POPULATION, NATURAL RESOURCES AND ENVIRONMENT

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Summary

Population-environment studies have implicitly permeated demography but only until the mid-20th century has the debate been rekindled and research expanded. This article reviews the origins and history of the population-environment debate and attempts to provide insight into the most recent approaches and methodology. Beginning with the most traditional relationships established between demographic and environmental dynamics, some of the most relevant relations and findings are presented and discussed. This state-of-the-art revision is organized by some dimensions of these dynamics, and is by no means exhaustive. The relationships between population and food availability, land use, water resources, energy and climate change are some of the most visible and studied within this emerging field of study. Some final methodological remarks and suggestions for future research are outlined.

1. Introduction

Human populations have been forced to adapt to biological, economic and social restrictions since the dawn of civilization and have transformed ecosystems to ensure and enhance their survival. The 20th century witnessed two of the most profound social and demographic changes in recorded history. On one hand, population rose from around 1.6 billion in 1900 to over 6 billion in 2000. On the other, the transformation of a considerable portion of natural ecosystems in order to accommodate and supply this population grew accordingly in complexity and magnitude. Studying the relationship among population, resources and the environment has been a challenge taken on by various disciplines due its complexity, but also because of the controversy and implications of the debate. Although population growth has been the most obvious demographic trend in this relationship, urbanization, age and household structure, poverty and migration are but a few of other demographic transformations essential to understanding these interactions.

Biophysical research has established that since the end of the 18th century –but especially since 1950- terrestrial and marine ecosystems have suffered profound transformations. Atmospheric changes have been thoroughly documented as well. The conversion of practically unaltered ecosystems to cropland and the use of new production technologies account for most of the transformation observed in terrestrial ecosystems. In marine environments, excessive fishing is pointed out as a direct driver of recent transformation, while freshwater ecosystems have been profoundly affected by changing water regimes and pollution. Nitrogen and phosphorus application directly related to human activities have generated clear environmental imbalances. Finally, previous and ongoing climate change has been decisively linked to greenhouse gas emissions. Ever-improving data availability and evidence of these changes have brought population-environment studies to the forefront of academic debate, posing a challenge within different disciplines but also among them; it is clear that biophysical sciences and social sciences must work together to better understand the challenges of environmental change and provide environmental- and human-friendly solutions to these problems.

Demography has studied the population-environment relationship since its modern origins, but started treating it as a specific field of study until the late 20th century. The decades following the 1960’s observed an academic boom exploring and discussing this field, increasingly incorporating different demographic and ecological dimensions, spatial and temporal scales and methodological approaches.

Given the predominance of quantitative approaches and the fact that they allow for descriptions, explanations and future projections, these studies can no doubt contribute to reaching sustainable development. Most studies have focused on developing countries mainly due to the relatively higher population growth rates and the diversity of ecosystems found there, as well as the fact that the relationship between the two dimensions is clearer than in developed countries.

2. History of the Debate

Optimum population levels and population growth have been noted and discussed since ancient times. Cuneiform texts dating from 1600 BC already expressed concern about excessive population. Confucius, Plato and Aristotle were known to discuss optimum population in terms of governance, although population growth was widely regarded as a positive trend. Roman and medieval policies that promoted population growth are well documented. By the end of the 17th century, Dutch scientist Antoni van Leeuwenhoek had estimated that the Earth's land surface could support as much as 13.4 billion inhabitants.

Throughout the 18th century, the debate concerning the sustainability of population growth, most notably in terms of food requirements and their supply, was relatively widespread, and several texts discussed the apparent incapacity of the Earth to produce enough means of sustenance for an ever-increasing population.

It was not until Thomas Robert Malthus anonymously published his *First Essay on Population* in 1798 that the debate became well-known and a primary concern for several thinkers. Three elements that may have been crucial at making Malthus' work the best known concerning this subject are: the political-historical context at the time he first published, the simplicity of his premises, and his ability to link it with the terms and debate of an up-and-coming discipline known as political economy. The French Revolution had raised a number of questions and concerns linked to the new relationships between population and the distribution of wealth. Malthus' theory consisted of a simple syllogistic argument: food production grew arithmetically while population grew geometrically, necessarily implying that the Earth's capacity to feed this population would one day reach an end. Population increased when wages were high, but this very increase eventually resulted in a reduction of wage levels. Whenever population grew too large, wages fell below subsistence levels and extreme poverty reduced population size. He later polished this theory to include the possibility of workers restraining themselves from having too many children. Whether it was hunger, vice or family planning, population was kept below a certain level by these positive checks. The most important implications or corollaries of his theory were that of fixed per capita income, fixed land supply (and decreasing marginal productivity of this factor) and little or scarce technological progress.

Studies made in the late 20th century have pointed out that, ironically, the relationships he established among population growth, income, and fertility rates seem to adequately fit data for several centuries, but were beginning to undergo transformations at the very time he wrote and published his ideas. To Malthus' credit, he lucidly pointed out several demographic phenomena that have been retaken by several demographers, namely migration as a resource to avoid positive checks and the influence of gender roles and woman subordination on fertility rates.

Karl Marx and Henry George are probably Malthus' best-known 19th-century critics. Marx mostly criticized the wording and epistemological implications of Malthus' theory, denouncing the fact that poverty and misery were to be interpreted as a lack of employment in the world of capital accumulation rather than an excess of low-income population. Henry George on the other hand, together with many other American thinkers who participated in the debate, pointed out that population was a driving force of economic growth rather than a limitation. Regardless of these and other insightful counterarguments, Malthus' theory and implications thrived at an academic level during a period which, in retrospect, would falsify them; the technological changes and demographic transition that took place in Europe during the end of the 19th century and beginning of the 20th have no doubt proved the specific implications and corollaries of

Malthus' theory wrong.

The decades that followed World War II witnessed an unprecedented decrease in death rates that were not accompanied by a drop in fertility rates in developing countries, in contrast with what had occurred in Europe a century earlier. Late 20^{th}-and early 21^{st}-century concern for environmental degradation and insufficiency of natural resources to provide for an ever-growing population arose in the 1960's mainly as a result of this demographic transition gone awry. While D.O. Duncan's POET model (Population, Organization, Environment and Technology) redefined the conceptual framework of the population-environment debate, most theories that followed tended either to side with Malthusian views or oppose them, and only recently has the debate regained a certain degree of neutrality in that respect that characterized Duncan's ideas.

In *The Conditions of Agricultural Growth*, published in 1965, Danish agricultural economist Ester Boserup proposed a population-environment paradigm radically different from that of Malthus: it was not agricultural production that limited population growth, but population growth and density that pressured agricultural production to increase through technological change. This approach was not only the first coherent academic counter-proposal to Malthus' theory to be taken seriously, but was also highly compatible with neoclassical economics; the latter provided important theoretical underpinnings for an integral Boserupian paradigm, including relative scarcity, prices, markets and incentives for technological progress. In fact, modern development economics would be unthinkable without Boserup's arguments.

The late 1960's and the 1970's, however, witnessed the peak of neo-Malthusianism when American ecologist Paul Ehrlich published *The Population Bomb*, followed by Dennis Meadows' and the Club of Rome's *The Limits to Growth*, which predicted global collapse by 1985 and 2025, respectively. The latter employed a dynamic systems model with positive and negative feedback loops and interactions among five variables: population, food production, natural resources, industrial output and pollution. The model's rigid assumptions and bleak forecast influenced public policy and promoted family planning in developing countries under the leadership of United Nations; the 1974 World Population Conference in Bucharest gave rise to national population councils in several countries aimed at controlling or curbing fertility rates. The demographic community in this context was limited to reporting on population dynamics and projecting possible population growth scenarios that focused on high fertility rates in the developing world. The 1976 World Fertility Survey remains a benchmark in demographic data compilation and research.

A Boserupian backlash soon followed; whereas Ehrlich and Meadows had presented extremely pessimistic forecasts, Herman Kahn and Julian Simon responded with excess optimism, for which they would be dubbed Cornucopians. Kahn *et al*. argued that population growth would progressively decrease and that technological progress would not only allow the Earth to sustain almost 15 billion inhabitants by the 22^{nd} century, but also raise world per capita income to unprecedented levels. Simon published *The Ultimate Resource* in 1981 and is best-known for taking Boserup's thesis to the extreme; population growth increased human ingenuity for solving resource scarcity and also represented a growing market for such solutions.

An alternative perspective inspired mostly by Marxist political economy, and dependency theory, holds that the relationship between population and environment is determined by historical and structural inequalities regarding control, access and use of natural resources among and within countries.

3. Contemporary Approaches

Contemporary research on the population-environment relationship has addressed a wide variety of demographic and ecological topics, and has been dominated by the notion of sustainable development, namely the long-term capacity of meeting the needs of present generations without compromising those of future generations. The most influential demographic factors in this relationship are the population's size, growth, density, structure, distribution, consumption patterns and mobility at different levels of aggregation and different spatial and temporal scales. The main environmental phenomena that interact with these demographic factors are land use cover change, water resources and their availability, energy, climate change and natural or industrial disasters. Most population-environment literature has been concerned with the influence of population over the environment, and only a smaller proportion has paid significant attention to dynamic interactions. Previous reviews have organized literature on the subject following different criteria:

- The dominant theories that have attempted to study each topic (land use cover change, water resources, etc.)
- The main methodological approaches
- The chronological sequence of research topics
- A combination of the above approaches

Considering the diversity of topics, theories, and methodologies employed in this research, their systematization implies arbitrary decisions concerning the dimensions and categories used to organize them, and –as other authors have recognized- most of these categories are not mutually exclusive.

While Malthus' and Boserup's original theories were linear and relatively simple, subsequent research has proposed and delved into more complex relationships.

The environmental Kuznets Curve, for instance, is an empirical relationship from which many valid hypotheses have emerged. It outlines a non-linear relationship between environmental impact and level of development that graphically resembles an inverted U-shape; for low and high levels of development, environmental impact is relatively low, while intermediate levels of development have higher impacts. Most theories that use this concept as empirical support work under the assumption that at high development levels, demand for environmental quality tends to increase, and there are means and a willingness to pay in order to bring it about.

Theoretical and methodological progress –and progressively, data availability- in the social sciences has allowed for different models that best explain population-environment interactions. Below are listed and explained some of the most important or elemental developments used to study these interactions.

The notion of human carrying capacity refers to an ecosystem's capacity to sustain a certain amount of population. Estimates of the Earth's human carrying capacity depend widely on the assumptions made by each model or study and have ranged from 2 billion to 13 billion people in the literature. These exercises are essentially neo-Malthusian and underlie a large portion of population-environment literature.

The concept of ecological footprint consists of transforming a nation's consumption in various categories (grain, meat, energy, etc.) into its equivalent in the land area necessary for supplying this consumption and for absorbing its wastes. It shares an important weakness with other approaches, as it does not consider the relationship among population dynamics, economic development and technology. Its main virtue, however, is its straightforwardness in pointing out the high ecological impact of cities or countries that import resource-intensive products, deceitfully appearing to be low-intensity polluters. Another criticism to this theory is that it may underline economic impact differentials among countries while underscoring said differentials within countries.

The development of statistical and econometric models has allowed studies to not only incorporate correlations, but also improve specific discussions concerning causality, interactions (feedback loops in both ways), uncertainty and non-linearity among studied variables and dynamics, significantly refining forecasting exercises. Data requirements for these methods are particularly difficult to meet in developing countries, particularly when dealing with environmental variables. It is essential to note that, when studying relationships as complex and varying as population-environment interactions, statistical models cannot be relied upon to establish definitive causality. Also, the spatial scale and time span that are studied have important implications for the validity of assumptions and results. Institutional, qualitative and context-based approaches should not be neglected as both an alternative and a complement to quantitative approaches.

IPAT models consist of and receive their name from the equality $I = P \times A \times T$, where I stands for environmental impact, P stands for population, A stands for affluence (output per capita), and T stands for technology (impact per unit of output). The model dates back to a 1970's debate in which Ehrlich took part. It has mainly been used for the study of the impact of population growth on global emissions, but also for studying other environmental factors like energy and fertilizer use. The model's main virtue is its versatility, as replacing or further deconstructing the variables on the right-hand side of the equation is relatively simple. IHAT models, in which population size and growth are replaced by growth in the number and structure of households, have proven useful as well.

STIRPAT models are based on the IPAT model but are essentially different, being stochastic in nature and employing regression analysis. These models borrow heavily from neoclassical production functions and offer an interesting and flexible approach to population-environment studies. However, they should be treated with the same caution as any other regression model. The selection of a functional form is for the most part arbitrary and the assumptions of the model are far-fetched, particularly when dealing with macro-level data. Even if a correct functional form existed and the assumptions of the model were correct, the interpretation of the regression coefficients –the relevant output of said models- remains ambiguous and subject to even more assumptions. STIRPAT models represent the simplest econometric approach to P-E studies, and represent a useful albeit naïve effort to quantify certain dimensions of this relationship.

General equilibrium models are also heavily influenced by neoclassical economics and basically consist of equilibrium situations that, upon exogenous disturbances, reach a different or the same equilibrium as a result of the interaction of its variables. These models can incorporate specific structures and interactions of technology, markets or other institutions. Thus, they allow for endogenizing population growth, technological changes, and economic growth, among other phenomena. The complexity of these models makes the discussion over functional form more specific and the interpretation of regression coefficients more straightforward within a given approach. This very complexity, however, requires very robust and precise data.

Vicious circle models can be viewed as an amalgamation of general equilibrium models in development economics and Garrett Hardin's common goods paradigm. The latter states that, in the absence of clearly defined and enforced usage of common pool resources –firewood, pasture, or fishing resources, for instance-, individual or household decisions will tend to overexploit these resources. These models basically argue that, under certain conditions, high fertility, poverty and environmental degradation are closely linked and can combine into a snowball effect of higher population growth, increasing poverty and an ever-deteriorating environment. Drawing heavily from vicious circle approaches, the PEDA model simulates and explores the interactions among population changes, the environment, socioeconomic development and agriculture, and has been used in diverse contexts, predominantly in Africa. This model's framework is solidly based on neoclassical growth theory and differs from vicious circle models due mainly to the thoroughness in its specification, innovation in its selection of variables and the ambition of its scope. Unfortunately, due to the estimation method and under-identification of coefficients, several far-fetched assumptions must be made in order to reach any conclusions. Results suggest that population policy be accompanied by improvements in education and gender empowerment.

Other dominating tendencies and concepts in population-environment studies include the incorporation of consumption patterns, population aging at different spatial scales and particularly in developed countries, and the reciprocity and multidisciplinarity of the P-E relationship.

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Biographical Sketches

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