Promising Directions and Methods for Population-Environment Analysis

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Abstract

The scientific analysis of the interactions between the human population and its natural environment is highly complex and full of traps. Studies in this field often focus on just one specific mechanism by which population changes impact on environmental changes (or vice versa) in very specific settings. A broad variety of analytical tools, ranging from GIS-based studies over qualitative/anthropological research to computer simulation models, and the fact that these studies need to draw on several scientific disciplines, tend to make such studies less straightforward than the more conventional studies within one discipline. The combination of this analytical complexity with the fact that population-environment interdependencies are often perceived as being of greatest importance for the future makes this field particularly vulnerable to advocacy groups that have another agenda than the scientific one. In this presentation I will try to review the field and summarize the findings of a recent survey of promising methods in population-environment analysis (published as a supplement to *Population and Development Review*, Vol. 28, 2002, edited by W. Lutz, A. Prskawetz, and W. C. Sanderson).

Introduction

No human being can exist without the air to breathe, clean water to drink, other species to supply the food to eat, and an atmosphere that protects from extraterrestrial radiation. These are all aspects of the environment. Increasingly, our natural environment is being altered by human action. Hence, there can be no doubt that population changes and environmental changes influence one another. Within the last few decades, this commonsensical observation has given rise to hundreds of scientific articles and reports, and the flow shows no sign of abating. The premise of this lecture is that this literature forms the groundwork for a new and interdisciplinary field of studies that we call population-environment (P-E) analysis.

Is P-E Analysis a Specific Field of Study?

This paper[2] is built on the premise that P-E analysis is indeed an emerging and distinct field of scientific analysis. What justifies this statement? There seem to be three criteria that in combination justify to call a certain body of research studies a distinct field: (a) a critical mass of people that work on these issues, (b) a set of joint research questions, and (c) a set of common methodologies. For some fields of scientific studies all three criteria are being met; for other fields only the first two. Take Japanese studies as an example of a field that nobody would challenge as being distinct. It clearly has a critical mass of scholars working on Japan and has a common research focus although there is hardly a common methodology. The range of methods applied may include linguistic, geographic, anthropological, and economic approaches. In other fields such as nuclear physics or demography, there is a set of standard methodologies in addition to the critical mass and the common object of analysis. How do these criteria apply to P-E analysis?

(a) Several hundred P-E studies have been published in the formal or gray literature over the past years. It is hard to come up with a precise figure because the bounds of the field are fuzzy and one must largely rely on self-identification of the authors. Another indicator of an emerging critical mass is the fact that in the last decade international population conferences – especially the PAA (Population Association of America) and IUSSP (International Union for the Scientific Study of Population) conferences – have consistently had several sessions on P-E topics on their agendas. Also, funding agencies have launched special calls for P-E studies and one (the MacArthur Population-Consumption-Environment Initiative) has systematically funded case studies in the field for many years. Recently, IIASA (International Institute for Applied Systems Analysis), IUSSP and UNU (United Nations University) launched a Global Science Panel on Population and Environment that largely followed the example of US-NAS panels at the international level and produced high level input on the topic to UN conferences such as the Johannesburg Summit on Sustainable Development. Finally, an increasing number of institutions of higher education offer courses on population and environment as part of their standard curricula. Taken together these developments show that indeed a critical mass has been building up in the field of P-E analysis.

(b) The unifying research question is probably the easiest part in identifying P-E analysis as a field. The field is defined by two rather simple research questions: What are the impacts of changes in the human population on the natural environment (P-E)? and What are the impacts of changes in the natural environment on the human population (E-P)? These research questions – as research questions in any other field of studies – need to be operationalized in a specific context, particularly with respect to the specific environmental aspects considered. But these two rather unambiguous research questions are probably the most powerful unifying element for defining the field.

(c) The range of methods applied for addressing the P-E research question is still heterogeneous. There is no standard methodology that defines the field and there probably will not be a broadly accepted standard in the near future. This paper attempts to address the issue of methods in P-E analysis. Hopefully it will contribute to greater clarity and compatibility of future P-E studies. It does not attempt to establish a standard set of methods, but the two recommendations discussed later on, namely the need to be explicit about both the P and the E dynamics and to be specific about which mediating mechanism one addresses, seem to be necessary next steps in order to make sure that different studies in the field can be meaningfully related to each other.

Conceptual Framework for P-E Analysis

Fields of study are defined by philosophy as well as methodology. The discussion of P-E methodology in this paper is based on the broader view of the subject matter, or what might be called a P-E analysis philosophy. For clarity, it is useful to state the conceptual positions clearly before proceeding.

In the presentation of conceptual models in the P-E field, one typically finds different boxes connected by arrows. Hence the typical approach, which is also behind the linear identity equation known as the I=PAT or Ehrlich-Holdren identity (see discussion in O'Neill et al. 2001), shows population as a box impacting on the environment (another box). There are several other conceptualizations that directly or indirectly link population and the environment considering various kinds of intermediating processes (see, e.g., Bilsborrow and

Okoth-Ogendo 1992; Bilsborrow and Carr 2000; Jolly 1993; Marquette and Bilsborrow 1999; Cohen 1995). Here we will not review any of these approaches in detail but instead go to a still more general level in which the human population is not seen as something outside nature (a separate box) but just as one distinct species on this planet in which we happen to have a special interest because we belong to it.

It seems very strange to think of the human population and the natural environment as two independent autonomous systems. One cannot draw a line around nature and see the human population as outside this line. Nothing is independent of the environment, including the human species, which is part of nature and in all basic life-supporting functions depends on the environment. Rather than viewing population-environment linkages in terms of a linear causal chain of separate boxes, it should be visualized as a series of concentric circles where the inner circles are fully embedded in the broader ones.

My view is presented in Figure 1. In the innermost circle we have the human population classified by individual characteristics, such as age, sex, location, education, and other socioeconomic characteristics. We call the next larger circle the human-made environment. It includes a wide variety of items from infrastructure, the economy, the government, policies, social structures, traditions and history, technology, and information. The outermost area contains the natural environment and it includes everything from the levels of tropospheric and stratospheric ozone, to biodiversity, to the availability of solid waste dumpsites, and the accessibility of beautiful mountain views. In order to deal with it in a systematic manner, it can be classified into broad categories having to do with air, water, land and other species on this planet.

Figure 1 emphasizes that every life on earth, every economic activity, and every kind of development is embedded in the laws of nature. In this sense, the environment is not only seen as a constraint, but also as the basic life-support system that makes all human activities possible. It is simply impossible to think of any human activity as being independent of the physical environment; changes in this environment impact on humans.

Within the sphere of the human-made environment, people are the agents. They are the ones who conduct the activities, develop routines, traditions, cultures, knowledge, and infrastructure, and change the natural environment. People are the victims of environmental degradation with the vulnerability to such change being mediated through the human-made environment. There is no doubt that human life is dependent on certain forms of social and economic activities, and that further development of these activities makes a better and longer life on earth possible for more people. This is why the population is fully embedded in the circle of human-made environment, which comprises social and economic activities. There is no human population without production and consumption.

At the center of Figure 1, we have placed the human population classified by individual characteristics. Traditional demographic analysis focuses on the age- and gender-distribution of the population. We believe that, in most contexts, educational attainment and location (such as rural/urban place of residence) should be added to that list as important characteristics of the population. Interactions between the human population and the natural environment go in both ways and in both cases the impacts are mediated through human-made infrastructure, development and institutions.

A P-E study can either try to analyze the salient features of the full environmental circle – as has been done in the comprehensive PDE studies described in Lutz et al. 2002b – or can be represented as a slice (see, e.g., the sector focusing on population and water in Figure 1) of the concentric circles that contains elements both of P and E. Naturally, every such slice linking P with a specific aspect of E will contain elements from the human-made environment as well.

Dimensions of P-E Analysis

P-E analysis may be thought of as a chair with four legs: (1) P (population dynamics), (2) E (environmental dynamics), (3) influences of P on E, and (4) influences of E on P. All four aspects can be studied scientifically either in separation or jointly. A full P-E study should consider all four aspects jointly especially if it is intended to be a comprehensive study. But even if the study only focuses on a certain slice in Figure 1 and even if it only looks at one direction of the influence, it is still preferable to be explicit about both the dynamics of P and the specific dynamics (e.g., hydrology) of the aspect of E studied, as will be discussed later. So far the overwhelming majority of P-E studies has focused on one of the four legs, namely (3) the influence of P on E. This is clearly legitimate and useful for a better understanding of specific mediating mechanisms as long as it is seen as part of the bigger picture of multi-dimensional P-E interactions. Many of the contributions in a recent PDR supplement (Lutz et al. 2002a) focus on this most prominent and most popular aspect (3), while others go beyond this and propose different ways to link this aspect to the other three legs of the chair. In the following sections, special reference will be made to the contributions in this PDR supplement (Lutz et al. 2002a).

Population dynamics

In classical demography, populations are disaggregated by age and sex. The cohort-component model of population projections is the appropriate way to describe the population dynamics by age and sex. It is possible and interesting to go beyond this in a number of ways. One possibility is to aggregate populations into households as in O'Neill and Chen (2002). As O'Neill et al. (2001) and O'Neill and Chen (2002) show, it makes a difference to emissions forecasts, whether people or households are used in forecasting. Another way to go is to further subdivide the population by other dimensions such as rural/urban place of residence, education, ethnicity, labor force participation, etc. To use education as a dimension of desegregation is particularly relevant because educational attainment has important effects on fertility, mortality, and migration and plays a role in population-environment interactions.

Many P-E studies tend to view population only in terms of total size or in static terms, i.e., as a given distribution. Others tend to study it only in terms of one of its components of change, e.g., only look at the number of in-migrants without considering natural population dynamics. All these approaches do not capture the full dynamics of P, which – as most demographers tend to believe – should at least include the full dynamics of the age and sex structure over time and if possible even additional dimensions. There are easily available demographic tools for doing this.

Location

Much of the work in P-E is preoccupied with the question of location and the spatial distribution of the human population. Since location is not static and many people are on the move, this typically involves efforts at understanding the dynamics of migration and how it is affected by environmental conditions and how it affects environmental conditions. There are countless studies on the interactions between migration, land use and natural resource consumption (Marquette and Bilsborrow 1999). Cramer (2002) and Curran (2002) discuss steps in this direction of studying P-E interactions along the location dimension. Curran makes it clear that, for some problems, we have to understand not only the number of people who are living in each area, but also the migration status of those people. It would be a challenge to incorporate concepts like social capital and social embeddedness into the familiar cohort component framework.

Environmental dynamics

Like population, the environment has dynamics of its own. As discussed above, the kind of environmental dynamics described will depend on the specific aspect of the natural environment to be considered, i.e., the slice to be chosen from Figure 1. One important distinction to make in dealing with the environment is the difference between stocks and flows. Usually, the environment is thought of as a stock, while human effects over some period of time are the flow. For example, the emission of greenhouse gases during a particular period is a flow, while the climate at a certain date is considered a stock that is influenced by that flow. Many other things, of course, influence the stock as well. In Chu and Yu (2002), the cutting down of the rainforest is the flow and biodiversity (which decreases with the loss of rainforest area) is the stock.

There are exceptions to the rule that we should be clear about in the distinction between flows and stocks. Transitory air pollution is an example where the flow and the stock are the same thing. Many studies of tropospheric air pollution, such as Cramer (2002), fall into this category. As with population dynamics it is important to adequately choose the time scale of describing the environmental dynamics in trying to capture the P-E interactions.

Interactions and feedbacks

The interactions and feedbacks between the various elements of a P-E analysis are crucial to our understanding. Some P-E analyses deal with causation in one direction, either from population to the environment, or from the environment to the population. Others allow causation to run in both directions. Where there is bi-directional causation, there can be negative or positive feedback loops. Negative feedback loops cause perturbations to be dampened and die out. Positive feedback loops cause perturbations to be reinforced. In this case, small initial changes can lead to large induced effects. Cramer (2002) gives an example of an analysis with a negative feedback loop. Other things equal, larger populations generate more pollution and the greater the level of pollution, the lower the rate of population growth.

P-E analyses sometimes produce nonlinear dynamic systems. In addition to generating positive and negative feedback loops, these systems produce a number of interesting phenomena that have clear counterparts in the world. The closer integration of the theory of

nonlinear dynamic systems and P-E analysis could have a big payoff. The small PEDA model in Lutz et al. (2002c) is an example of this (see also Milik et al. 1996; Gröller et al. 1996; Gragnani et al. 1998).

Spatial scale

Scale enters P-E analyses in four different ways: (1) spatial scale, (2) temporal scale, (3) scale of the analysis, and (4) the relationship between the scale of human activities and their environmental consequences. We distinguish three levels of spatial scale, the global level, the meso (national or regional) level, and the local level. P-E analyses are being conducted at all three scales which should be seen as complementary rather than alternatives. O'Neill and Chen (2002) discuss carbon dioxide emissions at both the global and meso (national) levels. Curran (2002) deals with P-E analysis on a local level. In the future, we might see the development of new methods that include interactions across spatial scales.

Linking studies conducted at different scales is a key challenge to the field because only through this linkage can we get a full picture of the nature of P-E interactions. There are forces operating across spatial scales in both directions: individual and community level behavior accumulates to national and even global impacts; on the other hand, global changes such as climate change will affect the lives of communities and individuals. The meso, i.e., national, level plays a key role in this process because this is the level at which many of the institutional, economic, and political mechanisms operate.

Temporal scale

Temporal scale is another important dimension of P-E analyses. Where there are no feedbacks from the environment to fertility and mortality, and migration is unimportant, population sizes and age structures can be forecasted quite accurately for around twenty years because most of the deaths in the forecast period will be of people who are alive at the starting date, and most of the births will be to mothers who are alive at the starting date. As the duration of the forecast increases beyond twenty years, the range of plausible outcomes increases substantially. Significant migration or feedbacks to fertility and mortality add uncertainty to forecasts even twenty years ahead. Where possible, population forecasts should include some measure of their uncertainty and the increase of uncertainty over time.

To understand environmental change, we sometimes need to view time differently. There is such significant short-run variation in questions having to do with rainfall and drought that they are best considered on a monthly or weekly basis. One month with no water to drink or with serious floods can have an important effect on a population, even if the average water supply for the year is normal. The climate of a place, which affects its rainfall and drought patterns, normally changes slowly. A twenty-year forecast might reveal only the beginning of what ultimately could be substantial climate change. The interaction of time scales is an important phenomenon. Sometimes population change and environmental change occur at very different speeds. The mathematical approach called "geometric singular perturbation theory" can be applied to study such systems whose variables change with very different velocities, i.e., systems that exhibit slow-fast dynamics (see for example, Milik and Prskawetz 1996; Milik et al. 1996).

Feedbacks are also affected by both the time horizons and the time scales of the dynamics considered. Therefore, the time horizon of the analysis and the temporal scale should be related. The specific choice will depend on the nature of the question; there may be tradeoffs because it may be practically difficult to consider 200 years (an appropriate time horizon for climate feedbacks) in monthly steps (an appropriate scale for floods and droughts).

Analytical complexity

Another important question for P-E methodology is the scale or better the complexity of the P-E analysis itself. Some P-E models, such as Targets (Alcamo et al. 1998), contain many thousands of equations. Others such as the reduced PEDA model contain only three equations. A special issue of the journal *Mathematical Population Studies* (Rogers 1995) was devoted to answering the question of whether simple or complex population models produced better forecasts. The answer was that the complexity of the tool that was best depended on the details of the problem.

Lutz et al. (2002c) signals a direction in which future research could be fruitful. They ask whether small models and larger models could complement one another in deepening the understanding of P-E interactions, and they demonstrate such a complimentarity. In the future, we may think of P-E studies as producing not a single model, but a set of consistent models at different scales each of which allows us to see clearly different aspects of the underlying P-E reality. Simple models isolate and more clearly illustrate key dynamics, whereas complex models have greater realism, include more control (policy) variables and can explore more potential feedbacks.

Scale of human activities and environmental abundance

Still another sense in which scale is used in P-E studies is in terms of the relationship between human activities and the ability of the environment to support those activities on a sustainable basis. Scale, in this sense, requires the definition of constraints. The contents of the PDR supplement (Lutz et al. 2002a) are very different from what they would have been had it been written two or three decades earlier. Previously, there was concern that humans would run out of raw materials. Various studies warned us of how many years it would be before we ran out of oil, iron ore, and copper. The constraints that people saw were constraints of raw material availability.

Today, we do not worry very much about these non-renewable resources. Generally, they are priced and allocated well enough by markets. These markets look well into the future. Expected future shortages are signaled by increases in price, which have the effect of reducing contemporaneous demand and increasing the incentive to search for more supply and for substitutes.

Markets and institutions

We see the most important P-E problems of the future as those for which markets do not exist or where they function poorly. Cramer (2002) concerns local air pollution. O'Neill and Chen (2002) deal with energy use and CO_2 emissions. Chu and Yu (2002) deal with biodiversity,

and Curran (2002) deals with common property coastal ecosystems. These four contributions in the PDR supplement (Lutz et al. 2002a) deal with cases in which markets do not exist. This is not to say that governments cannot use economic tools to help solve environmental problems in those areas; they certainly can. But social control through governments or other institutional arrangements is the basis for maintaining environmental systems, where markets do not exist.

Where markets do not exist, it is not simply a matter of producing pseudo-markets by putting valuations on non-priced portions of the environment. Smil (2002) argues cogently that such an approach is doomed to failure. Smil argues that valuation of non-priced renewable resources must result from a social process. Further research could focus on the nature of that social process and how it relates to the social control of the environment.

The constraints of renewable resources are mediated through institutions. McNicoll (2002) discusses the importance of these institutional arrangements in P-E analyses. McNicoll suggests that we think about institutional arrangements in terms of how they define P-E systems boundaries, monitor environmental change, and value the outcomes of policy interventions. Each of these could be an interesting area of research in its own right.

Normative versus positive approaches

P-E analyses can have normative and positive aspects. The normative aspect of a P-E analysis is the portion that discusses how things should be. The positive aspect of a P-E study is the discussion of the way things are or will be, under certain circumstances. Normative aspects of P-E studies have generated much heated and inconclusive debate. Sustainable development is an often used normative concept, but its common definition, meeting the needs of the current generation without jeopardizing the ability of future generations to meet their needs, has not lead to a generally accepted empirical formulation. Economists often use the normative concept of maximizing the discounted value of current and future utilities. This has lead to an unresolved debate on whether discounting is appropriate and what the correct discount rate should be. McNicoll (2002) and Chu and Yu (2002) comment on the difficulties of finding a suitable normative criterion. An important item on the agenda of P-E research is the formulation of such a criterion.

More generally, it can be observed that the P-E field still suffers in terms of its scientific rigor from the fact that many authors enter it with a pre-defined normative goal and often use rather simplistic methods to “scientifically” argue that point. Here a clear distinction between positive approaches and explicitly stated normative criteria would be helpful. We will never reach a perfect separation between normative and positive aspects since any choice of categories and variables depends on implicit preconceptions, but certainly further progress toward clearer distinctions can be made.

Vulnerability

An important field for future research is the mortality and morbidity consequences of environmental conditions. Urban air and water pollution can affect health and longevity. Global climate change can alter the areas in which malaria-carrying mosquitoes can thrive and therefore affect death rates from malaria. Work on global health changes due to human

induced alterations in climate have been studied in some large P-E models such as the Targets model (see Alcamo et al. 1998).

McNicoll (2002) suggests the approach of disaggregating populations according to whether they are gainers or losers from some environmental policy or condition. Climate change is an interesting illustration of this. Recent work (Fischer et al. 2001) shows that, on balance, agriculture will be helped in some of the richer countries of the world and harmed in some of the poorest. The research on population and emissions discussed in O'Neill and Chen (2002) can be combined with the winner/loser disaggregation suggested by McNicoll (2002) to provide a more complete picture.

An important motivation for studying P-E interactions is to find ways of alleviating poverty, yet poverty has often been overlooked in these studies. The PEDA model of Lutz and Scherbov (2000) and Lutz et al. (2002c) point us in that direction. The large and small PEDA models explicitly consider the inequality in the distribution of food. One dimension along which P-E methodology could develop is to develop further ways of considering such distributional questions.

Uncertainty

The methodology of P-E analysis could be broadened to consider uncertainty more explicitly. Recently, steps have been taken in this direction for P through the use of stochastic population forecasting (see Lutz et al. 2001; Lee 1999; Lutz et al. 1999b). The Intergovernmental Panel on Climate Change assessment (Nakićenović et al. 2000) develops one way of considering uncertainty in P-E analysis. Instead of formulating a probabilistic analysis, it proposes a set of internally consistent storylines (dynamic scenarios) in which both population and CO_2 emissions (and therefore climate) change. Incorporating uncertainty explicitly into P-E analyses is an important step in developing P-E methodology.

In the future, it could be productive to enrich our understanding of P-E and E-P interactions by including concepts from ecology such as surprise, resilience, adaptability, and adaptive management. The concept of surprise is related to the concept of uncertainty, but different. We can be surprised about single elements of P-E systems. Vulnerability, resilience, adaptability, and adaptive management, on the other hand, are best applied to entire P-E systems.

Advancing the Field of P-E Analysis

The state of the art in P-E analysis is both reassuring and disappointing. It is impressive to see how the field has evolved over the past 10–15 years from methods that tended to be chosen on a rather ad hoc basis – depending largely on what the authors happened to be familiar with – to more rigorous considerations about the appropriateness of specific methods for the chosen research questions. For many studies the concern about the substantive questions and especially the fear about man-made environmental degradation tend to be so dominating that methodological questions seem to be detail of secondary importance. Unfortunately, however, the substantive findings crucially depend on the methods chosen. Some recent contributions to the field impressively show that this has started to change, and systematic considerations of the question of appropriate methods increasingly receive the necessary attention.

On the other hand, we are still far from a matured set of standard methodologies that characterize many other fields of research. The methods presented here still show a high degree of heterogeneity. Methodological plurality is not necessarily a problem; it can even be a virtue if, in the end, there is a way to relate to each other the findings derived from applying different approaches. Without a bigger context, differing results from different methods only lead to a maze or puzzle.

I will try to summarize what we have learned by working through these methods and alternative approaches and present some criteria and proposals that could contribute to a further methodological consolidation of the P-E field of analysis.

Criteria that future P-E studies should try to meet

Criterion 1: Be explicit about both the P and the E dynamics.

When you set out to study the interactions between population and the environment, it would seem obvious that you should explicitly include both population and environment variables and their dynamics of change over time in your analytical model. Yet a large majority of studies that call themselves P-E studies is neither explicit about population dynamics nor about environmental dynamics.

This is surprising given the fact that unambiguous and easily accessible models of population dynamics exist in demography. The same is true for the dynamics of many key environmental variables, where the methods for describing the dynamics of the natural environment depend on the aspects of the environment concerned (water, air, land, etc.). Hence, let's assume a more precise research question of how population (P) interacts with fresh water availability (W as one aspect of E) on a certain island (to exclude natural imports of water). The most straightforward way to address this question seems to be to describe the population (P) in terms of the demography (changes by age and sex as driven by fertility, mortality and migration) and the fresh water system (W) in terms of the hydrological dynamics (precipitation, evapotranspiration, discharge, groundwater, etc) and then try to identify and quantify links between the two systems. Links between P and W certainly exist because the population cannot survive without water. W on the other hand can well exist without P but the water dynamics may be significantly altered by the activities of the human population. Hence, there are impacts going in both directions with changes in P affecting W and changes in W affecting P. The task of P-E analysis now is to pin down all relevant effects from P to W and from W to P. This cannot be meaningfully done without simultaneously capturing the most important features of the specific local systems of population and water dynamics because otherwise one cannot link the two. To manage this, one might expect that such a study should at least include a demographer and a hydrologist (or in rare cases one person who manages to be both). In addition there can be a cultural anthropologist, economist or whatever special skills are needed to understand the ways and mechanisms through which P and W interact.

This seemingly straightforward approach to addressing a clear question is not what seems to happen in the vast majority of P-E studies. Very few studies explicitly consider the population dynamics and the environmental dynamics whose interactions they want to study. Only very few study teams include demographers and natural scientists in addition to anthropologists and economists (who seem to constitute the bulk of authors in the field). Why is this the case?

One answer to this question may lie in the fact that many researchers turn their attention immediately to some of the processes and mechanisms that mediate between population dynamics and environmental dynamics. These mechanisms may indeed be highly complex and require the full attention of research teams. But is it meaningful to study certain mediating mechanisms without giving explicit attention to the dynamics of the phenomena P and E that shall be linked? This could only be justified if the researchers were reasonably certain that over the time horizon considered, P and E do not change in any significant manner or at least not in a way that should influence the mediating mechanisms, e.g., the change in the population size and structure being insignificant as a driving force for certain land use changes (L) as compared to the change of social institutions (SI) like land tenure systems. Such an approach, however, no longer qualifies for a genuine P-E study, or P-L study in this specific example, but instead reduces it to a SI-L study, which does not explicitly address the impacts of changes in P via SI on L.

Another more prosaic reason for the frequent neglect of explicit consideration of P and E dynamics in what is still called P-E analysis is the fact that it is quite difficult to put together truly interdisciplinary research teams that are up to the state of the art in demography, environmental modeling and the various qualitative and quantitative approaches used to comprehensively and adequately study the complex mediating processes. Even if one manages to put together such a research team (there are not many individuals who can cover this broad field of expertise) the well-known problems of communication across disciplines, especially when spanning the natural and social sciences, can present a formidable problem and tends to make such teams less efficient in terms of output than purely mono-disciplinary efforts.

In the early phases of establishing a new field of studies, however, such partial approaches and experimenting with alternative methodologies can serve the important purpose of preparing the grounds for more systematic and more comprehensive P-E study designs. At the current stage of the field, however, we see no reason why studies that focus on important P-E mediating mechanisms should not also explicitly address population dynamics and the natural science dynamics of the specific environmental phenomenon studied. Clear and easy to use methods exist for capturing these dynamics and one can only win by including them in the study design. By doing so the often very strong assumption that, e.g., the dynamics of population change by age and sex is only of minor importance for the phenomenon studied, can be replaced by the precise description of what change in the population (by age and sex) has what kinds of impacts on the mediating mechanisms. If these impacts turn out to be very small, then this is at least scientifically documented and explicit (and deserves the title P-E study). If these impacts turn out to be significant, then any study without considering them would be wrong and misleading. In both cases the quality and relevance of the study can only improve.

Criterion 2: Be explicit about the specific mediating mechanisms between P and the aspect of E that you choose to address.

Figure 1 presented the relationship between P and E in the form of concentric circles. Between the characteristics of the population at the center and the specific features of the natural environment on the outside there is a sphere of the human-made infrastructure that is called development. This sphere includes all the mechanisms that human populations have built by interacting with the natural environment, ranging from forms of social organization to culture and the building of a knowledge base to physical infrastructure such as bridges, dams

and factories. No P-E study can possibly do justice to all these mediating mechanisms and cover them all in significant analytical depths. Instead, Criterion 2 suggests that as a minimum, future P-E studies should be (a) very explicit about which aspect of the natural environment they study with respect to its interaction with population (i.e., which sector of the circle of environmental issues as shown in Figure 1), and (b) for a given environmental variable, which specific mechanisms of interactions with the human population are being studied.

It is meaningful to single out specific mechanisms and investigate them in greater depth, even if they are not assumed to be the dominant or most visible mediating forces between population and the environmental aspect chosen. A series of studies focusing on different mechanisms can then contribute to better understanding of the full set of mediating forces. A basic prerequisite for this to be a successful strategy is, however, to be precise in describing the chosen mechanism and be explicit about which kinds of interactions it is supposed to cover and which ones it will not cover. An absence of such precision and explicit definition of the research focus in P-E studies contributes to confusion and does not help to advance the field. It therefore seems to be a reasonable minimum standard for future studies that should help to advance our understanding of P-E interactions. Such studies become even more useful if this precision is complemented by an analysis of the broader context as suggested by the following criterion.

Criterion 3: View the specific P-E question chosen in the broader context of all relevant interactions between a given population and its natural environment.

Unlike the first and second criteria, this third one is not considered an absolutely necessary precondition for a useful P-E study. Meeting this criterion, however, significantly improves the value of the study in terms of advancing the field and improving our understanding of the complex P-E interactions. In a nutshell, the main point of this criterion is "to see the wood in addition to the trees." An in-depth analysis of one specific mediating mechanism becomes much more meaningful if it is viewed in relation to other important mechanisms at work. Only if we know what else is operating can we assign the specific mechanism its proper place.

How can such a holistic picture of all relevant mechanisms be gained? There is no recipe but there are several strategies for making progress toward this goal. Typically this level of analysis is based more on qualitative understanding than on formal modeling. It may involve communication with various stakeholders, with policy makers and with "average people," discussions with scientists who are either very involved in the study of the specific region or those who are very distant and express independent views. Special efforts should be made to talk to people who have dissenting non-conformist views; their arguments should be carefully evaluated. Taken together these different pieces of information can provide a more comprehensive picture of the most relevant factors that shape the interaction of the human population in a given region with its natural environment.

A proposed way of capturing population dynamics as a common element of P-E studies

In the following we propose a way of capturing the most important elements of population dynamics. This can be seen as a practical proposal of how to meet Criterion 1 at least on the side of P. The aim is to contribute the essence of state of the art demographic analysis in a clear and accessible way to P-E analysis. It is primarily based on age and sex, the two basic

population dimensions that most demographers would like to see included. It also allows for the inclusion of other key dimensions such as level of education, rural/urban place of residence, ethnicity or labor force participation. It comes with easy to use software and data that should be available at least for most macro- and meso-level studies. It is therefore proposed to use this structure as a common element capturing the dynamics of the P variable in future P-E studies.

The demographic model of population dynamics as discussed here structures the population of any given (geographical) unit of analysis by age and sex. Over time the population can only change through the three components fertility, mortality, and migration. The tool to describe the change of the population size and structure over time is the so-called "cohort-component model" that is the basis of any standard population projection software. In addition to the basic dimensions age and sex, it is proposed to subdivide the population into educational categories and possible further dimensions such as rural/urban place of residence, labor force participation, ethnicity or other aspects considered central to the specific analysis. But as discussed below, only education is proposed as an additional standard dimension for the P-E population module. The multi-state population projection tools for capturing the population dynamics by age, sex, and education (plus possible other dimensions) are slightly more complex than the standard cohort-component methods, because there are education-specific fertility, mortality, and migration rates plus educational transition rates. However, easy to use software is freely available.

The explicit consideration of age and sex in the analysis of population dynamics is standard because they represent important sources of heterogeneity that significantly influence the dynamics. For example, the momentum of population growth can only be understood and modeled when the age structure of the population is considered. Sex composition by age is essential for determining the fertility level. It is also very relevant for mortality rates because male and female mortality patterns tend to be quite different. Migration tends to vary strongly with both age and sex. For these reasons age and sex would be the absolute minimum that a demographer could accept in a population module. However, the literature of demo-economic and other modeling that aims at studying the consequences of population trends is full of examples of models that consider only total population size and the crude birth and death rates, i.e., the number of births and deaths per thousand persons in the population. Most of the hundreds of P-E studies conducted so far do not consistently consider the full age and sex structure of the population. Because these models do not consider the effect of the age structure on the birth rate (that is independent of the number of children per woman) or on migration and death rates, their findings are sometimes greatly misleading.

Education is not a demographic variable in the strict sense but it is a population characteristic that is increasingly considered one of the most relevant aspects for not only fertility, mortality, and migration, but also for economic productivity, technological change, and more generally empowerment and the ability to cope with changing conditions. There is an enormous amount of literature indicating that education is one of the most important, if not the single most important, covariate of demographic behavior. Education seems to be one of the key variables in a broader understanding of development as a change from a rather fatalistic attitude toward life to more rational planning. There is much evidence for this on both the micro- and macro levels. Generally, better education leads to lower fertility, lower mortality, higher migration, higher empowerment, and higher productivity.

Education appears to play an equally important role with regard to the effects of population composition on economic and socioeconomic development in general. Again and again, studies show that the skills of the population – and of the labor force in particular – are a major determinant of progress in virtually every field. Better education is clearly a key ingredient of social development and higher productivity. A recent study on population and climate change (O'Neill et al. 2001) looks at education in the context of the ability of populations to adapt to changing environmental conditions. It turns out that skills for developing coping strategies which are closely linked to education are key for coping with possible negative effects of environmental change on human health and quality of life.

The measurement of education is less straightforward than the measurement of age and sex. There are two main criteria for the distinction between educational groups: by reading and writing skills (literacy), or by years of formal education completed. The usefulness of the two approaches depends on the status of the specific population in the process of social development. In an industrialized society, where almost everybody can read and write, the distinction by formal education is much more useful, whereas in a country with large proportions still illiterate, reading and writing skills are the most important criteria.

Lutz et al. (1999a) discuss whether education should be added to age and sex even in standard population projections. It can be nicely handled with demographic methods (changes along cohort lines), and tends to be an important source of heterogeneity that may significantly impact on population dynamics. Lutz and Goujon (2001) apply these methods to forecast the future educational composition of the world's population. Similar to population growth, educational improvement has a great momentum. Efforts in improving school enrolment of children only shows up in the educational composition of the adult population decades later.

The structure chosen for the proposed minimum version of the model dealing with population dynamics to be included as a common element in P-E studies is given in Figure 2. The first state includes all children and the total population in school or university. All newborns start in this category. When leaving school they go to the population group with some primary education or some secondary education or some tertiary education. The age- and sex-specific rates at which men and women move from one group into the next are based on empirical data for the starting year and subject to scenario specifications for all years thereafter. Multiple transitions within one time period – which is usually five years – are possible. For instance, someone may leave school, enter the group with secondary education and later move on to tertiary education. Within each group women have children according to the schedule of age-specific fertility rates, which can be defined separately for each group and which may change over time according to scenario specifications. Newborns do not enter the group of their mother but start at age zero in the group of children and students.

In addition to the possible transition to another group – where the model is hierarchical in the sense that men and women can only move to higher educational groups – people can leave the states by either emigration or death. People may also enter the states by immigration. Age- and sex-specific death rates can be defined separately for each group. Because of the lack of empirical information on differentials in these rates, and the fact that they mostly affect the oldest age groups one often assumes identical mortality rates in all states. Migration is specified in terms of absolute numbers and assumed to differ substantially with educational groups, with the most educated showing the highest mobility.

Such a straightforward model of population dynamics can be applied to reconstruct past population trends or to forecast future trends. It might also be used as a population projection tool in its own right but its input and output parameters can be nicely linked to other sectors of analysis describing the genuine environmental dynamics by whatever complex mediating processes one chooses to apply. These mediating processes can be full blown economic models, specific partial pathways of causation, considerations about institutional structures and responses and many of the mechanisms described elsewhere in the literature.

Conclusions

It is important to note that P-E analysis is not just one field of studies: it is a particularly important field of studies. Unlike medieval numismatics – a well established field – P-E analysis addresses some of the key questions for future human wellbeing on this planet. Since the human population cannot exist without basic life support systems and environmental services secured, ignorance about the nature of P-E interactions may destroy the functioning of these support systems and lead to a reduction in population size through the unpleasant mechanism of increasing mortality. It therefore is not just intellectual curiosity that leads to the development of this field but an imperative in securing our future wellbeing. Shying away from the field because of its inherent complexity – as practiced by many demographer colleagues – is not a solution. As one distinguished demographer said when the IUSSP Council discussed possible P-E activities in 1998: "My mother tells me that this is the most important issue that we should study, but I do not know what to do about it." I hope that the scientific work produced in the meantime has given some demographer colleagues a better idea of what can be done about it.

Finally, quasi as a postscript, a word of caution. The field of P-E analysis has suffered in its scientific credibility by the fact that it is rich in contributions in which experts go beyond their field of expertise and make statements that lack the scientific scrutiny that they are used to applying within their own field. There seems to be an unfortunate tendency in highly controversial and even ideological fields such as P-E analysis – where by the very nature of the research question several of the traditional disciplines are involved – to not apply the same scientific standards to all aspects of the analysis. No one person can be an expert in all fields relevant for P-E analysis. The solution should not be to fill the gaps in personal expertise with personal conjectures. Instead, one should link up with other experts who have the necessary science-based expertise on those issues. Interdisciplinary analysis is very different from non-disciplinary or even un-disciplined analysis. Applying rigorous scientific standards in all parts of such analyses requires significant efforts, and the importance of P-E analysis deserves such efforts.

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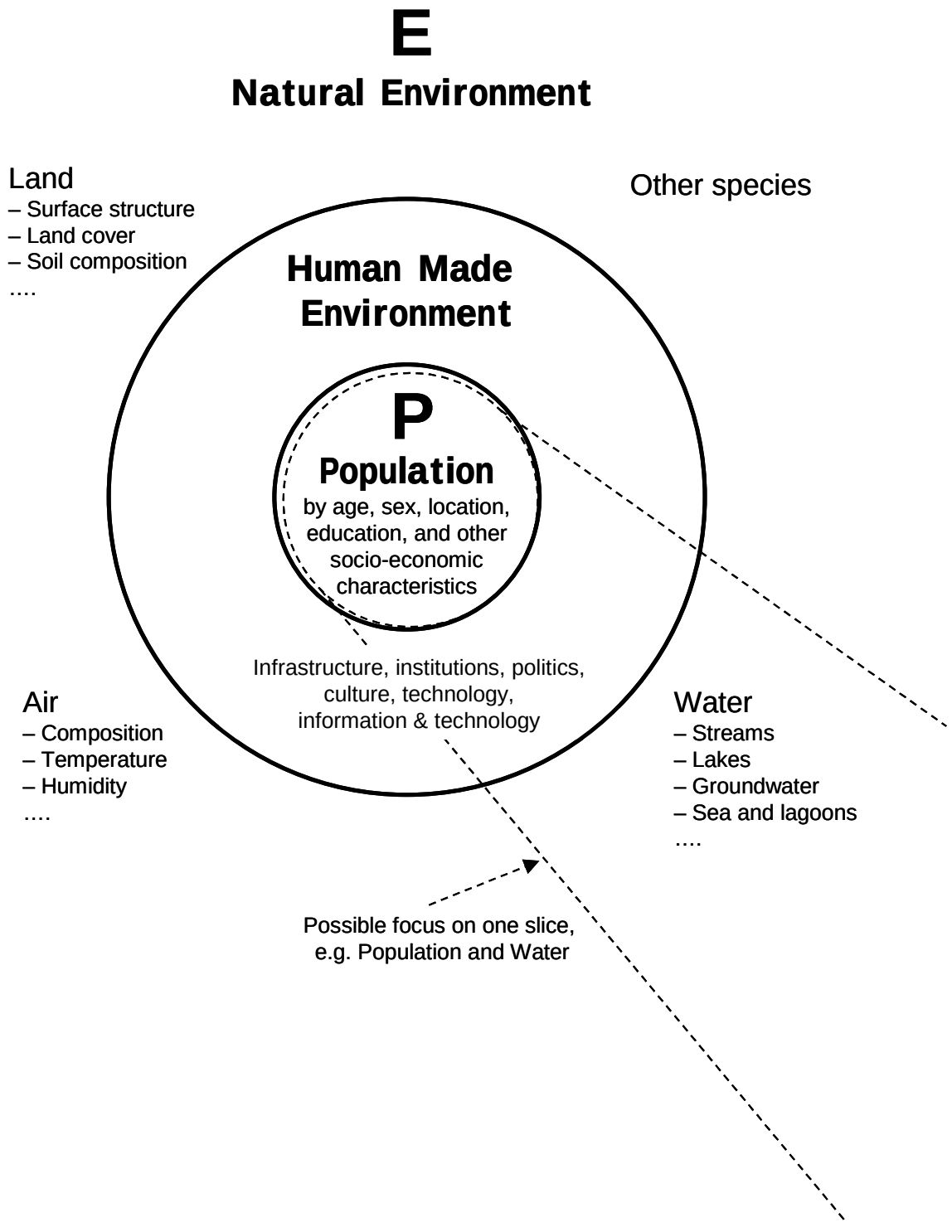

Figure 1. The human population and the man-made infrastructure as being fully embedded in the natural environment and subject to the laws of nature. P-E studies may analyze certain sectors (see dotted line) or try to comprehensively study the full system.

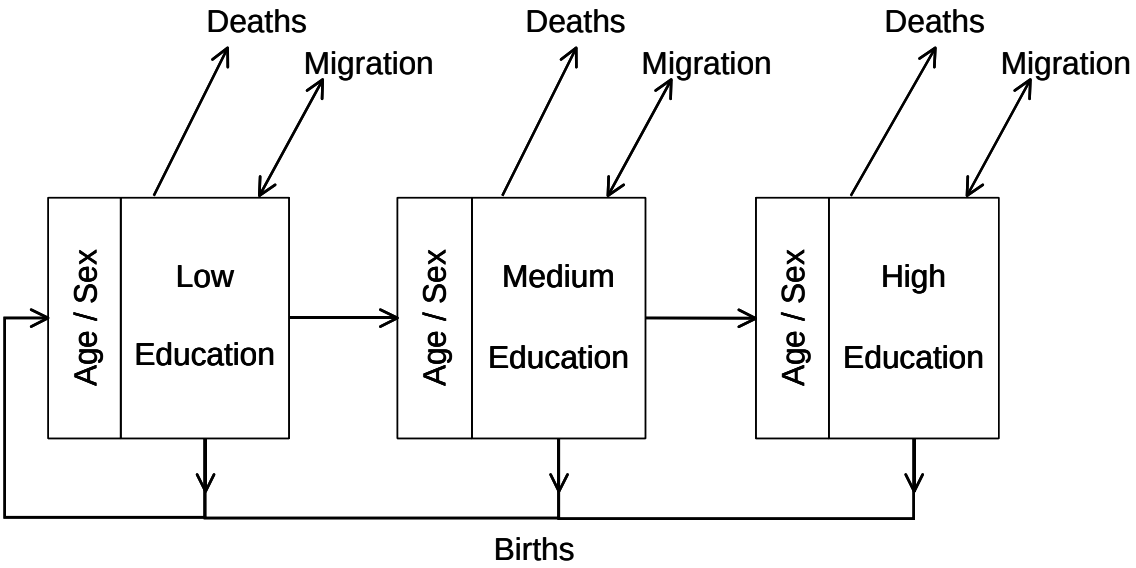

Figure 2. A multistate model for population by age, sex and education.

Notes

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