View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by University of Queensland eSpace

ASSESSING THE SOCIAL AND ECONOMIC IMPACTS OF CHANGES IN COASTAL ECOSYSTEMS

M. COX*°, R. JOHNSTONE*° AND J. ROBINSON*^

** Cooperative Research Centre for Coastal Zone, Estuary & Waterway Management*
° Centre for Marine Studies, University of Queensland
^ School of Economics, University of Queensland

SUMMARY: Humans have wide-ranging impacts on many of the world's ecosystems. Understanding the contribution of ecosystems to human well-being is an important part of improving management of these systems. Current methods to value ecosystems rely on economic techniques that do not adequately reflect contributions of ecosystems to all aspects of human well-being and do not incorporate objectives such as ecological sustainability or fairness. It is proposed therefore that a dynamic model demonstrating the contributions of ecosystems to specific aspects of well-being, such as health, economic production, employment, recreation and social interaction, would be a useful tool in informing and improving environmental management and decision making. This model would be valuable as it could include multiple objectives, be used to make quantitative predictions of impacts, and could be used in parallel with existing valuation and decision-making techniques. The need for this type of model, and an outline of the model proposed are presented in this paper.

1. INTRODUCTION

It has been estimated that humans appropriate approximately 38.8% of potential net terrestrial primary production (Vitousek et al. 1986), use approximately 54% of available freshwater runoff, and 26% of terrestrial evapotranspiration (Postel et al. 1996). The extent of human impacts covers wide spatial and temporal scales across many ecosystems and in some cases these impacts have jeopardised ecosystems' ability to continue to support human life. Humans therefore have a responsibility to manage impacts on these systems so that they can continue to sustain human and other life into the future.

Frequently, human use of the world's ecosystems has been focused on maximising short-term gains. This focus has resulted in a perception that the goals of maintaining natural ecosystems and human well-being are in conflict, and that to improve or maintain the condition of ecosystems, some aspect of human well-being (typically economic production, income or jobs) must be sacrificed (Templet and Farber 1994; Rees 1998). Humans have historically seen themselves as independent of natural systems and there has been a perception that natural systems can be replaced by purely human systems, with no effect on human survival or well-being (Tietenberg 2000). In addition, human well-being has, in the past, been equated solely with economic production and growth, such that changes in other aspects of well-being such as health or social relations have not been explicitly considered. Decisions made under these perceptions have frequently led to degradation of natural systems (Templet 1998).

Recently though, there has been a growing acknowledgement that human and natural systems are intricately linked (Costanza 1989). Humans are dependent on resources provided by natural systems for every aspect of survival and well-being, including food, shelter and recreation (Daily 1997). Changes in natural systems therefore have corresponding impacts on humans and the contribution of ecosystem goods and services to human well-being needs to be accounted for when decisions are made regarding the management of these ecosystems.

Quantifying the effect of a change in ecosystem condition on people is a powerful way to explain the importance of ecosystem goods and services to managers and decision makers (Ulrich et al. 1990; Norgaard and Bode 1998). This does not mean that the intrinsic value of organisms and ecosystems should be ignored, but that, in most cases, the argument of an effect on people is more likely to elicit management concern or action than an argument based on changes to the natural system alone. In any case, as humans are wholly dependent on ecosystems, over the long term, positive changes in ecosystem condition must result in improvements in the human condition. There has recently been many attempts to quantify the economic value of ecosystems to humans (Costanza et al. 1997). Most valuation methods focus on providing a monetary value for ecosystems using a variety of economic techniques. However, these techniques rely on assumptions that are often inappropriate when valuing ecosystems. A more appropriate technique for informing decision making would incorporate information on impacts on wider aspects of well-being, such as health, economic resources, and social interactions, without requiring these to be expressed in dollar terms.

A better understanding of the impacts of environmental change on humans is essential if management of natural systems is to be improved. The aim of this paper is therefore to present a new approach for measuring these impacts, which incorporates measures of well-being additional to monetary valuations. For ease of construction, the model will be developed specifically for coastal ecosystems in Australia, although the general framework could be more widely applied.

This paper is structured in two sections. The first contains an overview of the most common methods currently used to value natural systems with emphasis on their benefits and limitations. The second part of the paper will focus on the method proposed to measure and model the links between natural and human systems. This also discusses further work required to develop the method, potential problems to be resolved, and application of the method to decision making processes.

2. ASSESSMENT OF CURRENT APPROACHES

2.1 Monetary valuation methods

Most evaluations of ecosystem goods and services have focussed on estimating monetary valuations. Monetary valuations have traditionally been used in decision-making processes. As there are rarely markets for ecosystem goods and services, they do not have a clearly defined monetary value. Several techniques have therefore been developed to estimate values for these services including contingent valuation, choice modelling, travel cost, replacement value and hedonic pricing techniques (Commonwealth of Australia 1995; Haab and McConnell 2002). The details of these specific techniques will not be discussed here. Rather, the benefits, limitations and underlying assumptions that are common to all monetary valuation techniques will be briefly discussed, to provide background for the proposal of an alternative, complementary technique.

The main argument for valuing ecosystem goods and services in monetary units is that it enables direct comparisons of the value of ecosystem goods and services with economic goods and services in the same units (Costanza et al. 1998). It is argued that, for non-scientists, scientific descriptions of ecosystems are difficult to understand, and that it is therefore necessary to express benefits and costs in monetary terms. In the absence of any explicit monetary valuation, it has been suggested that ecosystems are implicitly valued at zero, and that it is therefore necessary to estimate a monetary value to ensure that these values are recognised in decision making (Costanza et al. 1998). For these reasons, attempts to provide monetary valuations for ecosystem goods and services are common. However, there are some limitations and assumptions inherent in conducting monetary valuations.

One of the basic principles underlying monetary valuations of any goods or services is that people act purely to satisfy their own preferences, and that satisfaction of these preferences increases their welfare. In fact, welfare is dependent on many factors other than satisfaction of personal preferences (for example, feelings of freedom, other people's health). People may also make decisions based on grounds other than preference satisfaction, such as on aesthetic, moral, religious, political or scientific grounds (Sagoff 2000; Spash 2000; Sagoff 2003).

Using individual preferences to value ecosystems assumes that individuals are fully informed of the benefits that they would derive from ecosystems and that their expression of value includes all these benefits. However, the contribution of many ecosystem elements to overall system function is not known, and interactions between ecosystem elements is unclear in most cases (Toman 1998). Generally, the importance of ecosystems or their elements may not be recognised until they fail completely (Rees 1998). In this case, preference expressions are likely to significantly undervalue ecosystems (Howarth and Farber 2002). A further problem with using individual preferences as a measure of value is that preferences can change over time and may be influenced by education, advertising, changing cultures, or public discussion (Costanza and Folke 1997; Norton et al. 1998). Expressed preferences therefore do not necessarily provide a stable and objective measure of value.

A further problem with this principle is that in many cases it may not be appropriate to value goods and services based solely on their utility to consumers. Making decisions based on individual consumer preferences may be appropriate when the goal is the efficient allocation of scarce resources between potential conflicting uses. However, goals other than economic efficiency may be important, such as sustainability, social equity, complying with standards, norms or cultural values (Bingham et al. 1995; Costanza and Folke 1997; Sagoff 2000; Sagoff 2003).

A method of measuring the contribution of natural systems to human well-being is therefore needed that does not rely on consumer perceptions of benefits, nor on satisfying only the objective of economic efficiency. There are several non-monetary decision making tools or techniques that are currently available to meet this need, which are discussed in the following section.

2.2 Non-monetary valuation and assessment methods

Many authors suggest that a more appropriate way to make decisions regarding ecosystems is to use deliberative or discourse based methods, such as multiple criteria analysis or citizen juries (Sagoff 2000; Wilson and Howarth 2002). The main advantage of these methods is that they allow consideration of multiple objectives. One of these objectives can be (and often is) monetary, and monetary valuation techniques can be used as an input into these processes. As they consider multiple objectives, these techniques can use information from different disciplines and can also use different types of data, including qualitative data, expressed in different units.

They also assume that participants make decisions as citizens; that is, for the general good, rather than as individual consumers (Aldred and Jacobs 2000).

One of the limitations of these approaches (as with monetary valuation methods) is that they assume that the outcomes of any management alternative are fully understood. However, this is usually not the case; often, the economic costs of conserving the environment and the benefits of utilising the environment can be relatively easily measured (for example, in terms of jobs or profits), while the benefits of conserving and the costs of utilising the environment are less well known.

Modelling techniques may be used to estimate impacts even when full information is not available. The construction of conceptual models or causal loop (feedback) diagrams can be very useful as a first step in identifying interactions and feedbacks, can provide insights into possible effects of assumptions and simplifications made in the model and can be used as a basis for a quantitative model. These initial models can also be used to identify appropriate indicators for data collection. Where full information is not available to validate a model, sensitivity analysis can be used to identify the areas that are critical in the model function, as well as those that require further research and data collection. The modelling process can also be iterative, and stakeholders can be involved in the process from the beginning, making the outcomes from the modelling more readily understood and accepted by decision makers. In addition, quantitative models can be used to make predictions of future impacts, where the reliability and precision of the predictions depends on the quality of the data on which the model is based. Advances in graphical modelling techniques, where models can be constructed using symbols rather than equations, mean that it is no longer necessary to have a detailed understanding of programming to be able to construct and understand simple models (Hannon and Ruth 1994; Costanza and Gottlieb 1998). These models can also be used in conjunction with monetary and non-monetary valuation techniques.

2.3 Desired characteristics of an assessment framework

From the above evaluation of methods currently used it is possible to distil the characteristics or criteria for a method that could be used to assess the impacts of environmental change on human well-being. Ideally, any method used should lead to more informed decisions; i.e., it should be intelligible, influential and useful to decision makers. For this reason, the method needs to take a human-focussed approach as this is likely to have the strongest impact on decision makers (Ulrich et al. 1990; Norgaard and Bode 1998). In addition, the method should be able to be used in conjunction with both monetary and discourse based valuation methods, as there is value in multiple assessments and different methods may be appropriate in different situations (Opschoor 1998; Toman 1998). It should contribute information on the links between ecological and human systems that can feed into existing methods. It should not rely on the expression of individual preferences as a measure of welfare, but should examine links with aspects of well-being not measurable in monetary terms. It must be able to deal with multiple (possibly conflicting) objectives, and with different data types and units. It should be able to be used to make predictions regarding impacts on human well-being; ideally, these predictions would be quantitative, with some measure of confidence. A proposed method for assessing the impacts of changes in coastal ecosystem condition on human well-being that meets the criteria above is described in the following section.

3. PROPOSED METHOD FOR ASSESSING IMPACTS ON WELL-BEING

The approach proposed here is directly aimed at resolving the issues discussed in the previous section and providing a more robust method for assessing impacts on human well-being. The method is initially based on developing a simple quantitative model that clearly identifies the interactions between specific aspects of ecosystem health and human well-being. The use of a model is proposed as this is a practical way to make predictions regarding the response of the system to management actions and also a means of integrating and incorporating concepts, assumptions and objectives into a tangible process that can be tested. Semi-quantitative components can also be included where continuous data are not available. Model building is inherent in all decision-making; all decisions are based on at least a simple mental model of the system under consideration. Constructing a quantitative model is therefore useful to allow a clear statement of the assumed components and interactions and to allow refinement and elaboration of the initial model. Very few models have been developed to date that deal with impacts on human well-being directly (Grossmann 1994; Cleveland et al. 1996), and even fewer have included social aspects of well-being, although there have been several economic-ecological models developed (for example, Liu 1993; Bockstael et al. 1995; Costanza and Gottlieb 1998; Costanza and Ruth 1998).

Modelling includes several steps. The first step involves developing the conceptual model, deciding on the scope and scale of the model, and identifying interactions and expected behaviour. The second step involves quantifying the conceptual model; that is, collecting and interpreting empirical data to develop quantitative relationships between variables. This step also involves solving equations over time steps. The third stage is the model evaluation, which includes validation, sensitivity analysis, and evaluating the usefulness of the model. Finally, management scenarios can be run, and the usefulness of the model evaluated (Grant 1998).

3.1 Indicators of well-being

There are numerous existing frameworks and indicators for measuring human well-being. The Australian Bureau of Statistics (ABS), which is responsible for reporting on well-being in Australia, recognizes eight areas of concern as relevant to quality of life in Australia: health, family and community, education and training, work, economic resources, housing, crime and justice, culture and leisure (Trewin 2001). Of these eight areas of concern, health, family and community, work, economic resources, and culture and leisure are potentially directly affected by the condition of coastal ecosystems. The proposed model therefore includes indicators of each of these areas of concern, although in other contexts other aspects of well-being could be included as relevant. The model will predict effects of changes in ecosystem condition on individual aspects of human well-being, rather than attempting to estimate an overall index of well-being. It is considered that, at least in the early stages of model development, it is more effective to concentrate on the effects on individual indicators as the interactions are clearer and information could be lost in the process of combining indicators into one index. The indicators of well-being that will be included in the model are economic production, human mental and physical health, social cohesion, social networks and sense of place and community.

3.2 Development of conceptual models

The first and one of the most important steps in modelling is the development of an initial conceptual model. A conceptual model is necessary to identify all the important components and interactions that are relevant, and helps to clarify the scale and scope of the model. It can also be a useful first communication tool, and, as it is relatively simple to understand and construct, it can be developed in conjunction with stakeholders or decision makers. The conceptual model can be used to identify and resolve components or links that are well understood, and those that need to be targeted for further research and data collection. Of course, the conceptual model can continue to be modified according to the results of data collection, and the final version can be a useful tool when communicating the results to stakeholders or decision makers. The first stage of developing the conceptual model has been completed as part of an ongoing research project, and is discussed in Cox et al. (submitted). Figure 1 provides a simplified version of the conceptual model. Even in its simplest form, the diagram clearly shows the links between ecosystem condition and economic, social and health aspects of well-being.

3.3 Quantitative modelling

A relatively simple dynamic systems model will be developed from the conceptual model using the values for indicators and equations for interactions derived from the data collection. Dynamic modelling is useful in that it can incorporate spatial and temporal lags, non-linearities and disequilibrium conditions in order to simulate complex behaviour (Cleveland et al. 1996; Costanza and Ruth 1998). The process of constructing and refining the model can also be used to build consensus among stakeholders and decision makers.

As mentioned previously, the model will concentrate on individual indicators of well-being. This will have the benefit of making the model more adaptable to different situations, and will enable decision makers to make their own judgements about how to weight indicators with regards to their contribution to overall well-being. The spatial scale of the model will be a region, or catchment; that is, a region large enough that it has measurable internal economic activity within and between industry sectors, but small enough that measures of community are relevant. The model will be run over several years, as this period is long enough to allow changes in well-being to be measured.

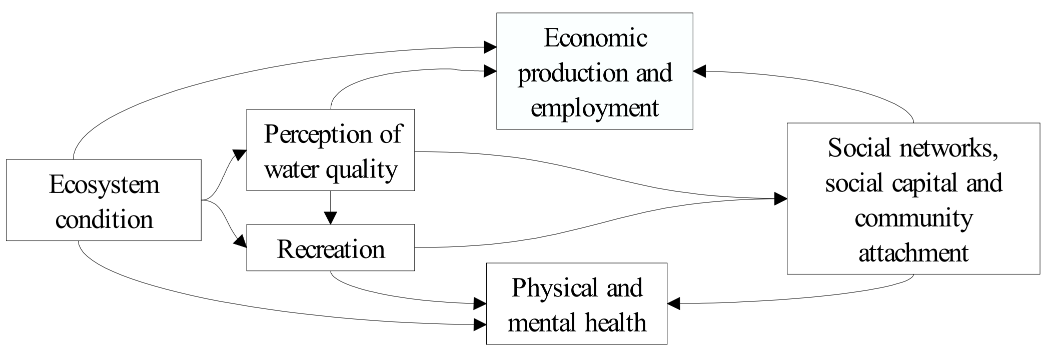

Figure 1. Simplified conceptual model of effects of ecosystem condition on human well-being.

The outputs of the model will include measures of economic production, employment, risks to physical and mental health, levels of community attachment and involvement, social networks and social capital. Most of these outputs will be derived directly from the systems model, but input-output modelling will be used in conjunction with the systems model to derive outputs for regional production and employment.

Input-output modelling is an economic technique that records the production and exchange of all goods and services in an economic system over a given time period, between all industry sectors. It is useful as it estimates the direct and flow-on effects on the regional economy (in terms of production and employment) of changes in demand from individual industry sectors

(Jensen and West 1986; Duarte et al. 2002). In this case, the effects of changes in coastal systems on tourism, fishing and aquaculture sectors, and the resulting flow-on effects in the wider regional economy, would be measured.

3.4 How does this modelling framework meet the criteria?

The modelling framework proposed meets the desired characteristics of a method for assessing impacts of environmental change. It can be used in conjunction with monetary valuation methods; indeed, identification of the links between specific aspects of ecosystems and human well-being would provide information that would be useful in improving valuations. For example, specific monetary estimates of impacts on economic production, employment, and particular health effects could readily be made, without relying on estimates derived from consumer preferences. Information from the model would also be very useful in multiple objective and discourse based assessment methods, as stakeholders and decision makers to obtain a decision of overall impact would provide outputs for multiple indicators that could be assessed and weighted. The framework includes 'objective' indicators of well-being, rather than relying on the assumption of welfare being equivalent to preference satisfaction. The specific indicators could be varied from region to region, depending on information available and the concerns of the community. As it is a quantitative modelling technique, it could be used to predict impacts, and these predictions can be made with a known degree of confidence. The relevance of the model can only fully be assessed once the model is operational and scenarios have been run; however, local councils, state government and community groups have already expressed interest in the project.

3.5 Limitations of the method

There are several difficulties inherent in attempting to model joint natural and human systems. There are differences in the time scales and resolution between the two systems (Bockstael et al. 1995). For example, economic systems are usually measured on yearly time scales; the time scales of social change are relatively unknown, while ecological systems react to some impacts in a matter of days, but may take decades to manifest effects from other impacts. The spatial extent of human and natural systems are also different; ecological systems work on physical boundaries (such as high relief areas forming catchment boundaries), while economic and social systems tend to be more open, with changing boundaries that may be difficult to define. The resolution of the systems also varies; most ecological variables can be measured on small spatial and temporal scales (at sites down to metres, and as frequently as daily, or less), while economic and social systems can typically be measured only on regional scales, and at yearly intervals (Cleveland et al. 1996). There are also likely to be time lags in the links between the two systems. These problems are inherent in any modelling of joint human and ecological systems, but can, at least in part, be addressed by the use of a dynamic systems model rather than a static statistical model (Cleveland et al. 1996; Costanza and Ruth 1998).

3.6 Application of model

Coastal managers to explore the potential impacts of management actions on the human population can use this model. Currently, system models may be used to predict effects of management on ecosystem components (for example, the effect of reductions in sewage nutrient concentrations on ambient nutrients and phytoplankton populations). However, there is currently no appropriate method for measuring the ensuing benefits to people of improvements in ecosystem condition (for example, increased recreation or tourism due to the reduction in algal blooms). This model could be used to fill this gap, by predicting the social, economic and health effects of ecosystem changes as a result of coastal management actions.

There are two main criteria for judging the effectiveness of the modelling framework proposed. The first is whether it can usefully inform decision-making, and contribute to better (more informed) decisions. This can only be judged by creating a model of a real situation, and by determining from the managers or policy makers the usefulness of the information generated. In ongoing research the model is being applied to local coastal management decisions, in order to assess the applicability of the model and the information generated to decision-making processes. The second criteria is how accurate the model is in predicting outcomes of management decisions; this is only possible after the event, but evaluation of the model in these terms is a very important part of the process, as it informs further model development and refinement.

4. CONCLUSIONS

A framework that can be used to quantitatively assess the impacts of changes in ecosystem condition on human well-being has been presented. This is a potentially powerful method and that application of this method has great potential to improve our management of natural resources. The model has advantages over monetary valuation methods as it provides useful information on the links between ecological and human systems, uses measures of well-being other than individual preferences, can include multiple objectives and include data in different units and can be used to make predictions. This model can be used to assist and inform environmental management decisions, as it is only when the benefits provided by natural systems to humans are fully recognised that people will be able to manage these systems sustainably.

ACKNOWLEDGEMENTS

This research is supported by funding from the Cooperative Research Centre for Coastal Zone, Waterway and Estuary Management, and the Queensland Government's Growing the Smart State program.

REFERENCES

Aldred, J. and M. Jacobs (2000). Citizens and Wetlands: Evaluating the Ely Citizens' Jury. *Ecological Economics* 34(2): 217-232.

Bingham, G., R. Bishop, M. Brody, D. Bromley, E. Clark, W. Cooper, R. Costanza, T. Hale, G. Hayden, S. Kellert, R. Norgaard, B. Norton, J. Payne, C. Russell and G. Suter (1995). Issues in Ecosystem Valuation: Improving Information for Decision Making. *Ecological Economics* 14: 73-90.

Bockstael, N. E., R. Costanza, I. Strand, W. Boynon, K. Bell and L. Wainger (1995). Ecological Economic Modelling and Valuation of Ecosystems. *Ecological Economics* 14: 143-159.

Cleveland, C., R. Costanza, T. Eggertsson, L. Fortmann, B. Low, M. McKean, E. Ostrom, J. Wilson and O. Young (1996). A Framework for Modeling the Linkages between Ecosystems and Human Systems. *Beijer Discussion Paper Series No. 76*. Stockholm, Sweden.

Commonwealth of Australia (1995). Techniques to Value Environmental Resources: An Introductory Handbook. Canberra, Commonwealth Department of the Environment, Sport and Territories, the Commonwealth Department of Finance, and the Resource Assessment Commission.

Costanza, R. (1989). What Is Ecological Economics? *Ecological Economics* 1(1): 1-7.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill and J. Paruelo (1998). The Value of Ecosystem Services: Putting the Issues in Perspective. *Ecological Economics* 25(1): 67-72.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton and M. van de Belt (1997). The Value of the World's Ecosystem Services and Natural Capital. *Nature* 387: 253-260.

Costanza, R. and C. Folke (1997). Valuing Ecosystem Services with Efficiency, Fairness and Sustainability as Goals. *Nature's Services*. G. C. Daily. Washington, Island Press.

Costanza, R. and S. Gottlieb (1998). Modelling Ecological and Economic Systems with Stella: Part Ii. *Ecological Modelling* 112(2-3): 81-84.

Costanza, R. and M. Ruth (1998). Using Dynamic Modeling to Scope Environmental Problems and Build Consensus. *Environmental Management* 22(2): 183-195.

Cox, M. E., R. J. Johnstone and J. Robinson (submitted). *A Conceptual Model of Impacts of Environmental Change on Human Well-Being*. Airs, Waters, Places: A transdisciplinary conference on ecosystem health in Australia, Newcastle, Australia.

Daily, G. C. (1997). *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington DC, Island Press.

Duarte, R., J. Sánchez-Chóliz and J. Bielsa (2002). Water Use in the Spanish Economy: An Input-Output Approach. *Ecological Economics* 43: 71-85.

Grant, W. E. (1998). Ecology and Natural Resource Management: Reflections from a Systems Perspective. *Ecological Modelling* 108(1-3): 67-76.

Grossmann, W. D. (1994). Socio-Economic Ecological Models: Criteria for Evaluation of State-of-the-Art Models Shown on Four Case Studies. *Ecological Modelling* 75-76(0): 21-36.

Haab, T. C. and K. E. McConnell (2002). *Valuing Environmental and Natural Resources : The Econometrics of Non-Market Valuation*. Cheltenham, Edward Elgar Publishers.

Hannon, B. and M. Ruth (1994). *Dynamic Modeling*. New York, Springer Verlag.

Howarth, R. B. and S. Farber (2002). Accounting for the Value of Ecosystem Services. *Ecological Economics* 41(3): 421-429.

Jensen, R. C. and G. R. West (1986). Input-Output for Practitioners Volume 1: Theory and Applications. Brisbane, Department of Economics, University of Queensland.

Liu, J. (1993). Ecolecon: An Ecological-Economic Model for Species Conservation in Complex Forest Landscapes. *Ecological Modelling* 70(1-2): 63-87.

Norgaard, R. B. and C. Bode (1998). Next, the Value of God, and Other Reactions. *Ecological Economics* 25(1): 37-39.

Norton, B., R. Costanza and R. C. Bishop (1998). The Evolution of Preferences Why 'Sovereign' Preferences May Not Lead to Sustainable Policies and What to Do About It. *Ecological Economics* 24: 193-211.

Opschoor, J. B. (1998). The Value of Ecosystem Services: Whose Values? *Ecological Economics* 25(1): 41-43.

Postel, S. L., G. C. Daily and P. R. Ehrlich (1996). Human Appropriation of Renewable Fresh Water. *Science* 271(5250): 785-788.

Rees, W. E. (1998). How Should a Parasite Value Its Host? *Ecological Economics* 25(1): 49-52.

Sagoff, M. (2000). Environmental Economics and the Conflation of Value and Benefit. *Environmental Science & Technology* 34(8): 1426-1432.

Sagoff, M. (2003). On the Relation between Preference and Choice. *Journal of Socio-Economics* 31(6): 587-598.

Spash, C. L. (2000). Multiple Value Expression in Contingent Valuation: Economics and Ethics. *Environmental Science & Technology* 34(8): 1433-1438.

Templet, P. H. (1998). The Neglected Benefits of Protecting Ecological Services: A Commentary Provided to the Ecological Economics Forum. *Ecological Economics* 25(1): 53-55.

Templet, P. H. and S. Farber (1994). The Complementarity between Environmental and Economic Risk: An Empirical Analysis. *Ecological Economics* 9(2): 153-165.

Tietenberg, T. (2000). *Environmental and Natural Resource Economics*. Reading, MA, Addison-Wesley.

Toman, M. (1998). Special Section: Forum on Valuation of Ecosystem Services: Why Not to Calculate the Value of the World's Ecosystem Services and Natural Capital. *Ecological Economics* 25(1): 57-60.

Trewin, D. (2001). Measuring Wellbeing: Frameworks for Australian Social Statistics. Canberra, Australian Bureau of Statistics.

Ulrich, R. S., U. Dimberg and B. L. Driver (1990). Psychophysiological Indicators of Leisure Consequences. *Journal of Leisure Research* 22(2): 154-166.

Vitousek, P. M., P. R. Ehrlich, A. I. Ehrlich and P. A. Matson (1986). Human Appropriation of the Products of Photosynthesis. *Bioscience* 36(6): 368-373.

Wilson, M. A. and R. B. Howarth (2002). Discourse-Based Valuation of Ecosystem Services: Establishing Fair Outcomes through Group Deliberation. *Ecological Economics* 41(3): 431-443.