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Theoretical and Methodological Issues in the Analysis of Population Dynamics and Supply Systems

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Background Paper for the Population-Environment Research Network (PERN) Cyber-seminar on "Theoretical and Methodological Issues of the Analysis of Population Dynamics and the Environment"

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1. Introduction

Causes and consequences of demographic changes and the possible ways of influencing population dynamics in terms of a 'demographic sustainability' have been repeatedly the subject of debate within science, politics and the public. However, as far as population dynamics and its connection to *sustainability* is concerned, the body of knowledge needed for an integrated, problem-oriented understanding of these matters is quite fragmented, dispersed over a broad spectrum of disciplines, embracing a variety of theories, paradigms, models and methodologies. Links between development per se and demographic change and dynamics have been studied for a long time. However, this is not the case for the links with *sustainable development* (except for references to population growth), and attempts to address connections between demography and sustainable (or unsustainable) development continues to spark fundamental controversies, both within science and within society. Therefore, a critical evaluation of existing theory and methodology in the field of population-environment-development studies is needed, one which seeks to bring the impact of theory on policy and praxis into focus. This is a central goal of the cyberseminar, during which we expect to discuss a wide range of theoretical frameworks and methodological approaches in population-environment-research.

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A related objective is the introduction of the social-ecological perspective, an interdisciplinary approach that allows structuring the nexus of population, environment and society in theoretically and methodologically novel ways. Through the cyberseminar, the applicability of this approach will be discussed by comparing it with other perspec-

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tives such as sustainable livelihoods, carrying capacity, IPAT/STIRPAT, ecological footprint and political ecology.

This background paper aims to present a succinct review of topics relevant to the cyber-seminar theme, in an attempt to build common ground to foster brainstorming and discussion during the seminar.

The paper first addresses a critical perspective on the international population discourse (section 2). In section 3, the most relevant approaches of the analysis of population-environment relationships are briefly discussed, while section 4 touches on some theoretical and methodological issues. Section 5 introduces the social-ecological approach, its theoretical principles and some empirical findings derived from case studies. Section 6 sketches some considerations about inter- and transdisciplinary research and its relation between scientific knowledge production and political practice. Finally, section 7 introduces the issues to be discussed during the PERN-cyberseminar.

2. Critical perspective on the population discourse

The Millennium Ecosystem Assessment (MEA 2005) counts the development of human population among the central driving forces of global ecosystem change. According to the MEA framework, physical and biological drivers such as changes in climate, plant nutrient use, land conversion, diseases and invasive species are considered direct drivers, straightforwardly influencing the ecosystem processes. Indirect, anthropogenic drivers such as demographic factors operate more diffusely by altering one or more direct drivers. Other anthropogenic drivers include economic, socio-political, cultural and religious, scientific, and technological factors. Thus, the MEA considers that changes in ecosystem services are caused by the interactions of these multiple drivers. They work over time, with, for example, population and income growth interacting with technological advances, these factors then together inducing climatic changes. Such drivers interact across spatial, temporal and organizational scales, and the combined effects of multiple drivers are amplified by reciprocal action and feedback loops (cf. Nelson et al. 2006).

However, the *interactions* among anthropogenic and bio-physical drivers remain only partly understood. And there is also the recursive relationship to consider – that the changes themselves are affecting the *drivers*. For example, the 2008 Human Development Report affirmed that climate change will be one of the defining forces shaping prospects for human development during the 21st Century (Watkins et al. 2007: 24) through its impacts on human health and potential population displacements.

Therefore, a critical look at population dynamics is required. Over the last decades, the world has witnessed tremendous demographic changes. At a global level, recent demographic transformations are characterized by continuing population growth (although at a decreasing pace), declining fertility rates, increasing migration and urbanization, higher life expectancy and continuous demographic aging (Population Reference Bureau 2008; United Nations 2007). While these transformations appear as overall general demographic patterns at a global level, at the same time population dynamics have produced unprecedented demographic diversity across regions and countries. In addition to these overall trends, a disparity and a-synchronicity of demographic changes has most characterized global population dynamics. These factors have become apparent between, as well as within, individual regions and countries, e.g. with respect to changes

in fertility rates and their pace, or alterations of the population's age structure. Thus, the diversity of demographic changes must be considered.

There have been different, and sometimes contradictory problem descriptions, as well as marked shifts in scientific and public discussions of demographic changes. On the one hand, population growth in developing countries is frequently regarded as a major cause for ecological degradation such as increasing emissions, land-degradation, deforestation and the overuse of natural resources. As a result, some theoretical approaches have been strongly shaped by a 'northern perspective', one that blames the poor for having too many children and thus causing environmental problems. On the other hand, this discussion about the negative effects of population growth on the environment and welfare in developing countries is being increasingly displaced by a discussion about demographic changes in more developed countries – at least in the European context. Instead of growing populations, here it is *de*creasing population size, aging societies, and their respective impacts – particularly for the economy (e.g. labor market, social welfare systems etc.) – which have dominated the discussion of demographic change in most Western societies. Shrinking populations are mainly regarded as providing relief for ecological problems.

Usually, studies of the demographic drivers of (global) environmental change concentrate on the direct determinants of population change - fertility, mortality and migration – and concomitant changes in the population size and distribution. This reflects a somewhat reductionist view of the reciprocal impacts of ecosystem functions and population dynamics, since, demographic changes and population dynamics also include phenomena such as changing household and family structures, lifestyles, income, education level, social status and consumption patterns. Urbanization is a good example: As a worldwide social phenomenon, it is connected with changing needs and habits; higher incomes and a rise in living standards, with these changes combining with changing individual values, preferences and demands. As a result of urbanization and globalization, Western lifestyles seem to be becoming more attractive around the globe, which in turn is altering consumption behavior, with related effects on ecosystems. How does Population-Environment research address these issues?

3. Analysis of Population, Environment and Development

In recent decades, research on population and environment has advanced institutionally and intellectually, spanning different scientific disciplines, including (among others) demography, geography, economics, and anthropology. This emerging interdisciplinary field of studies is frequently designated as "P-E analysis" (Lutz et al. 2002a). By virtue of its pluralistic nature, P-E analysis comprises a variety of theoretical perspectives and methodological approaches, along with various ways of structuring the field. Generally, one can distinguish four different perspectives: linear, multiplicative, mediating and system-theoretical approaches (see also Marquette and Bilsborrow 1999; Van Wey et al. 2005):

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▪ ***Linear perspectives*** assume a direct, causal and linear relation between population and environment. An example is the ***Malthusian theory***, which claims that populations

grow exponentially in the absence of checks. The underlying assumption is that the availability of resources is directly tied to the needs of a population and, as a result, resource availability is directly limited by population growth. However, one central thesis found in state of art P-E literature (de Sherbinin et al. 2007; Hunter 2000; Lutz et al. 2002a; Jolly 1994) holds that direct causal explanations simplify complex realities and are thus not very instructive. Therefore, the Malthusian view has generally been discarded, at least within scientific discussions. In the public and political debate, on the other hand, the notion of demographic growth as the major cause of ecosystem degradation still prevails, along with the idea of the urgency of reducing population growth and fertility rates in the South through population policies (de Sherbinin 1995).[5]

▪ In ***multiplicative approaches*** population is viewed as linked to other factors, in particular economic activity and technological factors. One well-established model is the IPAT formulation, i.e. environmental impacts (I) are analyzed as product of population (P), affluence (A) and technology (T) (Ehrlich & Holdren 1971). This model has been the subject of much debate, among other reasons because it has been argued that it does not account for interactions *among* the terms and omits explicit reference to important variables such as institutions, culture, and social organization (Curran & de Sherbinin 2004). In light of such criticism, there have been several attempts to develop and refine the original IPAT-model further (McKellar et al. 1995; Preston 1996), for example, by referring to non-demographic concepts such as the analysis of material flows, consumption research and by combining the model with the ecological footprint concept, also referred to as the STRIPAT-approach (Dietz et al. 2007). These models suggest that for impacts to be reduced, one needs to look beyond population policy and address the affluence and technology side of the equation, for example through policies aimed at improving energy efficiency.

▪ In recent studies, population dynamics has been broken down into more specific units of analysis. Studies have analyzed specific population changes (e.g. in density, composition or numbers, sex and age structure) and their impacts on specific environmental changes such as land degradation, deforestation, climate change, etc. (see for example de Sherbinin et al. 2007, 2008). Furthermore, more emphasis has been given to the intervening conditions affecting the population-environment relationship and thus population-environment researchers have begun to incorporate in their models the social, cultural and institutional factors mediating between 'population' and 'environment'. This ***mediating variable approach*** stresses the fact that the relationships between population dynamics and the environment are highly dependent on – and mediated by - a range of contextual factors such as macro-economic policies, globalization and the production of exportable resources, and the institutions governing resource access, as well as local or region-specific dynamics. These perspectives are close to the theory of social embeddedness (Granovetter 1985), a reminder that population-environment relationships do not happen in a vacuum (Adamo and Guzmán 2001). For example, the ***political ecology*** approach focuses on the recursive relationship between society, population and the environment, seeking to disentangle the ultimate, underlying causes of social-ecological problems such as the co-occurrence of poor people and environmental degradation (Jol-

[5] Domingo (2008:725-26) coined the term 'demodystopias' for those dystopias (a version of hell as a projected societal future) related to demographic change (for example the population explosion) or that make population mattes a salient concern.

ly 1994). The political ecology or regional political ecology approach emphasizes historical and structural factors as mediators in the relationship, incorporating spatial and temporal dimensions, and integrating different levels and scales of analysis (Gutmann et al. 1996; Little 1994; Schmink 1994; Blaikie and Brookfield 1987). In addition to the political ecology approach, mediated perspectives include the 'development-dependency approach', which concentrates on how development processes mediate population-environment relationships (Marquette and Bilsborrow 1999).

Fig. 1 shows an example of a conceptual framework for the relationship between population and environment. However, teasing out the relative contribution of each factor and significant mechanism remains tricky.

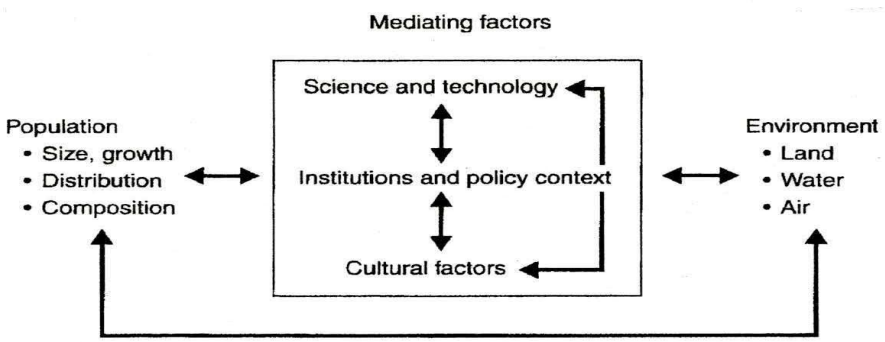

Fig. 1: Mediating variable approach. Source: Hunter 2000.

▪ Taking a micro and meso level perspective, the ***sustainable livelihoods approach*** (SL) focuses on household dynamics and social networks, in particular those of rural people as well as the latter's access to and use of resources (de Sherbinin et al 2008; Aggarwal 2006, Carney 1998). Basically, this approach argues that there is a need to understand and act upon the asset and access limitations of disadvantaged populations, the risks they are confronted with, and the institutional environment that either facilitates or blocks them in their own endeavors to build pathways out of poverty and economic hardship in general. The SL framework places people, particularly rural poor, at the center of a web of interrelated influences that affect how these people create a livelihood for themselves and their households. Closest to the people are the resources and livelihood assets they have access to and use. These include natural resources, technologies, skills, knowledge and capabilities, education, networks of social support etc.

▪ Meanwhile, some P-E studies go beyond purely demographic variables and include factors such as education, ethnicity, income etc. For example, this is true for mediating perspectives in general. Central questions in this literature are: How do basic fundamental demographic processes, like population growth, or changes in fertility, mortality and migration, affect the environment? What demographic outcomes result from environmental changes? What are the reciprocal relationships and interdependencies among demo-

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graphic and environmental variables? Most studies have focused primarily on providing evidence of linkages between demographic characteristics and processes, on the one hand, and environmental outcomes and conditions, on the other. Meanwhile there is growing recognition in the research field that

> "populations are composed of people who collectively form societies, and people and societies cannot easily be reduced to food and material demands that result in some aggregate impact on the environment" (de Sherbinin et al. 2007: 363).

This perception has been accompanied by the increasing impact of ***system theoretical approaches*** in the P-E research field. The recursive nature of population-environment relationships has long been recognized (Gutmann et al. 1996). System theoretical approaches view environment and population as interacting systems, and thus they focus on the reciprocal impacts of environmental and social changes (Liu et al. 2007). For example, the 'complex system and adaptive strategy approach' adopts a systemic framework and looks at mediating factors, environment and population as structured, complex and interrelated system (Marquette and Bilsborrow 1999).

One of the most sophisticated methodologies in P-E analysis is the 'PDE-model' - population-development-environment. This model has been adopted in various empirical case studies, and, through these, has been continuously further developed (Lutz et al. 2002b). The goal here is to understand the most important factors that are likely to shape the population-environment nexus in a chosen region; correspondingly, the studies have taken an unusually broad approach.

In order to be useful for the issue of food insecurity in African countries, the model was enlarged to include agriculture (A) as a factor, becoming a 'PEDA-model'. As figure 2 illustrates, it links population parameters (sex, age, migration etc.) to other non-demographic socio-economic variables, such as education and gender-specific labor force, with all of these in turn being linked to issues such as land degradation, food production and distribution (Lutz & Sherbov 2000).

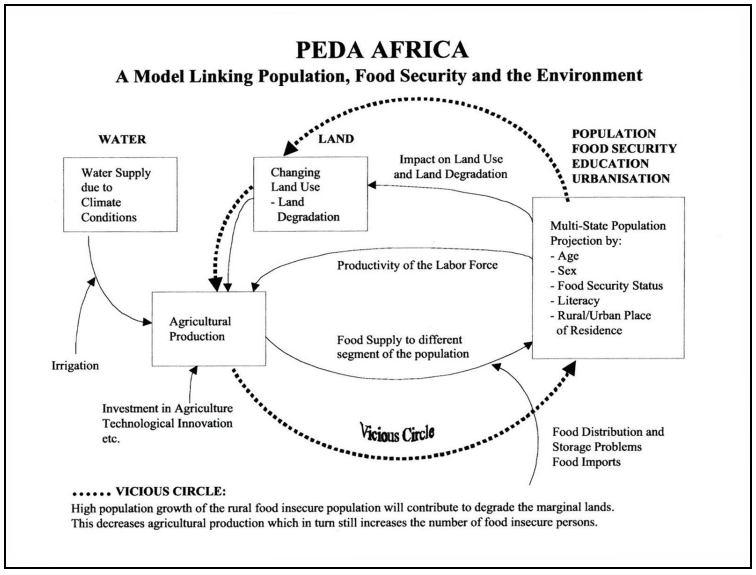

Fig. 2: Basic structure of the PEDA model. Source: Lutz & Scherbov 2000.

The PDE and the PEDA model have been used for a number of years in case-studies covering different economic and socio-political contexts, each with specific social and ecological problem constellations, with a particular focus on 'less developed' or 'least developed' regions, e.g., Mauritius, Namibia, Botswana, and the Yucatán peninsula in Mexico. In contrast to a static framework, this dynamic model allows researchers to combine multidisciplinary qualitative analysis and interdisciplinary quantitative modeling at a meso scale (national or sub-national), with the model also taking into account changes in the population, changes in different relevant parts of the natural environment, influences and feedback loops in both directions, while also identifying specific key mechanisms underlying crisis-prone developments (for a summary of case-study results and methodology see Lutz et al. 2002b).

Taken together, the P-E field of study has advanced considerably in recent years. Looking at these developments we see that more specific dimensions of P-E analysis have been introduced - interactions and feedback loops, spatial and temporal scale, non-linearity, vulnerability, and uncertainty, among others (Lutz et al. 2002a: 5ff.). Such progress notwithstanding, some scholars have noted a lack of comprehensive methodology (cf. de Sherbinin et al. 2008). And, one could add, there has also been a lack of a broadly accepted reference *theory*, owing to the complexity of the issues. We would like now to look more closely at these shortcomings.

4. Theoretical and methodological issues

Lutz et al. (2002a: 5) describe P-E research 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. However, to continue with the metaphor, since the focus of most P-E analysis is on the first three legs, the chair is slightly wobbly. Indeed, there is a strong consensus in P-E analysis that population dynamics impact social, cultural, political, economic and ecologic development, with demographic processes in turn being influenced by social, cultural, economic and ecological conditions. Thus it is generally agreed that there are causal relations at work. But much more is needed. In fact, a reciprocal relationship must be assumed in the sense of circular causality: the effects of the dynamics and the bundle of factors in turn influence the initial causes. Thus, models are needed which can map this circular causality, including all positive and negative feedback loops. The PDE-model is moving in this direction.

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However, what is striking is the absence of an explicit reference to the category 'society' within the P-E nexus. Society (or societal development) seems to be a black box. It is considered with respect to some socio-economic or socio-cultural aspects, or it is subdivided into different intervening factors such as institutions, culture, and politics etc. However, it remains unclear, for example, if 'society' is held to be synonymous to 'human made environment'. To put it more pointedly: P-E analysis lacks a notion of society and societal development.

Moreover, there are several pitfalls regarding the category 'environment' which need to be avoided. In P-E analysis, environment is subdivided into 'natural' and 'human made', and further into different ecological constituents such as soil, water, forest, while being made more specific in terms of different environmental problem fields such as natural resource depletion or pollution of air or coastal zones. Clearly, in order to describe issues such as contamination and degradation of soils or resources, the term 'environmental problems' is indispensable in its everyday use. However, from a theoretical point of view, a number of issues arise by virtue of the *relational character* of the notion 'environment'. Environment always constitutes the environment of something. People do not refer to their environment as isolated individuals, but always as members of society and as civil subjects (or citizens) within specific cultural, social, economic and political conditions, for example by practicing agriculture, producing goods and services, or developing energy supply systems (Hummel 2000: 308ff.). Thus, not only humans, but also institutions (e.g. markets, laws, or rites) maintain relations to their specific environments. Very different entities can refer at different levels to their specific, shared environment: individuals, groups, organizations, societies. By studying the relationships between humans and their particular natural and societal environments it thus becomes clear that one cannot refer to an objectively determinable environment defined *ex ante* (cf. Becker & Jahn 2006: 142f.). The following section introduces and discusses a social-ecological perspective that explicitly attempts to address this.

5. Social-ecological approach: Demographic changes and societal relations to nature

This social-ecological approach attempts to avoid both a naturalist as well as a sociocentric perspective, seeking instead to pursue a critical and integrated view. It relates demography to the interactions between 'nature' and 'society', focusing on interactions between demographic processes and social-ecological problems (Hummel & Lux 2006; Hummel et al. 2008a). This approach will be illustrated in the following in greater detail, since its applicability will be discussed during the cyberseminar by relating it to the other interdisciplinary approaches such as the livelihoods approach, political ecology or IPAT/STRIPAT, as sketched above.

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One basic assumption of a social-ecological approach is that demographic changes are always and everywhere connected to social-ecological problems, with the latter not being assignable to one or the other of two exclusive categories, 'nature' or 'society'. Interest is thus not restricted to the effects of demographic changes on either the environment or society in isolation. Population changes depend on bio-physical conditions, and on social, cultural and economic settings, and in turn such changes influence these factors. In this sense, demographic changes also indicate transformations *of societal relations to nature*, that is, the relational network formed by individuals, societies and nature in interaction (Becker et al. 2006).

Within these relations societies and individuals utilize or shape nature in the form of a specific environment (the material-energetic dimension) and in doing so give it a collective meaning (the cultural-symbolic dimension). Any kind of production and reproduction may be described in terms of societal relations to nature: For in supplying food, for example, land, water and other resources are used and by this usage an environment will be modified. By supplying food, basic needs are satisfied – hunger is filled. But the way resources needed to achieve this goal are used and which kind of food is produced and consumed, is a matter of cultural practices as well. For example, eating sushi may be an expression of traditionalism (in Japan), but may also be an expression of social distinction (in Western Europe). The kind of relation between society and nature changes with rising or falling population numbers and fertility rates, changes in age structure, migration, urbanization processes or household structures. Thus, demographic changes and their conditions are intricately linked to such societal relations to nature such as work, production, food and nutrition, mobility or housing. The analysis of population dynamics in the context of social-ecological transformations needs therefore to be connected with the issue of the adaptation of societies to demographic changes, the development capacities of societies and forms of social-ecological regulation.

Population dynamics and supply systems

Within the social-ecological approach, demographic changes are systematically related to the issue of provisioning[6]. The point of departure of this theoretical approach is the assumption that the number of people in a given society implies regulatory problems for provisioning structures, resulting in social-ecological problems. This is implicitly a normative assumption because it is presumed that all people should be provided with goods indispensable for a decent life. Instead of seeking to analyze relevant demographic factors and their environmental outcomes, or to study the conditions of 'sustainable population development', the *non-sustainability* of provisioning is stressed by focusing on the social-ecological transformation and regulation of supply systems, and their adaptive capacity for coping with demographic changes.

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A central argument of the social-ecological approach is that it is not population dynamics per se that generates these problems, but rather the *adaptive capacity* of supply structures to cope with demographic changes. Given the resulting societal *and* scientific problems, a transdisciplinary model has been developed for analyzing the interactions among population, nature and society.

Provisioning structures based on ecosystems (e.g. water, food, energy, transport, housing) are selected so that the connections between natural resources and their utilization

[6] This social-ecological approach has been developed by the interdisciplinary research project "Demographic trends, needs and supply systems – *demons*" at the Institute for social-ecological research (ISOE), Frankfurt/ Germany.

come to the fore. Accordingly, supply systems cover bio-physical and material-energetic dimensions (e.g. technical artifacts such as wells or bridges) as well as cultural-symbolic aspects of life (e.g. gender and social roles, needs, values, attitudes, cognitive orders), and thus the social and the natural are linked in certain, context-specific ways and develop specific problem dynamics in which social, economic, technical, political and ecological problems closely interact. Provisioning structures developed by societies to satisfy the basic needs of their population can be conceptualized as social-ecological systems with these modeling the dynamic relational patterns between the natural and the social sphere (Hummel et al. 2008a). They can be structured and simplified as follows:

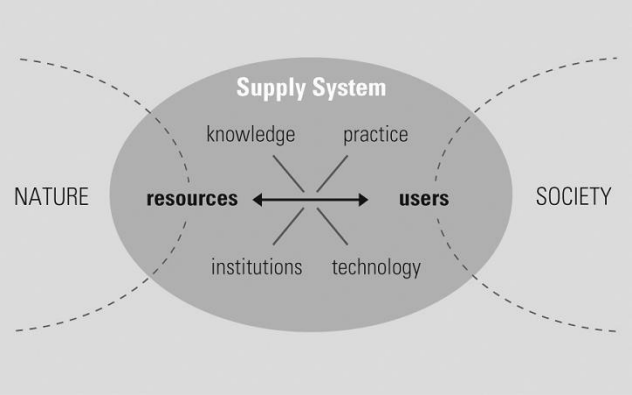

Fig. 3: Supply systems as social-ecological systems. Source: Hummel et al. 2008.

Natural resources and their users are major components in the process of resource utilization for particular purposes. *Resources* comprise the material-energetic, organic and spatial structures within an ecological and biophysical complex that are relevant and useable for supply systems, including such things as food, water, or energy. Renewable and nonrenewable resources as well as further ecosystem services, such as life-support processes, climate regulations or sinks for pollutants and waste etc., are also considered resources. Regulation of access to resources determines the level of provisioning and the degree of provisioning security.

A key feature of this model is that users are understood to be an integral part of supply systems.

A key feature of this model is that *users* are understood to be an integral part of supply systems. 'User' refers to actors and actor constellations, including both providers and receivers of supply system services, i.e. producers and consumers, and it can be distinguished in terms of the direct and indirect, as well as quantitative and qualitative, use of resources. The users of supply systems are, however, not identical with a population; each group of users must be analyzed for a specific supply system. Different categories of users correspond to different parts of the population: For instance, water supply systems' user groups usually encompass various types such as individuals, households, public water utilities, industry, and agriculture. Within food supply systems, only individuals and households, as well as the groups of people who process foodstuffs, represent societal user groups. Depending on specific

supply systems, distinctions must be made between and within different user groups (individuals, households, urban or rural habitants, consumer sectors). These distinctions can also highlight competition among different user groups and among purposes of resource use (e.g. cultivating crops as aliment, as animal feed, or as bio-fuels), as well as conflicts between societal use of resources and preservation of ecosystem functions.

The process of resource utilization, however, does not involve a direct relation between users and resources. Rather, their specific interactions are determined by certain mediating dimensions: knowledge, practices, institutions, and technology. These dimensions specify how resources are made available and allocated, and they determine the vulnerability, adaptivity, scope and options of provisioning regulations.

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Knowledge comprises both scientific and expert knowledge, on the one hand, as well as everyday life knowledge, on the other. ***Practices*** represent routinized types of behavior which encompass forms of bodily and mental activities, practical activities and their representations, as well as the interactions among these factors. The term includes both social, discursive practices, and material ones, all of which are carried out by various specifically situated societal actors. ***Institutions*** represent societally established rules of action, including both informal constraints and formal rules, with such rules of action structuring political, economic and social interactions, thus constituting a framework of action. ***Technology*** comprises all material structures designed, built and controlled by humans for achieving specific purposes, including physical infrastructures, logistics and other technical elements used by producers or consumers of provided services. These intervening dimensions are related to one another in specific ways depending on each particular context. For example, cultivation forms are embedded in specific socio-cultural, economic, political and institutional contexts including practices such as gender-specific divisions of labor, knowledge about appropriate cultivars, availability and application of technical equipments, financial resources, legislation, subsidies, etc.

Empirical findings

The supply systems model has been applied in different case studies, in order to find answers to the question of how demographic changes and transformations of supply systems structurally relate to, and interact with one another, resulting in specific regulatory and adaptation problems. The studies have covered different scales (national, sub-national, regional); and each one has concentrated on specific demographic aspects - migratory movements, population distribution, population growth, urbanization processes and decreases in population size. In this way it has been possible to address the temporal and spatial heterogeneity of demographic changes, as well as different supply systems for water and food. For example, one case study focused on the interactions among urbanization processes and food supply systems in Ghana; another one on shrinking populations and water supply in Germany. One study focused on migration, population distribution and integrated water resource management in Namibia, and

another on population growth and water conflicts in the Middle East. Although covering considerably diverse social, cultural and economic contexts, as well as ecological conditions, it is possible to discern some common patterns with respect to the interactions of demography and transformation of supply systems, as well as common challenges for the adaptivity and regulation capacity of supply systems (for details see Hummel 2008 and Hummel et al. 2008b).

In all of the case study regions one encounters significant diverse and a-synchronous demographic processes. Therefore, a nuanced consideration of spatial patterns of demographic dynamics seems reasonable. The effects of demographic changes in the different regions arise from a superimposition of various subsets of dynamical population processes rather than from a single factor (for example, a high or low birth rate). pective of the variety of population dynamics in the different regions, it is possible to identify striking parallels and common patterns regarding their relevance for supply systems. Population size clearly influences the structure of demand for provisioning goods and services, and thus plays an important role in the transformation of a supply system. However, population size is not the sole explanatory variable determining water and food consumption; rather, variables such as profession, income, education, household structures and social or kinship networks also are critical. These variables, and in particular shifts in household structure, are often associated with changes of population distribution and settlement patterns. Migration turns out to be the most relevant driving force for the transformations of supply systems. Improvements in a supply situation can function as an attractor, or pull-factor, promoting spatial population movements; and the hope that better and more secure provisioning services will be found can be seen as an important motive for migration to urban centers. Migration processes are tied to changing population distribution and settlement patterns, and because of their temporal dimensions they present a particular challenge for the adaptation and regulation of supply systems, since they are associated with strong fluctuations in demand and use of resources, and are at the same time extremely difficult to predict.

Population size is not the sole explanatory variable determining water and food consumption; rather, variables such as profession, income, education, household structures and social or kinship networks also are critical.

The case studies reveal that cause and effects cannot be described in terms of linear causal relations because there are reciprocal links, i.e. feedback effects, between causes and consequences. Thus we see a mutual reinforcement of demographic changes and transformations of supply systems. Here it becomes particularly clear that, although demographic changes are no doubt an important determinant for supply systems, they are certainly not so exclusively. Moreover, the interactions between demographic changes and transformations of supply systems represent a special challenge for predictions and estimates concerning future developments due to their non-linearity. The longer a prediction's time span, and the smaller the area for which it is valid, the larger the degree of its uncertainty, since ostensibly incidental changes in base parameters can lead to significant effects for a supply systems. For example, unexpected developments such as technological change or the modification of usage patterns as well as climate factors cause insecurity that make precise water demand forecasts almost impossible.

This problem is aggravated by the superimposition of long term and short term dynamics, both within demographic dynamics themselves, as well as within the interplay of demographic changes and transformations of supply systems. First, short term population dynamics (e.g. migration) and long term demographic changes (e.g. life expectancy) superimpose one another, and result in temporal-spatial fluctuations. Uncertainty is also connected to a superposition of short and long term dynamics in demographic trends, with changes in demand and in infrastructure development. Like population, supply systems have a dynamic of their own, and there is a lack of spatial-temporal congruence between supply structures (and their transformation) and population dynamics. For example, a major challenge for water supply and sewage systems is to take short-term demographic trends such as migration into account because of the long life cycles of supply and disposal networks. Technical components, particular the pipeline grid, must be maintained over a span of 40 to 80 years. However, water consumption can change faster than the technical infrastructure is able to adapt. This problem is combined with a high degree of path dependency, i.e. the strongly irreversible character of current structures and processes due to past decisions. Especially in the area of material infrastructure past decisions are difficult to rectify in the short or medium term. This lessens the reaction capabilities of supply systems with respect to changes in demand. In this way path dependencies can trigger feedback effects, which affect both population structure and supply systems.

A major challenge for water supply and sewage systems is to take short-term demographic trends such as migration into account because of the long life cycles of supply and disposal networks.

6. Making policy with inter- and transdisciplinary research: From knowledge to action

Applying the model of supply systems in research as well as for developing policy options and strategies means that an elementary understanding of systemic relation is necessary. Depending on the problem situation, the regional and cultural context, the kind and purpose of provisioning, the specific relevance and relation between knowledge, practices, technology and institutions needs to be identified. Based on this kind of integrated understanding of systemic relations and of the consequences and implications of various future actions, as well as those of predicted changes in demographic structure, one can make an assessment of proposed regulations or schemes for provisioning. This is particularly relevant with respect to global sustainability problems.

Societal and ecological consequences of climate change, loss of biodiversity or demographic changes are examples of problems displaying a novel and hybrid structure (Jahn 2008): Social action and ecological effects are closely intertwined with consequences for determining accountability with respect to problems and for assessing the requirements of practical action. Characteristic of these problems is the complexity and nonlinearity of causal processes along various spatial, temporal and social scales, with the consequence that future development becomes increasingly unpredictable. Another feature is the divergence of knowledge and values, resulting in a devaluation of traditional knowledge and an increase in (scientific) ignorance, as well as contested knowledge.

This is particular true for research on population-environment relations and its analytic, normative and political-strategic dimensions.

Given this background, research of a very reflexive kind is needed, and specific research approaches are required that transcend the boundaries of natural scientific and social scientific disciplines, as well as those boundaries separating scientific from practical knowledge in order to produce practically relevant strategies for problem solving.

P-E approaches need to be oriented towards action in the world beyond science and academia.

In other words, approaches need to be oriented towards action in the world beyond science and academia. This is the claim of transdisciplinarity, which conceives research as a learning process involving both science and society, a matter of mutual learning processes including stakeholder involvement and transdisciplinary knowledge transformation (Gibbons et al. 1994; Hirsch Hadorn et al. 2008). A crucial challenge lies in the interrelations and transfers between scientific based transdisciplinary learning processes and practical, policy and decision making based learning processes in the "real world".

7. Goals and Issues of the PERN-Cyberseminar

As mentioned before, the overall goal of this seminar is a critical evaluation of existing theory and methodology in the field of population-environment-development studies. Ideally, the seminar will identify the kinds of problems each inter- and transdisciplinary approach is most suited to address. Thus, this reflection of existing theory and methodology is not considered an end in itself, but seeks instead to bring the impact of theory on policy and praxis into focus.

Issues to be addressed in this seminar include:

1. State of the art with regard to conceptual frameworks:

Which inter- and transdisciplinary approaches of the analysis of population-environment-development are considered to be most relevant, and for what kind of problems? What are their theoretical backgrounds? In what ways are the interactions between demographic, environmental and social changes analyzed in these approaches? What methodology is applied?

2. Methodological issues related to theory:

▪ Problem of scale: Scale enters analyses of the population-nature-society nexus in different ways: spatial (global, national/regional and local level), temporal, and social (individual, community, society). Are the theoretical constructs referred to above relevant to all scales of analysis, or only for some scales?

▪ Integrated analysis: Which methodologies and instruments are needed and appropriate for analyzing the *interactions* of demographic, social, and environmental factors (e.g. ecological footprint, agent-based modeling, scenarios)? Which quantitative and qualitative methodology is needed to link demographic factors such as population size, distribution, growth, vital rates, etc., with factors such as changes in life styles, household structures, behavior, social networks, etc.?

▪ Normativity: Many studies on the population-environment nexus are oriented towards a sustainability concept and/or sustainability science. In which ways are normative aspects taken into account?

▪ Inter- and transdisciplinarity: In which way are the different approaches oriented toward developing not only inner-scientific problem solutions, but also problem solutions for society and politics?

3. Combination of different approaches

How might the following approaches be combined for improved results?

▪ Ecosystem services and supply systems

▪ Combination of livelihoods approach and supply systems approach

▪ Ecological footprint and other indicators

▪ Modeling and scenarios

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