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Ecological Economics 56 (2006) 402–411

ECOLOGICAL ECONOMICS

www.elsevier.com/locate/ecolecon

ANALYSIS

A complex systems approach to the value of ecological resources

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Received 19 November 2004; received in revised form 29 June 2005; accepted 14 September 2005
Available online 21 October 2005

Abstract

A theory of value sits at the core of every school of economic thought and directs the allocation of resources to competing uses. Ecological resources complicate the modern neoclassical approach to determining value due to their complex nature, considerable non-market values and the difficulty in assigning property rights. Application of the market model through economic valuation only provides analytical solutions based on virtual markets, and neither the demand nor supply-side techniques of valuation can adequately consider the complex set of biophysical and ecological relations that lead to the provision of ecosystem goods and services. This paper sets out a conceptual framework for a complex systems approach to the value of ecological resources. This approach is based on there being both an intrinsic quality of ecological resources and a subjective evaluation by the consumer. Both elements are necessary for economic value. This conceptual framework points the way towards a theory of value that incorporates both elements, so has implications for principles by which ecological resources can be allocated.
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Keywords: Ecological resources; Economic value; Complex systems

1. Introduction

A theory of value sits at the core of every school of economic thought (Cole et al., 1991); it is the philosopher's stone of economics. The classical conceptualisation of value is related to supply; it is also objectivist, locating the origin of value in the things from which objects are made, such as land or labour (Marx, 1906; Smith, 1776). In contrast, the modern neoclassical conceptualisation of value incorporates a convergence of supply and demand that produces an equilibrium or market-clearing price. Value is considered to originate in the minds of individuals, as revealed through their subjective preferences. In short, value is determined by the market-place.

Neoclassical market-based economics is seriously challenged by ecosystem goods and services because these involve significant non-market values, and often cannot be assigned unambiguous property

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doi:10.1016/j.ecolecon.2005.09.017

rights. Decisions about how to allocate ecological resources based on their economic value requires the use of techniques to impute value, as in shadow pricing methods or cost-of-production techniques. These methods merely extend and adapt the market model of value. Practical complications caused by imperfections of information about the resource, for example, must in effect be ignored. Non-market values are still the outcome of interactions between supply and demand, but these are now virtual rather than real.

The publication of economic valuations of 17 of the world's ecosystem services by Costanza et al. (1997) has significantly raised the public profile of this issue. This interest is beginning to take root within governments, industries and organisations seeking better outcomes, ranging from more positive public relations to realistic and sustainable cross-sector solutions to the allocation of ecological resources. A most telling indicator that ecosystem service valuation is making its way into the mainstream is a report recently published in *The Economist* (21 April 2005) that brought attention to the appearance of environmental entities on the balance sheet, with the by-line that perhaps some of the best things in life would no longer be free. Both the public and private sectors are therefore now recognising the biophysical and ecological bases of value. Increasingly, ecological resources are seen as being crucial to the current and future productive capacity of economic systems, with economic sustainability requiring ecosystems to be maintained in certain states of health and functionality (Common and Perrings, 1992; Costanza et al., 1997; Daily, 1997).

Economists acknowledge that price, as an allocation mechanism, has historically failed to reflect critical information about the state and quality of ecological resources (Georgescu-Roegen, 1975). However, to bring the treatment of ecological resources into line with the way neoclassical economic theory treats and allocates other types of resources, economists still often return to the notion of monetary valuation based on the neoclassical theory of value. The logic is that if markets fail and do not 'get the price right', then the creation of a hypothetical market can provide a solution for the good or service for which the initial market fails to account.

Estimation of the economic value of non-market ecosystem goods and services requires one of two approaches:

- *Demand-side valuation methodologies* are used to ascribe value based on the subjective preference theory of value, where value originates in the minds of individuals and is measured through their willingness to pay for an additional unit of the good or service; so marginal value, or price;
- *Supply-side valuation methodologies* are used to estimate value based on actual cost-of-production, where value originates in the things from which goods and services are made.

However, each of these approaches has a range of limitations. Demand-side methods as Patterson (2002) argues do not consider objective biophysical properties of ecological resources. Supply-side methods cannot provide 'true' welfare measures (Garrod and Willis, 1999) and have been described as valuing the outcomes of certain policies rather than the ecosystem good or service itself (Heal, 2000).

Non-market valuation has a more general and serious set of limitations. First, economic value should reflect *both* the intrinsic quality of the object of value and a subjective evaluation by the user (Georgescu-Roegen, 1968). Commonly, only one or the other type of methodology is used, so even if these methodologies are infallible, the hypothetical market is incomplete. Second, both approaches contribute a solution to market failure that is analytical rather than based on actual markets. Third, and underlying the previous concerns, is the fact that these two types of methodology are not based on one consistent ontology, analysis and theory of value.

Valuation of ecosystem goods and services is further confounded by the different perspectives of ecologists and economists. Ecological concepts view something as having value in terms of how it contributes to the achievement of some system goal. For example, Farber et al. (2002) points out ecologists talk about the "value of a particular tree species in controlling soil erosion in a high slope area, or the value of fires in recycling nutrients in a forest". In contrast, neoclassical economics conceives of value as the marginal benefit an individual receives from an additional unit of a good or service. Thus, in neoclassical economics something has value because it contributes to the maximisation of that individual's utility. The ecologist's perspective lacks consideration of the social processes and human preferences that guide resource use; economists ignore the biophysical and ecological processes that sustain ecosystem goods and services.

What is needed is a conceptual framework that firstly clarifies and reflects both the intrinsic quality and subjective evaluation elements of value, and secondly integrates the approaches of economists and ecologists to the allocation of ecological resources according to value. In this paper, I develop such a conceptual framework, based on a complex systems approach to value that seeks to incorporate both the biophysical and ecological reality of how ecological resources contribute to economic value (intrinsic quality), and the notion of value as subjective to an individual (subjective evaluation). I argue that both elements are necessary for there to be economic value.

I first articulate the ontology of value using a complex systems approach, where value is described as the result of connections within and between ecosystems and human-based systems. There is a system of 'ecological value' based on theories of ecology; a system of human value (called 'subjective value') based on theories of psychology, institutions and decision-making; and the specific set of interactions or connections between the two, referred to as the connective structure of value. In both systems, the set of components and the way in which these are connected together determine the functions that system can perform, which in turn determines contribution to economic value. I then continue to build a conceptual map of the notion of value, which includes the concept of the purpose for which objects are judged as having value, or 'instrumental value goal'. I conclude by pointing toward further explication of this conceptual framework through the development of theory and models based on the ontology presented here.

2. Ontology of value

A system has two fundamental building blocks: elements and the connections between them. The connections may be chemical, physical, biological or behavioural in nature. A systems perspective enables observation and analysis of the set of components, the particular way in which these components are connected to each other (its connective structure), how these connections change through time, and the dynamics and functions that arise from this connective structure and changes in this structure. Each element can itself be a system; and each system can be an element in a larger system.

Ecological value can be considered as a complex system composed of two subsystems: ecosystems on one hand, and an individual's decision-making or evaluation system on the other. In this way, ecological value is defined by the components and connective structure of an ecosystem (intrinsic quality), the factors influencing an individual's experience of value (subjective evaluation), and the interactions between them. *Processes and functions can be defined as the outcomes of interactions between the components of each system. Goods and services result from these processes and functions*. For example, in a particular ecosystem, water flow emerges from complex interactions between the atmosphere, vegetation and soil, and this then results in ecosystem goods and services such as water supply and drainage. These goods and services contribute to economic value through their impact on fish habitat, tourism, amenity value, etc.

An individual's decision-making or evaluation system also has a function—that is, to make a decision or evaluate a good or service as being able to satisfy a want or need. Decisions can be influenced by many factors. Our evaluation of the value of an object or experience emerges from the factors we consider and the specific interactions between these factors. The ultimate source of value is the specific set of components and connections within a system, and value emerges from this system. These ontological statements will now be considered in more detail for each subsystem in turn.

2.1. The system of ecological value

Ecosystems are complex systems whose natural processes can be described in terms of four functions: regulation, habitat, production and information (de Groot et al., 2002). Regulation is the "maintenance of the earth's biosphere", and includes soil formation, pollination and the regulation of

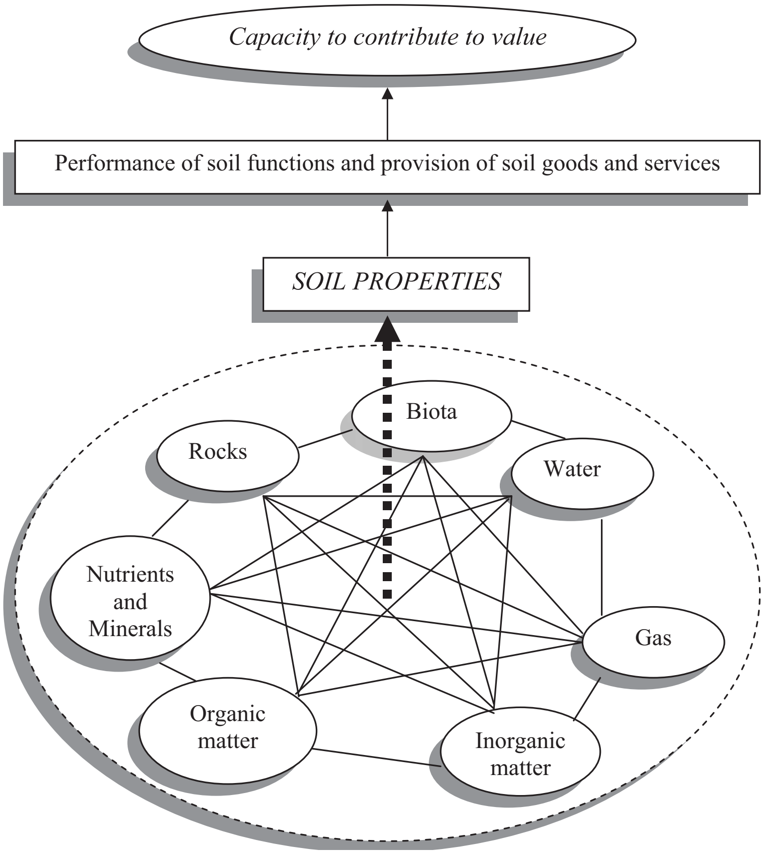

Fig. 1. Ecological value: an illustration of how value emerges from the connective structure of ecological systems.

water, gas and climate. The habitat function is the provision of "living space for all wild plant and animal species on earth… a necessary pre-condition for the provision of all ecological resources". The function of production provides all manner of resources such as "oxygen, water, food, medicinal and genetic resources, sources of energy and materials for clothing and building". Information functions refer to those that provide "a vital source of inspiration for science, culture and art, and…opportunities for education and research".

The goods and services arising from each function "are the result of complex interactions between biotic (living organisms) and abiotic (chemical and physical) components of ecosystems through the universal driving forces of matter and energy" (de Groot et al., 2002 p. 394). These complex interactions can be physical, chemical, biological or behavioural. It is the nature and state of components in an ecosystem, and the particular way in which they are connected that characterise the ecosystem and determine its functions, dynamics and the goods and services produced by it.

The system of ecological value concerns only those 'purely ecological' functions that do not depend on human influence, so includes the regulation, habitat and many of the production functions. The remaining production functions (e.g., crop production) and all the information functions require interaction with human systems, and so emerge from the relationships between ecological and human systems. The capacity of an ecosystem to perform the purely ecological functions is determined by the specific nature and quality of the components of that ecosystem and the specific set of connections between them.

For example, soil is a complex ecosystem made up of rock, nutrients and minerals, organic matter,

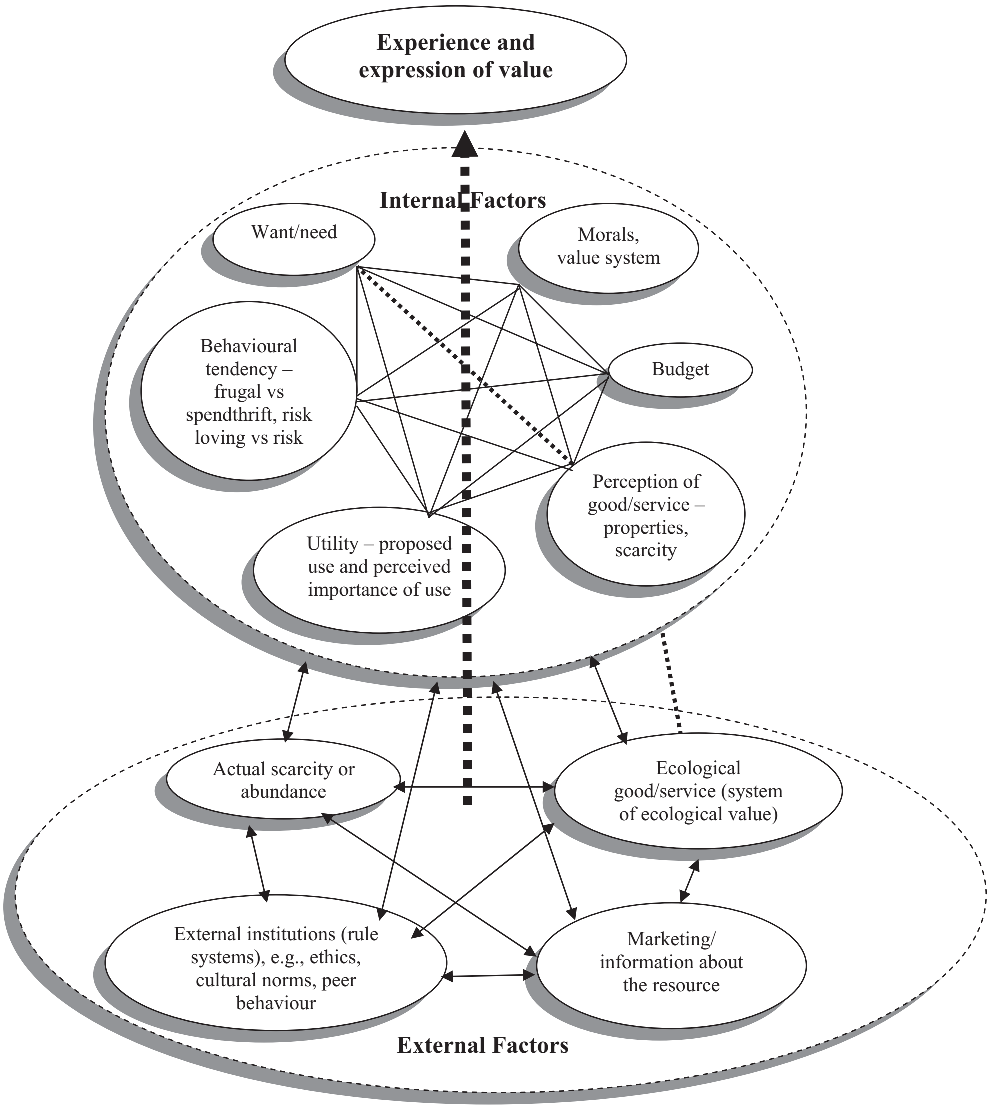

Fig. 2. Subjective value: how value emerges from internal and external factors to the individual.

gases, water, biota and the connections between all of these elements (Daily et al., 1997). The interactions between these components are the chemical, physical, biological and behavioural relations that determine the soil's ecological function, and therefore the production of ecosystem goods and services relating to water infiltration and productivity, for example. These outputs of the soil ecosystem contribute to economic value. The soil's *capacity* to contribute to economic value however ultimately depends on its functions, goods and services, *which emerge from its components and connective structure* (refer to Fig. 1).

If the state or quality of the components of an ecosystem changes, this will impact on the ecosystem's functionality, its goods and services and its contribution to economic value. Many soil properties are determined almost entirely by the soil's components. For example, the size and texture of soil components influence the rate at which water can move through the soil, its storage capacity and susceptibility to erosion and water-logging. Coarse soils allow rapid infiltration but low water retention and high erosion potential, while fine-textured clays have slow infiltration but high storage potential (Daily et al., 1997). Each set of soil components defines the type of soil, the types of vegetation it can support and its productivity, hence its capacity to contribute to economic value through tourism, forestry and agriculture, for example.

A different connective structure will also result in different functionality, goods and services of different states or qualities, and therefore, a different contribution to economic value. Consider two variants of the same element—diamond and graphite. Both are polymorphs of the element carbon, but have very different structures and properties that result from the arrangement of carbon atoms in their crystals. Diamond has a framework structure of three dimensions. It is one of the hardest substances found in nature. It has a broad colour range and high refraction, it conducts heat extremely well and has a very high melting point and a very low reactivity to chemicals. Graphite, on the other hand, has a sheet-like structure of two dimensions where the atoms are only weakly bonded to the sheets above and below. This makes graphite one of the softest minerals, a good conductor of electricity and a very good lubricant. The properties of diamond and graphite are determined largely by their respective connective structures, rather than solely by their (identical) elements. Changes in this connective structure, from a two-dimensional structure to a three-dimensional structure in this example, lead to definite and significant differences in the nature of the object, its properties, the functions it can perform, and its ability to contribute to value through performing these functions.

Thus, the ultimate *source* of value in an ecosystem is the specific set of components and the connections between them, because this is what determines the ecosystem's functionality. While value is also dependent on a subjective evaluation by the user, the objective properties of the resource and its ability to transform energy for some specific purpose, however, will always precede and influence its contribution to economic value.

2.2. The system of subjective value

An individual's subjective experience and expression of value can be seen as emerging from, and itself being, a complex system. As human beings we respond to a myriad of conscious and sub-conscious influences: to our basic needs (food, clothing and shelter) and to an ever-expanding range of wants. We respond to the behaviour of those around us. We respond to fads and trends, fuelled by well-funded marketing campaigns. We are influenced by our budget and perceptions of scarcity. We respond to our own vision of ourselves and of how the world is and should be. Most of these influences are perceptions, mediated by expectations and past experience. They form a system because the various influences come together as components connected in different ways and having different weights, and it is from this system that the individual's experience and expression of value emerges.

As shown by Fig. 2, various factors exist *internally* within an individual: behavioural tendencies, an identified want or need, a set of morals, the perception of an object or an experience that may be able to satisfy the identified want or need. These internal factors interact with a set of influences that are initially *external* to the individual, including ethical systems, cultural norms, marketing and publicised opinion. External influences become internal when considered by an individual. They then become a factor in their evaluation. All considered influences interact to form the final experience and expression of value.

The crucial or limiting connection is that between the actual good or service and the individual's perception that it can satisfy a want or need, which Menger (1950) called "a causal connection". If the set of influencing factors is not connected together in such a way that an individual perceives the good or service as being able to satisfy a want or need, then value will not be expressed.

If the factors influencing an individual's evaluation system change, this will impact on the way and extent to which a want or need is satisfied. For example, respondents to a contingent valuation survey about preserving the habitat of a particular species may have had no knowledge of such an animal before being approached by a researcher. Being asked to proffer an opinion, however, introduces this component into the respondent's set of factors to consider. It even indicates that this species may be important, and, in combination with other

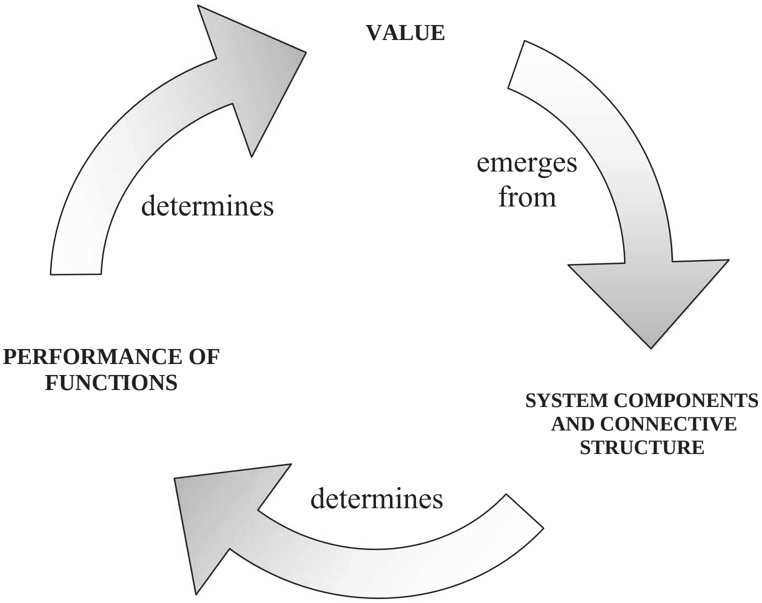

Fig. 3. A complex systems approach to value, showing relationships between: system components and connective structure; functionality; and value.

components in their system of subjective value, the respondent's experience and expression of value for the particular species will emerge. Subjective value is influenced by what we see, what we are offered and told and by what we imagine; preferences, wants and needs evolve as previous choices impact future choice and as the factors influencing choice change.

A different set of relations between the factors influencing value will also impact on the way and extent to which a want or need is satisfied. The connections in a system of subjective value change in nature and also in strength. The actual choice an individual might make will be contingent on the weight of each component of value relative to other components. For example, if individuals' concerns for local producers are stronger than their desire to have a particular brand of imported cheese, this may trigger their final decision.

As for the system of ecological value, it is the specific set of influencing factors and their connective structure that determines whether (and to what extent) the essential ecosystem function will be performed. Thus, the ultimate *source* of value is the specific set of components and the connections between them, because this is what determines the performance of that ecological function.

This complex systems approach to value reflects recent developments in economic models of choice, which are increasingly influenced by findings from neuroscience, biology, psychology, sociology, anthropology, economics, and behavioural game theory. There is a growing acknowledgement that there are many factors influencing choice and value that may be elusive and difficult to model—these factors include: personal ties, moral commitments, and 'second thoughts' (Sagoff, 1994; Solow, 1986). Recent models of choice recognise the dynamic nature of demand, listing its influences as including "habits, learning, state dependence, consumption inertia, temporal preference heterogeneity and initial conditions effects" (Swait et al., 2004). Choice models now account for the complexity of tasks and the complexity of the choice environment (Swait and Adamowicz, 2001), and for choices taking place over time (Swait et al., 2004). Models of the complex system of choice and of choice in complex systems have the potential to provide significant contributions to the understanding of value as a complex system.

3. Discussion: some implications for a complex systems theory of value

The two subsystems of value as described above come together when the properties of an ecological resource are perceived by an individual and become a factor influencing the individual's subjective evaluation. Changes in the components and/or connective structure of either subsystem can still influence value. While an individual's subjective evaluation, particularly their recognition or perception of something as being able to satisfy a want or need, may be the limiting factor, the objective properties of the resource and its ability to serve some specific purpose are necessary ingredients and will often precede and influence subjective value. Both subsystems are necessary for there to be value. A subjective evaluation alone is not sufficient for the good or service to have value (Buenstorf, 2002, p. 5). Each subsystem and the connected subsystems are complex: changes in the ingredients or connective structure of either system will influence value in ways that may be nonlinear, irreversible and unpredictable.

The relationships between 'systems' (components and connective structure), 'functionality' and 'value' are illustrated in Fig. 3. This conceptual framework clarifies the source of value as being 'a system' that is made up of components and their connective structure. If value is indeed located in 'a system', this has significant implications for how the value of ecological resources is conceptualised, measured and used as a basis for resource allocation.

It is impossible to talk about a concept of value without alluding to the goal against which objects or actions are often judged as having importance—that is, the 'instrumental value goal'. The way in which value is conceptualised is influenced by, and in turn, affects the instrumental value goal. As mentioned, ecological value is viewed in terms of how an object or process contributes to a system goal. This illustrates the essential difference between objective and subjective notions of value: (1) judging value against an objective outcome renders value as an objective quality, measurable in objective terms; (2) judging value against a subjective outcome renders value as a subjective quality, measurable through translation into objective terms, in this case, a monetary unit. This latter notion is the manifestation of the subjective preference theory of value on which the neoclassical market model and demand-side methods of economic valuation are based. One result of the application of this theory and these methods, however, is that the value of ecosystem goods and services changes as subjective preferences change. This does not reflect the objective qualities that are required for ecological resources to contribute to economic value.

What instrumental value goal is consistent with a complex systems approach to the value of ecological resources? The capacity of ecosystems to contribute to value lies within their components, connective structure and the functions they perform, so, the instrumental value goal must refer to the maintenance of the health and quality of these components and connections in a way that maximises their functionality. This in turn will maximise their potential for contributing to economic value. The maintenance of ecological functionality within the context of economic and social wants and needs is essentially the concept of sustainable development. Thus, the complex systems approach to the value of ecological resources judges value in terms of how an object or process contributes to the maintenance of functionality, or, to sustainable outcomes. While the maximisation of individual utility is an important function for a sustainable social-ecological system to perform, it is not the only function, hence not the only goal against which things should be judged as having value. Rather than asking "*what makes us happy?*" and making decisions based on theories of value that maximise the answer, the current approach suggests asking "*how can we maintain the potential for happiness?*".

To create and maintain social-ecological systems that support the instrumental value goal of sustained functionality we need scientific evaluation of which functions are essential, what makes a sustainable social-ecological system, theories of resource allocation that are built on such knowledge, and theories and methods of valuation and evaluation that are logically consistent with such an approach. What are the basic principles for creating a system with maintained functionality; a system that is stable enough to reproduce itself through time; one that performs the functions essential to its own survival; that is adaptive enough to make effective use of the impacts of disturbance and change; and that embodies notions such as health, resilience and integrity? What are the implications for how ecological and other resources should be allocated?

4. Conclusions and future work

Economic theory and applications have enormous impacts on people and ecosystems. The theory of where value comes from and how it can be measured and the goal against which ecological resources are judged as having value, impact crucially on what economists prescribe in terms of the allocation of resources. A different conceptualisation of value will reveal different principles for the allocation of those resources. The allocation of resources to uses based on different principles may result in very different outcomes for social-ecological systems and their capacity to perform essential functions and reproduce themselves through time.

This conceptual framework points towards the need for a theory of value that reflects both the intrinsic quality and subjective evaluation elements of value. A complex systems approach to value shows how the two elements can be conceptualised as systems using a common language and set of concepts. This approach has revealed the central role that functions play in determining where value originates, and future development of this conceptual approach may reveal new principles for the allocation of ecological resources. The current, neoclassical market-based model and approach to non-market valuation results in the allocation of resources to uses based on economic efficiency. A complex systems approach to value suggests that the crucial concepts are actually *quality* and *capacity*, neither of which is adequately captured through monetary valuation. Just as the raw energy content embodied in an object only reveals so much about what that object is capable of doing, so the monetary valuation of an ecological resource tells us little about its capacity or potential.

Further development of this approach will require the formulation of testable theoretical statements about the conditions under which value is enhanced and maintained. Fundamental to these hypotheses will be indicators of value that are observable and measurable. Associated with this is the question of which level of a system is important for determining the value of particular ecological resources. There will be levels to which one can deconstruct a system into its component parts that will be useless for deciding on resource allocations that enhance and maintain value. For example, the quality of each individual grain of sand in a soil will not be relevant to understanding the functionality and value of that ecosystem, nor will it be useful for the purpose of allocation. So value may only be relevant at a certain level of a system because it is at this level that the system's essential functions emerge. Value is emergent and the result of complex, nonlinear and often unpredictable interactions. Tools and methodologies for understanding and measuring value in this complex context are required. This theory will also need to be based on further exploration of specific circumstances in which changes in value are due to changes in the nature and/or quality of system components, versus changes in connective structure.

'Value' has a long and fascinating history and it continues to evolve as a concept central to decision-making for sustainable futures. The application of complex systems theory to important questions about the allocation of ecological resources is a difficult and ambitious task. The analysis, by necessity, refers to broad and sometimes abstract concepts relating to the structure of systems that are challenging to perceive, let alone to grasp with objectively measurable certainty. However, a complex systems approach to the value of ecological resources is a crucial and natural addition to the continuing evolution of the concept of value.

Acknowledgments

This work was conducted as part of my thesis submitted for the degree of Doctor of Philosophy at the University of Queensland. I would like to acknowledge the guidance of Richard Brown, John Foster and Jason Potts. I would also like to acknowledge the inputs of Alan Andersen, Kate Morrison and three anonymous referees.

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