Human Well-being and the Natural Environment: Research Challenges in Mathematical Sciences

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1. Introduction

Given the impact that humans have on the environment and the fundamental role that the environment plays in supporting human well-being, sustainable development will require improved understanding of human-environment interactions and intelligent decisions to guide human actions in ways consistent with maintaining human well-being in the long-run.

Human well-being requires, at the very minimum, an acceptable level of safe food, clean air and drinking water, safe shelter (housing) and protection from diseases. Two large problems are facing humanity in this century: (i) nearly half of the world population lives in poverty (less than $2.00 per day), and (ii) the high level of total energy and materials use are leading to global changes that threaten the life-support system of the planet. Increasing the material well-being of people in developing countries seems to be a global priority, yet bringing the entire world population to levels of consumption prevalent in developed countries, given current technology, is unsustainable.

Key issues for sustainable development involve precise definition of human well-being, how natural capital contributes to human well-being, how human actions impact on natural capital, multiple trade-offs among ecosystem services and other components of human well-being, and the role of institutions, technology and knowledge in promoting sustainable development.

In this paper I will focus on specific areas in the relationship between human well-being and the natural environment which can be advanced by research in the mathematical sciences.

2. Climate change and mathematical epidemiology

The average temperature on earth is predicted to rise by up to 5°F by the end of the century. This global warming may adversely affect a number of infectious diseases. Malaria is a leading example; 500 million malaria cases occur every year. But there is a controversy about the role of global warming in malaria: A review article by Reiter [1] states: "Speculations on the potential impact of climate change on human health frequently focus on malaria. Predictions are common that in the coming decades, tens – even hundreds – of millions more cases will occur in regions where the disease is already present, and that transmission will extend to higher latitudes and altitudes. Such predictions, sometimes supported by simple (mathematical) models, are persuasive because they are intuitive, but they sidestep factors that are key to the transmission and epidemiology of the disease: the ecology and behavior of both humans and vectors, and the immunity of the human population. A holistic view of the natural history of the disease, in the context of these factors and in the precise setting where it is transmitted, is the only valid starting point for assessing the likely significance of future changes in climate."

The article provides data to support this statement, but it does not develop mathematical models. It will be a challenge to develop such models, as well as to explore other infectious diseases that are potentially affected by climate change.

The report "Climate Change and Human Health, Risks and Responses", editors A. J. McMichael et al, published by WHO in Geneva 2003 is a 322 page manuscript available on the web. It provides a very broad scenario of diseases that may become exacerbated by global warming. Although no mathematical models are described, some can be found in the various references therein. This is an excellent source for new mathematical developments.

3. Climate change and ocean acidification effects on fish and fishery

International Symposium on "Climate Change" was held on April 25-29, 2010 in Sendai, Japan. It dealt with forecasting impacts, assessing ecosystem response and evaluating management strategies in ocean fishery. Another important effect on ocean fishery is due to acidification of the oceans as a consequence of rising CO_2 emission which is poised to change marine ecosystem profoundly by increasing dissolved CO_2 and decreasing ocean pH [2]. There are may mathematical models of ocean food-limited fishery; see, for instance, [3]. It would be interesting to incorporate into such models the effects of global change and ocean acidification. The effect of global warming on fish migration is another topic that can use mathematical models. Some basic facts about fish migration; see www.sciencedaily.com/fish_migration.

4. Global warming and human migration

Scientists are predicting human mass migration as a consequence of climate change: millions of people fleeing from rising sea levels and drought, leading to serious consequences for both migrants and receiving societies. A mathematical approach, modeling the connection between climate change and human migration, was developed by S. Perch-Nielsen [4]. Another interesting more recent article [5], with no mathematical models, assesses the impact of climate change on migration and conflict.

5. Water and air pollution

Water pollution from human activities, either industrial or domestic, is a major health problem in many countries. Every year, approximately 25 million people die as a result of water pollution.

Mathematical water-quality problems date back to the 1920's. A recent article by B. Pimpunchat et al [6] investigates the alleviation of pollution by aeration within a flowing river contaminated by distributed sources and the associated depletion of dissolved oxygen.

The question of how to reduce water pollution by economic stimulation was investigated in A.D. Rikun et al [7] by a mathematical model. This paper considers a scheme of economic stimulation in which payment for water pollution is partially used to compensate expenses for water conservation measures. A mathematical model is used to determine stimulation parameters, when potential polluters are interested in the decrease of discharged waste-water volume to an optimum level. Results of numerical experiments for calculating parameters of economic stimulation for a real case are presented.

However, there is a lot of uncertainty in identification of mathematical models of water quality and in applications of these models to problems of prediction [8].

Thus the mathematical challenge is how to make optimal decisions under uncertainty.

The same situation arises in air quality. In both cases, water and air, there is always the question of irreversible degradation of the environment. This issue was considered very recently in a mathematical model by A. A. Le Kama et al [9]. They consider an optimal consumption and pollution problem that has two important features. Environmental damages due to economic activities may be irreversible and the level at which the degradation becomes irreversible is unknown. Particular attention is paid to the situation where agents do not care a lot about the environment and/or Nature regenerates at low rate. They show that the optimal policy of the uncertain problem drives the economy in the long run toward a steady state, when ignoring irreversibility. The model, however, cannot rule out situations where the economy will optimally follow an irreversible path, which ends with an irreversibly degraded environment.

Making optimal decisions under uncertainty is a well developed topic in mathematical sciences. It could be very useful to apply such theories to water and air quality models. But any criterion of optimality must include the condition of sustainability.

6. Energy

The reserves of coal, oil, natural gas and uranium are limited. In addition, their emissions – carbon dioxide and radioactive waste – cannot be absorbed by Nature. Consequently they are not sustainable sources of energy. Nor is ethanol from corn, which requires fossil energy input for plowing the fields, distilling the mash, and large quantities of water. The only sustainable energy is renewal energy; solar, wind and hydropower.

As demand for renewal energy increases, it becomes important to devise optimal strategies for given demand goals. One such example is the paper by S. Iniyan et al [10].

In a different direction, A. Maros et al [11] developed a mathematical model, that builds upon S. Islan [12], which shows how sustainability (in energy or other resources) can be reached if compensation is allowed for, i.e., stocks for renewable resources being augmented as production depletes stocks of nonrenewable natural resources.

Mathematical models which deal with integrating sustainability in decision-making process can be described by a network whose nodes are tasks and goals, as described, for instance, in J. Cabot et al [13]. Developing mathematical models and analysis for dynamical models of this kind will undoubtedly advance this area of sustainability.

7. <u>Trade-offs in benefits</u>

The paper by T. Dietz et al [14] notes that most theories of environmental impact assume that exploitation of the environment provides benefits to human well-being. However, this assumption has not been subject to much empirical discipline. By contrast, in this paper they model human well-being as a function of physical, natural and human capital. In a preliminary test of this approach they operationalize human well-being as life expectancy, flows of physical capital as gross domestic product per capita, flows of natural capital as the ecological footprint, and human capital as education. Using data from 135 nations, they find that controlling for physical and human capital, exploitation of the environment has no net effect on well-being. This suggests that improvements in well-being may be attainable without adverse effects on the environment.

The model includes trade-offs between human and natural capitals. But it does not address the problem of non-renewable resources such as coal, oil and minerals.

Another paper by S. Bastianoni et al [15] introduces the concept of quasi-sustainability and a model whereby non-renewable resources are used to improve system capacity to exploit renewable resources.

A model of re-use of natural resources is developed in an article by W. Mellor et al [16]. The methodology introduced considers in multiple use phases by describing material recovery, and re-use and recycling. The model serves to generate the set of pareto-optimal choices needed to support multi-attribute decisions in which technical, economic and environmental performances must all be considered.

A recent book by M. DeLara and L. Doyen [17] offers a mathematically based course on trade-offs for sustainable management of natural resources. It introduces mathematical models of viability;

concepts such as decisions under uncertainty; tools such as the Pontryagin maximum principle; maximum approaches; robust control; and stochastic optimization.

A new mathematical framework for competitive equilibrium, in which emissions trading schemes can be analyzed, was very recently introduced in R. Carmona et al [18].

8. The role of institution in promoting sustainable development

This issue is address (but with no mathematical models) in an article by T. S. Veeman et al [19]. As they say, the role of institutions – chiefly, property rights and pricing systems for natural resources – is pivotal in achieving growth and improved distribution of income and wealth, in understanding environmental degradation, and in seeking improved policy. Particularly useful criteria and indicators of sustainable development relate to 'green' output and productivity measures in which the depreciation of natural capital is being considered. Special management problems exist for 'critical' components of natural capital to ensure that our heirs receive an undiminished patrimony.

It would be interesting to develop concrete models which address specific institutions.

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