretations

In the case of environmental degradation and, possibly, environmental collapse, it seems inevitable that the current trends in measures of EI are leading us in a dangerous direction. There is overwhelming evidence of diminishing biodiversity,[10,26] profound soil degradation[27,28] and acidification,[10,29] global warming,[30,31] and ozone depletion,[9,10] among other problems. In addition, perhaps the most powerful evidence for any future ecological collapse is from energy and materials throughput analysis. Ecological footprint analysis has revealed that, given current technology, we cannot sustain our current levels of consumption.[32,33] To make matters worse, all indicators suggest that with increasing global population and the economic and technological advancement of the developing world, global consumption is going to increase. In addition, the global economy enables rich and powerful countries to extract resources from anywhere in the world to sustain their consumption habits,[6] meaning that an ecological collapse will not simply be an isolated local event, as it might have been in the past, but rather a global one.[32,33]

We anticipated that there would be a positive association between improving human health and improving EI (or, conversely, diminishing EI would be associated with poorer health). It has become apparent, however, that this outcome would occur only if the local population depended on local resources and had overshot local carrying capacity, (that is, if it were suffering food and resource shortages). In the circumstances of this study, however, many high-income countries attained wealth and health initially by greatly disturbing their own landscapes and then, subsequently, by using their wealth to appropriate the biophysical output of distant lands. Thus, one might hypothesize in a study of this type that rich, healthy populations would inhabit greatly modified landscapes with low EI. Indeed, this hypothesis would be consistent with the present findings. In fact, the present study could be interpreted as showing how technology and trade insulate rich populations from the ill effects of local ecological disintegrity, thus blinding them to their *de facto* continued dependence on EI somewhere else.

Our results suggest that there is a separation of consumption from consequence. At least in the short term, countries are rewarded for environmental destruction with economic growth and ever-improving human health. If, however, the environment were no longer able to sustain an intense level of human activity, human health would surely decline rapidly.

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## Appendix

Countries included in the final regression model are the following: Australia, Austria, Belize, Bolivia, Brazil, Bulgaria, Canada, Chile, China, Colombia, Costa Rica, Dominican Republic, Ecuador, Egypt, El Salvador, Finland, France, Guatemala, Honduras, Hungary, India, Indonesia, Ireland, Japan, Kenya, Madagascar, Malawi, Malaysia, Mexico, The Netherlands, Nigeria, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, South Africa, Sri Lanka, Switzerland, Thailand, Turkey, Uganda, United Kingdom, United States of America, and Venezuela.

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