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# Integrating ecology with human demography, behavior, and socioeconomics: Needs and approaches

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**Abstract**

Humans have directly or indirectly affected almost every corner of the earth, through various activities. As a result, ecologists' traditional subjects of study (e.g., 'natural' or pristine ecosystems) are disappearing, and human-dominated or -influenced ecosystems are inevitably and increasingly becoming their new focus of study. This paper discusses an urgent need to integrate ecology with human demography, behavior, and socioeconomics in order to understand and manage ecological patterns and processes. It also introduces the ten papers in this special issue, which integrate ecological, human demographic, behavioral, social, and economic factors through computer modeling and simulation. Finally, this paper provides some perspectives on further integration across disciplines. © 2001 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

Traditionally, ecologists have focused their studies on pristine or 'natural' ecosystems, systems having no human impact. However, as global human population has exceeded six billion, almost every location on the earth is either directly or indirectly affected by human activities (Vitousek et al., 1997; Liu et al., 1999a). In fact, many ecosystems around the globe are dominated by humans (McDonnell and Pickett, 1993; Vitousek et al., 1997). Even in many protected areas established to protect natural resources and biodiversity (IUCN, 1998), humans are also present and carry out various activities (Dompka, 1996; Liu et al., 2001). In areas uninhabited by humans, human impacts may also be apparent such as timber harvesting in protected areas by residents of the adjacent communal areas (Vermeulen, 1996) and air pollution across borders (Park, 1998).

As pristine ecosystems become human-dominated or -influenced, ecologists have begun to study the effects of human domination and are faced with many new fundamental questions. For example, why, how, when, where, and to what extent do humans affect other organisms and their abiotic environment? What novel approaches should be developed to answer these questions? This paper and the ten papers included in this special issue make the first attempt to address these questions.

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## 2. Needs for integration

To study and manage human-dominated and -influenced ecosystems effectively, it is essential to truly (not just intuitively) understand human behavior or activity (e.g. forest harvesting and land use) (Dompka, 1996; Liu et al., 1999a). To understand human behavior, it is necessary to disclose the underlying mechanisms. Many studies have reported that human behaviors are influenced by demographic factors (e.g. human population size, population structure; e.g., Liu et al., 1999a), social factors (tradition, culture, perceptions, attitudes, intentions, choice, value system, wants, needs; e.g. Ajzen and Fishbein, 1980), economic factors (e.g., production, consumption; e.g. Ehrlich, 1988), and ecological factors (e.g. forest conditions; e.g. Pebley, 1998). The lack of integrating ecological–demographic–socioeconomic–behavioral factors leads to failures in understanding and solving real-world problems. For example, in order to reduce human impacts on the habitats of the endangered giant panda (*Ailuropoda melanoleuca*), the Chinese government and some international organizations tried to relocate residents of Wolong Nature Reserve, a high-profile reserve established in 1975 for panda conservation. In the early 1980s, the Chinese government and the World Food Program built a large apartment complex in an area less suitable for giant pandas within the reserve. The hope was to move local residents in the core area for the giant panda to the apartment complex, household by household (regardless of their ages). However, not a single household moved to the apartment complex. The failure of such an expensive project was partly due to the lack of understanding of the attitudes and needs of local residents. Liu et al. (1999a) found that the elderly were accustomed to their lifestyle and did not want to relocate. Furthermore, there was no land near the apartment complex for would-be migrants to farm. Because most of the local residents were farmers, they could not survive without land. Through integrating ecology with socioeconomics and demography as well as behavior, Liu et al. (1999a) showed that moving young people out of the reserve would have been more feasible and effective than the approach of moving entire households. First, young people would be more willing to relocate. Since they possess more technical skills, they could find jobs in the cities relatively easily. Second, moving one young person out of the reserve would be equivalent to relocating a number of the elderly, simply because the elderly will no longer bear children, whereas a young person would have children and continue to add to the population. Third, although the elderly did not want to relocate themselves, they are very supportive of their children and grandchildren relocating. In fact, they would be very proud if their offspring could go to college and settle elsewhere. Fourth, young people are the major labor force that harvests trees for fuelwood (the main energy source for cooking and heating), resulting in direct destruction of the panda habitat. Fifth, the percentage of young people in the local population is increasing dramatically (Liu et al., 1999b), which will cause more destruction to the panda habitat in the future. This example illustrates the interrelationships among social, demographic, economic, behavioral, and ecological factors as well as the importance of taking these factors into account explicitly in research and policy-making.

Unfortunately, like ecologists, researchers in other disciplines have also focused mainly on their own disciplinary issues. For example, human demographers are interested primarily in birth, death, immigration, and emigration of the human systems. Economists work on the allocation of scarce resources to maximize economic returns. Traditionally, human factors were treated as exogenous to ecological studies and ecological factors were treated as exogenous to other studies. Although disciplinary studies have produced many interesting results and are of course necessary, they inadequately address critical issues in human-altered ecosystems. Examples of these critical issues include: (1) understanding the patterns and processes of landscape fragmentation (e.g. wildlife habitat loss); (2) identifying mechanisms of population dynamics and spatial distributions of organisms (plants, animals, and microorganisms); (3) predicting human behaviors and their impacts on habitats and populations of organisms; and (4) developing feasible and effective strategies for economic development, biodiversity conservation, ecological restoration, and management of protected and unprotected areas.

In the recent years, numerous calls have been made for the integration of research across disciplines (e.g. Lubchenco et al., 1991; Odum, 1997). One emerging and rapidly developing field of integration is ecological economics, which attempts to couple ecology with economics (Costanza, 1991; Liu et al., 1994; Costanza et al., 1997; Barrett and Farina, 2000). However, relatively little work has been done in integrating ecology with sociology (Carpenter et al., 1999; Odum, in press, Vogt et al., in press), human demography (Liu et al., 1999b, 2001), and human behavior (Liu et al., 1999a). Integration of ecology with economics is not enough, because many human behaviors are by not only economic factors, but also other factors such as human attitudes (Ajzen and Fishbein, 1980; Becker, 1993). Thus, it is also crucial to integrate ecology with other social sciences (Wilson, 1998).

As most researchers have experienced, work on a single specific discipline is already very complex. Integration across disciplines is much more challenging because more factors have to be taken into consideration and new approaches need to be developed and implemented. However, it is possible to integrate multiple disciplines and meet new grand challenges, as demonstrated in the ten papers of this special issue that showcase the needs and various approaches to integrate ecology, human demography, behavior, and socioeconomics.

## 3. Ten examples of integration

The call for papers on integrating ecology with human demography, behavior and socioeconomics was announced at the end of 1998 on the listservers of four professional societies (Ecological Society of America, Society for Conservation Biology, the International Association for Landscape Ecology, and The Wildlife Society) and in the newsletter of the International Society of Ecological Modelling. The announcement received an enthusiastic response. Ten papers were selected to address a wide range of topics, including landscape changes, expansion and management of protected areas, ecosystem management, endangered species conservation, and game species management. These topics are addressed: (1) in four continents — Asia, Europe, North America, and South America; (2) in areas with different human population densities (nature reserves, wildlife refuges, rural, suburban, urban areas); (3) by integrating various demographic factors (human density, growth, population size, population structure), social factors (attitudes, perceptions, willingness to sell), economic factors (incentives, production, consumption, income, cost, ownership), and behavioral (e.g. forest harvesting, deer harvesting, land use, tiger poisoning, land selling and purchasing, use of fertilizer, agriculture, tourism, plantation, raising livestock); (4) at different scales (spatial — patch, landscape, regional; temporal — daily, seasonal, annual, decadal; organizational — individual, household, group, population, species, community); (5) using various sources of data (interviews, surveys, remote sensing imagery, aerial photos, government records, and field observations); and (6) taking different approaches to integrating various data (geographic information systems (GIS), C++, combinations of GIS and C++, STELLA, and XpertRule) for modeling and simulating the systems of interest. The following summarizes these ten papers.

Duffy et al. (2001) incorporated ecological, economic, and social factors affecting land-use decisions in the buffer zone of the La Amistad Biosphere Reserve in Costa Rica and Panama. The authors developed a computer model to simulate land-use decisions and potential shifts in the distribution of land among alternative uses (protected forest, managed natural forest, forest plantation, pasture, permanent crops, and annual crops) by local farmers at the individual farm level. Model outputs were more sensitive to economic and social factors (e.g. tourism profit, production costs, conservation subsidy, cultural and personal land-use preferences) than to ecological factors (e.g. topsoil depth). Such a study provides useful information for balancing biodiversity conservation and financial benefits to rural families, a central goal of Integrated Conservation and Development Projects (Barrett and Arcese, 1998).

An et al. (2001) integrated ecology with human demography and socioeconomics at the household level to assess fuelwood consumption in the Wolong Nature Reserve (China) for conservation of the endangered giant panda. Fuelwood is the main energy source for cooking and heating in Wolong, but its collection also destroys the panda habitat. Because fuelwood consumption takes place at the household level, it is essential to model how household demography (e.g. number of family members, age structure, relationships) and socioeconomics (e.g. attitudes toward schooling and child birth, production, consumption, income, cost) affect consumption levels. The authors found that households with senior members consumed more fuelwood than those without, because the elderly rely on heating for a longer period of time each year. In addition, more land available for cropping led to greater fuelwood consumption because more raw materials could be produced which need to be cooked as fodder for the pigs.

Cramer and Portier (2001) constructed an individual-based, spatially explicit model to evaluate the feasibility of reintroducing the endangered Florida panther *(Puma concolor coryi)* into northern Florida, United States. The simulation model incorporated both human and ecological attributes of the landscape using C + + and a geographic information system. Human attributes included population density, population growth, land ownership, and roads, whereas ecological attributes of the landscape consisted of land cover types, prey (deer) density, panther gender and residency status. Results of the simulations indicated that panther home ranges would be constricted as human density and development increased, panther mortality increased as road density increased, and the use of preferred habitat would be reduced. Furthermore, the sizes of panther home ranges were most sensitive to how panthers perceived the landscape and their place of reintroduction on the landscape.

Tigers *(Panthera tigris)* are another highly endangered species due to habitat loss and fragmentation. Only 17–25% of the tiger habitat is within protected areas, whereas the majority of the remaining habitat is in multiple-use forests (Ahearn et al., 2001). As protected areas alone are not sufficient to prevent tigers from extinction, these multiple-use forests are critical for tiger survival. However, the intensity of human activities (e.g. raising livestock) is rising in multiple-use forests. Because tigers may depredate livestock, local villagers often use poison to kill tigers. To understand the fate of tigers in these forests, Ahearn et al. (2001) modeled the human–tiger interaction in multiple-use forests in Nepal. The individual-based, spatially explicit model integrated key aspects of tiger biology and tiger interactions with wild prey and domestic livestock, as well as the relationship between villager attitudes towards killing of livestock by tigers and the probability of poisoning a tiger. Simulation results showed that changing the behavior and attitudes of the villagers towards tigers (e.g. increasing guarding of livestock and increasing tolerance of livestock kills) would greatly reduce tiger mortality caused by poisoning.

McDonald et al. (2001) developed a social–economic–ecological model to evaluate ecological consequences and socioeconomic feasibility of land acquisition projects. The model consisted of three primary components: ecological (e.g. land suitability as wildlife habitat), sociological (e.g. landowner's willingness to sell parcels of land), and economic (e.g. money needed to purchase parcels of land). It was parameterized using a proposed land acquisition project to expand the Shiawassee National Wildlife Refuge in Michigan of the United States. The current refuge contains no human residents, but expansion of the refuge depends on purchasing land from the adjacent private landowners. Simulation results showed that the types and amounts of land available for purchase were significantly affected by the landowners' attitudes towards selling. Without incentives, less than half of the proposed acquisition area could be purchased within the next 20 years. Most of the high-priority land was not available for purchase. Furthermore, many of the available land parcels were not connected to each other or to the existing refuge.

Ecosystem management has been proposed as a new paradigm for natural resource management (Christensen et al., 1996). One of the major requirements to achieve effective ecosystem management is to explicitly consider the interactions between humans and ecosystems. Janssen's paper (Janssen, 2001) focused on the management of lake eutrophication through the development and use of an exploratory model based on insights from social psychology, the consumat approach, and the multi-theoretical framework that describes environmentally related human behavior. The model includes ecological dynamics of the lake, the behavior of farmers (agents) using phosphorous, and the interactions between the lake ecosystem and the farmers. Simulation results indicated that a higher target level for returns on the use of phosphorus led to a more intensive use of phosphorus and a higher level of phosphorus in the lake.

Like many parts of the world, the structure and function of European landscapes have been significantly altered due to human behaviors such as land use. To evaluate the effects of land use on the skylark habitat and water balance, Weber et al. (2001) linked three models (economic, ecological, and hydrological) to simulate structural and functional changes of the landscape in the Aar watershed in central Germany. The three simulation models were developed or adapted to predict land use changes, analyze the influence of land use systems on the skylark habitats, and examine the water balance. Simulations showed that an economic incentive for grasslands would result in a significant loss of forested areas, a large decline of connected areas suitable as skylark habitats, and a sharp increase in stream flow and surface runoff.

While Weber et al. (2001) dealt with landscape changes in rural areas, Wang and Zhang (2001) focused on land use and land cover change in one of the most human-dominated urban landscapes — Chicago, Illinois, United States. The human population density is higher in Chicago than in any other areas studied in this special issue. By incorporating socioeconomic and demographic factors using utility functions of spatial choice, the authors modeled urban land expansion and its ecological consequences. The simulations indicated that by the year 2020 most agriculture land would be converted into urban land uses and natural areas would be more isolated and surrounded by urban land. The dynamic landscape simulation approach developed in this paper allows economic principles such as marginal utility to be imbedded in landscape simulation. It also avoids the shortcomings of static models that use a constant land-use transition probability.

It is well known that human activities have resulted in severe fragmentation of landscapes. Easterling et al. (2001) demonstrated the need to take a different modeling approach in fragmented landscapes than that in large-tract natural landscapes. Specifically, the authors modified the widely used gap models (e.g. Botkin et al., 1972; Shugart, 1984) to model succession of small forested strips in the Great Plains of the United States, because the traditional gap models were developed under the implicit assumption that forests were large enough and there was constant seed input from adjacent forests (Liu and Ashton, 1998, 1999). The authors simulated the effects of varying forest corridor widths on forest succession to mimic the effects of expansion and contraction of adjacent agricultural land. Simulation results demonstrated that large differences in widths could cause significant changes in the relative importance of some tree species.

Under many circumstances, data for research and management are qualitative instead of quantitative. While nine of the ten papers in this special issue focused on quantitative information, Xie et al. (2001) illustrated how qualitative data should and could be integrated for the management of white-tailed deer (*Odocoileus virginianus*) in Michigan of the United States. The authors developed a knowledge-based system to take attitudes of various stakeholders (e.g. deer hunters, farmers, and the general public) into consideration in the deer management decision-making process. The system linked deer population, deer habitat, weather conditions, and social carrying capacity. The hierarchically structured decision trees provided an easy-to-understand mechanism for the user to appreciate the rationale and process of particular management recommendations given various input conditions.

In summary, the papers of this special issue have demonstrated various needs for and different approaches to integrating ecology with human demography, behavior, and socioeconomics. The authors have demonstrated that ecological patterns and processes vary under different human-induced disturbances and the methods to study these patterns and processes need to be developed accordingly.

## 4. Perspectives on integration

The studies in this special issue provide a good foundation for future efforts in integrating ecology with human demography, behavior, and socioeconomics. Although a number of important topics have been addressed in this special issue, many fundamental questions remain to be answered. For example, should ecological theories and principles developed in 'natural' ecosystems be modified when accounting for human factors? If so, how? It is certainly not easy to answer all these and other related questions immediately, since it is more challenging to integrate across multiple disciplines than to work within one specific discipline.

The integration process would be accelerated if human factors are explicitly treated as integral parts of the ecosystems of interest and ecological factors are explicitly considered as internal components in demographic, social, economic, and behavioral studies. It is essential to take a systems approach to data collection (field observations, interviews, surveys, documents, literature, remote sensing, global positioning systems), data management (e.g. relational database systems), data analysis (e.g. statistics, geographic information systems), data integration (e.g. systems modeling, geographic information systems, decision-support systems), and information dissemination (e.g. publications, presentations, web sites, and meetings with stakeholders). It is also crucial to consider not only the factors within the system of interest, but also those factors beyond the boundary; not only conditions in the past and at present, but also dynamics in the future.

As the papers in this special issue show, it is not only necessary to integrate ecology with human demography, behavior, and socioeconomics in human-dominated ecosystems such as urban ecosystems (Redman, 1999), and but also essential to do so in areas with low human density or without human residence. From the perspective of biodiversity conservation, it is equally, if not more important to conduct integrated studies in areas with low or no human presence, because it is more feasible to conserve biodiversity in these areas than in areas already dominated by humans. Of course, it is also important to understand human–environment interactions in heavily populated areas, because they can have a significant impact beyond the boundary and thus indirectly affect biodiversity in areas with no human residence or low human population density.

Needless to say, work on integration needs strong financial support. It is very encouraging that funding agencies (e.g. the National Science Foundation, United States Department of Agriculture) have already begun supporting this kind of integrated research. Moreover, it is exciting to know that several government agencies have expressed strong interest in using this special issue as a basis for the development of new research programs. It is hoped that this special issue will stimulate further studies that integrate ecology with human demography, behavior, and socioeconomics. With the rapidly increasing interest in integration, funds for integration, and willingness to collaborate across disciplines, I am optimistic that the science of integration will soon emerge.

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