available at www.sciencedirect.com

journal homepage: www.elsevier.com/locate/biocon

Review

Classification of ecosystem services: Problems and solutions

*Ken J. Wallace**

Natural Resources Branch, Department of Environment and Conservation, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983, Australia

ARTICLE INFO

Article history:
Received 20 February 2007
Received in revised form
29 June 2007
Accepted 9 July 2007
Available online 5 September 2007

Keywords:
Biodiversity planning
Ecosystem services
Natural resource management
Decision-making
Values

ABSTRACT

Ecosystem values are not well accounted for in decisions concerning natural resources. In this context, the concept of ecosystem services offers an important opportunity to develop a framework to underpin the wise use of biodiversity and other natural resources.

Although the merit of using ecosystem services to frame biodiversity evaluations has been documented, the classification systems employed mix processes (means) for achieving services and the services themselves (ends) within the same classification category. This limits their contribution to decisions concerning biodiversity. Ambiguity in the definitions of key terms – such as ecosystem processes, functions and services – exacerbates this situation.

After clarifying definitions and discussing the basic components of an effective typology, this paper develops a classification of ecosystem services that provides a framework for decisions in natural resource management. However, further work is still required to resolve particular issues, such as the classification of socio-cultural services.

Although science can contribute to effective decisions by clearly classifying services and describing their links to processes, final decisions concerning biodiversity and other natural resources are inevitably socio-political, and embedded within a particular cultural context.

Contents

* Tel.: +61 8 9334 0341; fax: +61 8 9334 0367.
E-mail address: ken.wallace@dec.wa.gov.au

0006-3207/$ - see front matter
doi:10.1016/j.biocon.2007.07.015

1. Introduction

Ecosystem services are increasingly promoted as a means for documenting the values humans place on ecosystems and evaluating benefits derived from natural resources (Costanza et al., 1997; De Groot et al., 2002; Abel et al., 2003; Chee, 2004; Groffman et al., 2004; Eamus et al., 2005; Kremen, 2005; Millennium Ecosystem Assessment, 2005; Farber et al., 2006). This is an important trend, and particularly important in the case of biodiversity conservation where values are often difficult to describe in economic terms and rarely well-explained in natural resource decisions.

If ecosystem services are to provide an effective framework for natural resource decisions, they must be classified in a way that allows comparisons and trade-offs amongst the relevant set of potential benefits. In the language of the Millennium Ecosystem Assessment (2005), this means that the full range of benefits reflecting human well-being from ecosystems must be represented in any effective typology of ecosystem services.

However, the classification of ecosystem services by leading practitioners, such as Costanza et al. (1997), De Groot et al. (2002), Millennium Ecosystem Assessment (2005), and Farber et al. (2006) mix processes (means) for achieving services and the services themselves (ends) within the same classification category. Although these papers are very valuable works, their classifications thus present inherent problems for decision-makers, an issue explored below. The same problem arises within general texts and applied uses of ecosystem services and similar valuations (for example, Abel et al., 2003; Groffman et al., 2004; Anielski and Wilson, 2005; Kremen, 2005; Naiman et al., 2005).

The aim of this paper is to describe the current problems with classification systems and then build a consistent logic connecting human values to the implications of decisions concerning management of natural resources. Ecosystem services, defined and classified as benefits, are a vital link in this decision process.

Texts examined concerning ecosystem services varied in their definition and use of key terms, which leads to one aspect of linguistic uncertainty, an important problem in environmental decision-making (Burgman, 2005). To avoid ambiguity here, all the key terms are defined in Table 1 and more fully explained in the Appendix.

If the definitions in Table 1 are accepted, then the relationships shown in Fig. 1 are implied. Under this scheme, the structure and composition of ecosystems at time 1 are modified by ecosystem processes to a new structure and composition at time 2. Although the flow of matter and energy amongst the abiotic and biotic elements of ecosystems is a continuous process, humans measure structure and composition at different points in time to derive rates of change in processes and to quantify the distribution of matter (as ecosystem elements, generally assets) at particular instants.

We manage natural resources to maintain, or bring about a change, in ecosystem composition and structure more favourable to human well-being, which is taken here to incorporate spiritual/philosophical benefits, including ethical matters, as well as more material benefits. That is, we manage ecosystem processes with the goal of re-organising ecosystem elements to deliver ecosystem services that better meet human values. This practice is continuous and evolving with a new ecosystem structure and composition when measurements are made at time 3, time 4, and so on. This conceptual model underpins the following discussion.

2. Problems with current classification systems

For effective decisions, the classification of services must be constructed so that the choices evaluated form a coherent set with the properties described for multi-criteria decision analysis by Burgman (2005). The Millennium Ecosystem Assessment's (2005, Table 2.2 pp. 33–7) classification of services is representative of those in the current literature, and a simplified version of the relevant table is included here as Table 2. To test whether this classification system is well constructed, consider the case of a natural resource manager responsible for an area containing a mixture of agricultural land and natural vegetation.

The manager decides to use the list in Table 2 to ensure that the selection of management outcomes is logically constructed, and selects the following as the key services for initial planning:

- Food
- Fibre (construction timber)
- Fresh water

Table 1 – Definitions of key terms used in the text

Term	Definition
Asset	A thing of use (adapted from the Oxford Dictionary). Natural assets, natural resources and natural capital are synonymous terms
Biodiversity	The variety of life forms including the different plants, animals, fungi, microorganisms, etc. Use of the term is restricted to living things; therefore, the diversity of ecosystems is excluded. Throughout the document the term biodiversity refers to natural biodiversity unless otherwise stated, although the term itself encompasses both natural and cultural biodiversity
Biodiversity asset	A living entity, or group of living entities, that is of use to humans
Ecosystem	A "functional entity or unit formed locally by all the organisms and their physical (abiotic) environment interacting with each other" (Tirri et al., 1998). All the ecosystems considered here contain at least some natural elements
Ecosystem function	Provided ecosystem services, processes, structure and composition are adequately defined, this term is not required. Therefore, given that there is a history of differing and ambiguous usage of the term, ecosystem function is treated here as a synonym of ecosystem processes, and it is not used. See 'ecosystem function' in the Appendix for a definition of structure and composition and further explanation
Ecosystem processes	Ecosystem processes are the complex interactions (events, reactions or operations) among biotic and abiotic elements of ecosystems that lead to a definite result (based on Tirri et al., 1998). In broad terms, these processes involve the transfer of energy and materials (Lyons et al., 2005). An important distinction between ecosystem elements (both biotic and abiotic) and processes is that the former are generally tangible entities described in terms of amount, while the latter are operations and reactions and generally described in terms of rates (for example, production per unit time)
Ecosystem services	Used here in the sense defined in the Millennium Ecosystem Assessment (2005, p. 1) as "the benefits people obtain from ecosystems." These benefits include food, water, timber, cultural values, etc., and are the outcomes sought through ecosystem management. Use of the term 'service' in this context is somewhat ambiguous – an issue discussed in the Appendix
Human values	The preferred end-states of existence, including those required for human survival and reproductive success, which taken together circumscribe human well-being

See Appendix for further explanation.

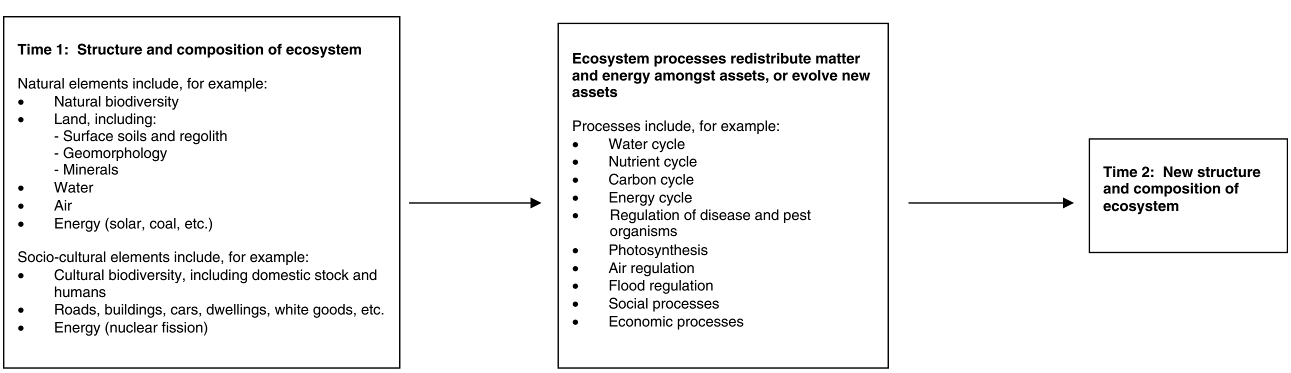

Fig. 1 – Description of the relationships among ecosystem elements and processes. (For simplicity it is assumed that natural assets are the sum of biotic and abiotic ecosystem elements, rather than a sub-set only.)

- Pollination
- Water regulation
- Recreation and ecotourism
- Spiritual and religious values
- Photosynthesis
- Soil formation.

To explore planning implications, the manager constructs a simple diagram outlining some of the ecological linkages that will need to be managed (Fig. 2).

From the relationships shown in Fig. 2, it is evident that pollination, water regulation, photosynthesis and soil formation are not ends that the manager will seek in their own

Table 2 – Categories of ecosystem service and examples of related services, based on Table 2.2 (p. 33) in the Millennium Ecosystem Assessment (2005)

Type of service	Service
Provisioning services	Food Fibre Genetic resources Bio-chemicals, natural medicines, etc. Ornamental resources Fresh water
Regulating services	Air quality regulation Climate regulation Water regulation Erosion regulation Disease regulation Pest regulation Pollination
Cultural services	Cultural diversity Spiritual and religious values Recreation and ecotourism Aesthetic values Knowledge systems Educational values
Supporting services	Soil formation Photosynthesis Primary production Nutrient cycling Water cycling

right. Rather, they are all means (processes) to achieve ends (services) such as food production and potable water. That is, the manager will pursue the management of these processes to the degree necessary to provide the quantities of food, fibre for construction, or spiritual experiences, and so on consistent with the overarching goals of management.

Thus the set of services listed in Table 2 are not a coherent set of services at the same level that can be explored and traded off in a decision system. Processes such as pollination, soil formation and water regulation are means of delivering many services. Using the definitions provided above, they are unequivocally ecosystem processes, and this immediately indicates that they are means to achieve services, not the services themselves.

A close examination of the arrangement outlined in Table 2 confirms these difficulties. At the broadest classification of service type – that is, the provisioning, regulating, cultural, and supporting categories – regulating and supporting services are, with one or two exceptions, means to achieving items listed under provisioning or cultural services. As argued above, water and erosion regulation are not in their own right services sought by humans, they are processes to achieve potable water, or to protect food and fibre resources, and so on. A similar argument applies to the service of pollination, which is a means of fulfilling one or more of the provisioning services. That is, the regulating services as defined in Table 2 are means to achieve ends. Equally, the supporting services listed in Table 2, such as nutrient and water cycling, are all means to human ends; they are not ends in themselves.

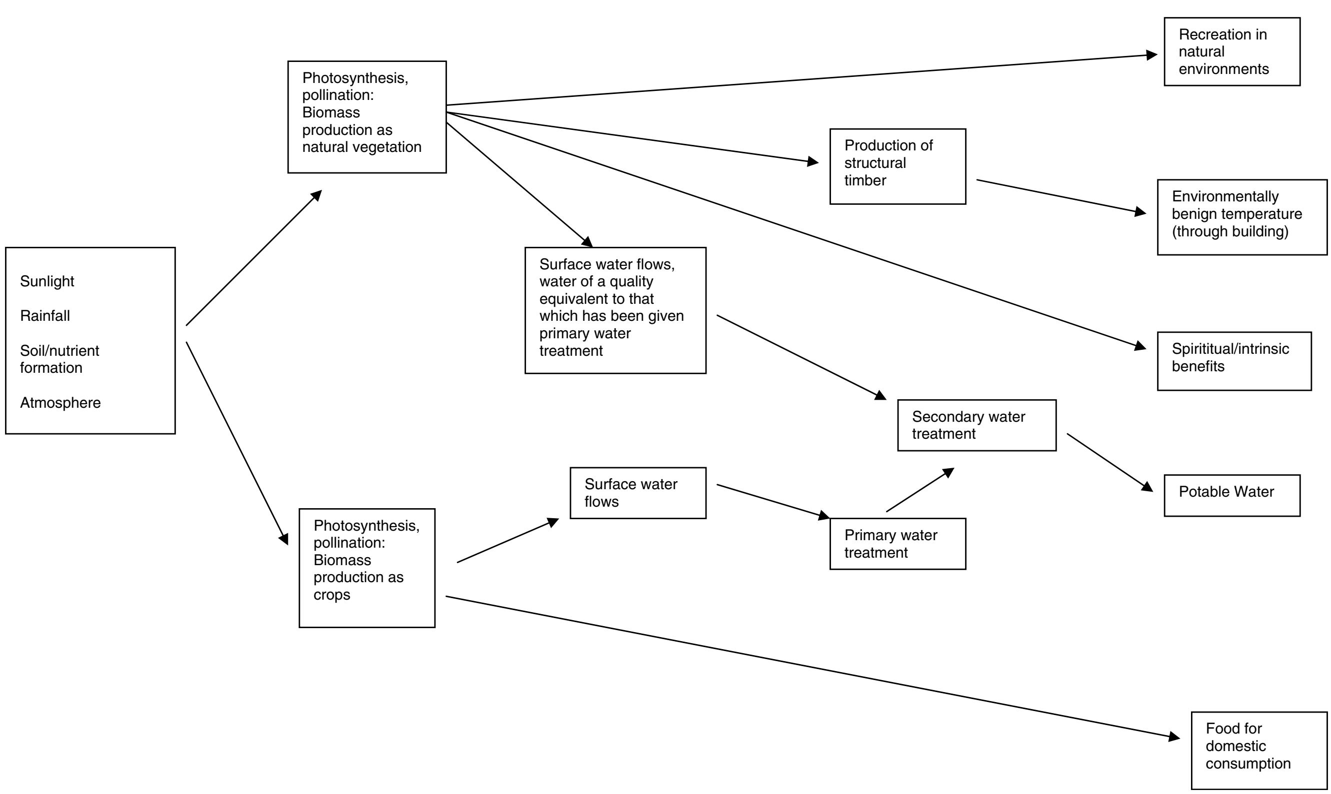

Fig. 2 – Simplified scheme of the ecosystem pathways for delivering five ecosystem services (right side).

Based on this analysis, an examination of the classifications of ecosystem services used by a range of authors including Costanza et al. (1997), De Groot et al. (2002), Abel et al. (2003), Groffman et al. (2004), Anielski and Wilson (2005), Eamus et al. (2005), Naiman et al. (2005), De Groot (2006), Farber et al. (2006); show that means and ends are mixed within the same category level and therefore the typologies cannot be used for effective decision-making.

Some authors have addressed aspects of this problem. For example, Hein et al. (2006) combine the regulating and provisioning service categories into a single class of regulating services. They also recognise that in valuing ecosystem services many of the regulating services underpin more than one service and there is thus a risk of double counting. However, rather than reconstructing the classification system they provide rules governing when to include regulating services in valuations. In contrast, a re-structured classification of ecosystem services is proposed here that removes the risk of double counting as well as dealing with other anomalies that prevent managers using typologies such as those shown in Table 2 in effective decision systems.

3. Components of an effective classification of ecosystem services

An effective typology of ecosystem services is underpinned by:

1. A minimum set of sharply defined terms that effectively encompass the topic.
2. Clarity concerning the terms used to characterise services.
3. Specification of the point at which linked processes deliver a service.

Definition of terms (1) was dealt with above and is further elaborated in the Appendix. Items (2) and (3) are discussed below as a basis for the proposed classification of ecosystem services that follows.

3.1. *Terms used to characterise services*

Based on the work of the Millennium Ecosystem Assessment (2005), the full range of benefits reflecting human well-being from ecosystems must be represented in any effective description of ecosystem services. From the definitions provided in this document, and the ecosystem components shown in Fig. 1, this aspect resolves into the question: Should ecosystem services arising from natural resource management be described primarily in terms of delivering a particular structure and composition of ecosystems, or in terms of maintaining a certain range, redundancy and intensity of ecosystem processes?

This question is not one of relative importance – ecosystems do not exist without both biotic and abiotic elements, and processes. Rather, the issue is whether in planning the management of natural resources we should focus primarily on ecosystem elements (or assets) to define goal options, or on ecosystem processes. It is argued here that the definition of goal options, and therefore services, should be in terms of ecosystem elements for three reasons.

Firstly, it is reasonable to assume that ecosystem resilience (as defined by Walker et al., 2004) is partly dependent on there being redundancies in ecosystem processes linked to the level of biodiversity (Main, 1981, 1992; Hooper et al., 2005); for example, many alternative pathways for nitrogen fixation. Therefore, an ecosystem's resilience and ability to continue producing services could be characterised in terms of ecosystem processes. Measures might include the types, rates and redundancy in processes at a particular site. However, at any one site we generally have a poor understanding of the full range of ecosystem processes and their interaction with ecosystem elements (Brooks et al., 2004). For instance, although our knowledge of some food webs (nutrient processes) is quite sophisticated, there is still considerable uncertainty about predicting the outcomes of change (Harris, 1988; Pimm, 1991; Hooper et al., 2005). We know even less about how multiple fluxes and cycles link to the composition and structure of particular ecosystems. While ecosystem elements, and particularly biodiversity, are also difficult to measure, we invariably have far more information about them than processes at a given site. The structure and composition of ecosystems are also more readily observed and measured.

Therefore, structure and composition are better surrogates for ecosystem processes than vice versa. As noted by Angermeier and Karr (1994, p. 694): "In practice, [biotic] elements are used more frequently than processes as indicators of integrity because elements are typically more sensitive to degradation, more fully understood, and less expensive to monitor. Thus, biodiversity is an important indicator of biological integrity".

Further supporting this conclusion is that we use undesirable changes in ecosystem composition or structure to signal that processes are threatening the human values of systems. In south-west Western Australia, the decline in abundance and distribution of medium-sized native mammals was a signal that one or more threatening processes were at work. Researchers investigated a range of processes before finding that predation by the introduced fox (*Vulpes vulpes*) was one of the major factors in the decline of native mammals (Kinnear et al., 2002).

Secondly, if we measure success in terms of maintenance of ecosystem processes, then given our lack of knowledge, it is likely that we would manage a limited subset of processes inadequate to support the range of ecosystem assets required for a satisfactory level of human well-being. Many species, or genotypes, or assemblages, may be considered irrelevant to maintaining key processes, and from a management perspective based solely on processes, their extinction would not be considered an issue. Both Angermeier and Karr (1994) and Hooper et al. (2005) note that maintenance of some ecosystem processes is not affected by the extinction of particular species.

Finally, humans measure their well-being either in terms of tangible benefits, such as food, water, property, gold, luxury goods; or in term of abstract benefits such as a sense of being loved, or contentment. In both cases the benefits are expressed in terms of quantity, not in terms of whether the nitrogen or carbon or political cycles are working adequately. If we are to engage a wide range of people in natural resource decisions, particularly those relating to biodiversity, then the measures used to evaluate options must be in concrete terms that are overtly relevant to the daily lives of people.

In conclusion, it is argued that goal options and ecosystem services should be described in terms of the structure and composition of ecosystem elements or their surrogates. In this context, the task of managers is to influence ecosystem processes to ensure that the composition and structure of ecosystem elements continuously delivers human well-being.

3.2. *Point at which linked processes deliver a service*

Ecosystem services are defined above as the benefits people obtain from ecosystems, a seemingly unambiguous end-point for decision purposes. However, different benefits may themselves be linked through processes. For example, cereal crops may either be used directly as food by humans, or fed to animals which are then eaten. At what point then, does the service arise? It is important to resolve this question otherwise double-counting of services may occur and decision sets may be constructed that do not form a logical set. The position taken here is that the point at which an ecosystem directly provides an asset that is used by one or more humans is the relevant end of a causal chain, the delivery of a service. In the above example, the point at which the asset is consumed by one or more humans is the point where the service occurs and should be evaluated.

This approach ensures that all services are equal in that they will always be ecosystem assets that are directly used or otherwise of benefit to individual humans. This is consistent with economic cost-benefit analyses where intermediate biophysical effects are ignored while related benefits are evaluated (Sinden and Thampapillai, 1995).

This discussion highlights the potential for ambiguity in endpoints, an issue that also arises in the next section where services are grouped according to the values they support. In this regard, it is assumed here that humans are individual organisms ultimately seeking to achieve values (see Appendix for details), the sum of which measure human well-being. These values are focused on survival and reproduction, but also reflect the aspiration of individuals to survive and reproduce under comparatively benign conditions. That is, humans do not make decisions concerning their lives merely to obtain the bare minimum to survive and reproduce, but to do this with a reasonable quality of life. The broad components that make up a reasonable quality of life are likely to be consistent across cultures, but the relative weighting, specification and means of achieving these components will vary among cultures and among individuals from any one culture. This is consistent with the second of Rokeach's (1973 p. 5) five assumptions concerning the nature of human values, namely that "all men everywhere possess the same values to varying degrees".

Thus, it is possible to examine trade-offs and other aspects of decisions at either the level of services or the level of values. This should not cause difficulties provided decisions are made among either services or values, not a mixture of both, and the set of endpoints chosen are relevant to the goal driving the decision.

Having resolved that the structure and composition of ecosystem elements are the form in which ecosystem services and human well-being should be defined, and also that the points at which ecosystems provide assets of benefit to individual humans are services, we can return to the issue of ecosystem services and their classification for decision-making.

4. An alternative classification

In developing the following classification the aim has been to provide a framework in which the consequences for human well-being of manipulating ecosystems may be assessed. This allows analysis of options for improved management of biological and other natural resources so that their contributions to human well-being may be both conserved and sustained.

This goal draws heavily on that of the Millennium Ecosystem Assessment (2005) where the issues pertaining to the development of a classification of ecosystem services are well described. In particular, the essentially anthropocentric nature of this exercise is acknowledged with the result that at least some constructions of intrinsic values (Callicott, 1986; O'Neill, 1992) are not accounted for (see also discussion of values in the Appendix).

The classification system proposed below (Table 3) builds on the conclusions of Section 3. The services are described in terms of the structure and composition of particular ecosystem elements (expressed as assets), and these services are in turn classified according to the specific human values they support. This typology is based on the needs of organisms outlined by Wallace et al. (2003, Appendix 4), which follows the work of Andrewartha (1971). The socio-cultural component of Table 3 draws on the values described in the Millennium Ecosystem Assessment (2005) and Wallace et al. (2003, Appendix 2). The ideas of Maslow (1970) have also influenced the construction of the table.

The categories of services used in this classification – adequate resources; benign physical and chemical environment; protection from predators, disease and parasites; and socio-cultural fulfilment – are human values. They are defined as follows.

4.1. *Adequate resources*

Resources are defined in Wallace et al. (2003, p. 55) as the "basic needs [that] support the life of individuals. They must be in sufficient supply for survival and reproduction – under normal circumstances they have a lower, quantity threshold, but not an upper threshold. This is one feature that distinguishes resources from physical and chemical tolerances. Some factors listed here (Table 3) overlap with physical and chemical factors .... However, they are included here as they represent a resource that becomes an issue when they are below a particular quantity, rather than needing to be within a specific range of thresholds for survival and reproduction". All resources may be expressed in terms of the composition and structure of ecosystems. For example, food must be of a type that supplies adequate nutrition, and be available in sufficient quantities in time and space to meet the needs of humans.

Table 3 – Proposed classification of ecosystem services and links to human values, ecosystem processes, and natural assets

Category of human values	Ecosystem services – experienced at the individual human level	Examples of processes and assets that need to be managed to deliver ecosystem services
Adequate resources	• Food (for organism energy, structure, key chemical reactions) • Oxygen • Water (potable) • Energy (eg, for cooking – warming component under physical and chemical environment) • Dispersal aids (transport)	*Ecosystem processes* • Biological regulation • Climate regulation • Disturbance regimes, including wildfires, cyclones, flooding • Gas regulation • Management of "beauty" at landscape and local scales. • Management of land for recreation • Nutrient regulation • Pollination • Production of raw materials for clothing, food, construction, etc. • Production of raw materials for energy, such as firewood • Production of medicines • Socio-cultural interactions • Soil formation • Soil retention • Waste regulation and supply • Economic processes
Protection from predators/disease/parasites	• Protection from predation • Protection from disease and parasites	
Benign physical and chemical environment	Benign environmental regimes of: • Temperature (energy, includes use of fire for warming) • Moisture • Light (eg, to establish circadian rhythms) • Chemical	
Socio-cultural fulfilment	Access to resources for: • Spiritual/philosophical contentment • A benign social group, including access to mates and being loved • Recreation/leisure • Meaningful occupation • Aesthetics • Opportunity values, capacity for cultural and biological evolution – Knowledge/education resources – Genetic resources	*Biotic and abiotic elements* Processes are managed to provide a particular composition and structure of ecosystem elements. Elements may be described as natural resource assets, eg: • Biodiversity assets • Land (soil/geomorphology) assets • Water assets • Air assets • Energy assets

Ecosystem services consistently relate to specific human values, but processes and assets do not. Most processes and assets contribute to a wide range of services.

4.2. *Protection from predators, disease and parasites*

The importance of this category is self-explanatory. However, it differs from other categories in that it relates to ensuring that the abundance and distribution of harmful organisms is sufficiently low that human well-being is not threatened. Thus, the category is still defined in terms of the composition and structure of ecosystems.

4.3. *Benign physical and chemical environment*

As noted in Wallace et al. (2003, p. 56), "organisms come into direct contact with a range of chemical and physical factors in their environment. Survival and reproduction will generally depend on these factors lying either within a specific range, e.g., moisture and temperature, or on these factors not exceeding certain intensity thresholds (such as in the case of fire)". Ecosystem processes that maintain the human physical and chemical environment within the tolerance levels of humans deliver this category of service. While most physical and chemical aspects of the environment are expressed in terms of ecosystem structure and composition, those relating to energy are not, and this raises the issue of just how energy should be treated in this analysis.

Energy can be expressed in two ways. Firstly, it may be counted as potential energy stored in ecosystem elements – for example, as an amount of carbohydrate available for use by one or more organisms. Secondly, energy may be expressed as a rate of change, as is the case with ecosystem processes. Here the dual nature of energy is accepted, but it is treated as an abiotic element of ecosystems for ease of classification. This is clearly not an entirely satisfactory solution, and the relevant concepts need to be explored further.

4.4. *Socio-cultural fulfilment*

Services leading to socio-cultural fulfilment shown in Table 3 are intended as an indicative list, and require considerable further development. For example, the spiritual/philosophical contentment category recognises that all humans operate within either an explicit or implicit set of beliefs that establish and explain the place of humans in the world and universe, including birth and death; and provide guidance for how we should live our lives and interact with other people, other organisms, and the inanimate world. Although it is assumed here that this category encompasses ethical positions including those related to intrinsic values, there are important alternative views (O'Neill, 1992; Lockwood, 1999). Just how such a category should be constructed requires further deliberation, and it is clear from the considerable diversity of environmental thought reviewed by Hay (2002) that it will be difficult to elaborate a single structural classification, although one is important for effective decision-making.

Overall, while the elements listed in the socio-cultural category are all important, their relationships both within a hierarchy and as a set of mutually exclusive elements need to be worked through much more thoroughly by people with the appropriate social, psychological and philosophical knowledge. As with energy, there is some ambiguity concerning the definition of social-cultural services within ecosystems. However, given that they are expressed as amounts, rather than rates, they are considered as ecosystem elements whose structure and composition may be assessed at different points in time.

In summary, the classification provide in Table 3 provides a consistent typology of ecosystem services linked to human values. However, there is still considerable scope for clarification as noted in relation to the socio-cultural category. Also, it is emphasised that while the categories of values are likely to be broadly consistent across different cultures, how they are achieved and their relative weighting will vary considerably.

Ecosystem services are arranged in Table 3 to match the values that they maintain. In contrast, ecosystem processes and assets are not specifically linked to any single ecosystem service or category of values – they generally contribute across all categories. These multiple linkages between both processes and assets on the one hand, and services and values on the other, make conceptualising decision-making complex. However, this classification system disentangles the frequent confusion between processes and services and provides a basis for elaborating decision systems. The final section below briefly examines the application of the ecosystem services structure shown in Table 3 to decisions using the ecosystem described in Fig. 2.

5. Decisions and ecosystem services

Fig. 2, a very simplified diagram showing some of the ecosystem pathways delivering five ecosystem services, was constructed using the classification system outlined in Table 3. Using this scheme, it can be seen that managers may influence ecosystem processes and assets to variously deliver the five services shown. While decision-makers can usefully concern themselves with the relative amounts of the ecosystem services that need to be delivered for human well-being, it is illogical to discuss the relative merits of the processes leading to these services except in the context of the services themselves.

For example, one cannot decide how much of the land surface of a particular region should be given over to natural ecosystems and how much to cropping ecosystems without knowing the relative degree to which the corresponding services are required for human well-being. Similarly, given the types of relationships shown in Fig. 2, it makes little sense to evaluate the merits of increasing surface water flows without knowing whether there is any need to increase potable water production. Even in terms of efficiency, one cannot know whether more efficient, and therefore cheaper, water delivery is important without knowing whether the price of potable water is affecting services, or whether providing cheaper water would come at an unacceptable cost to another service.

Although the classification of services in Table 3 provides a sound basis for developing a decision framework, there are other, important components of an effective decision process. These include spatially and temporally defined goals for the use of natural resources, mechanisms for evaluating management feasibility and risks, and clarity as to the human individual(s) and community(ies) to be included in decisions (local, regional, state, national, or global). These are vital issues that need to be dealt with in any effective decision process. Some of these issues, particularly in relation to goal-setting, are discussed in Wallace (2006); and Hein et al. (2006) outline the linkage between spatial scales, ecosystem services, and stakeholders.

Finally, although a classification of ecosystem services that clearly links ecosystem processes and elements with values improves decision processes, the relative weighting either among services or values is ultimately a socio-political assessment shaped by the specific context in which a particular decision is made. Such assessments and related processes may be described and informed by science, but are not themselves scientific.

6. Conclusions

The concept of ecosystem services can underpin effective natural resource decisions, including trade-offs. However, the above discussion has shown that it is essential to clearly separate means (processes) and ends (services) when classifying ecosystem services. Linguistic uncertainty attached to key terms – such as ecosystem processes, functions and services – has also caused difficulties in developing an effective typology of services.

This paper has clarified definitions and developed a system of classifying ecosystem services (Table 3) that may be used to evaluate alternative uses of biological and other natural resources so that decisions maximise the probability that human values can be maintained in the long-term. The classification system explicitly links values with ecosystem services, ecosystem processes and natural and socio-cultural assets. Values describe important aspects of human well-being, and thus should assist those charged with communicating the importance of natural resources. This is particularly important in decisions involving biodiversity where values are often not clearly stated and thus compete weakly when trade-offs occur.

However, it is acknowledged that this framework needs further development. Socio-cultural aspects of ecosystem services and human values, in particular, need much more comprehensive analysis. This is properly the role of a collaborative partnership among biologists, philosophers, sociologists, psychologists and economists. Further improvements will also better describe the place of energy in ecosystems and its relationship to ecosystem services.

Although the concepts developed in this paper have evolved from experience managing natural assets in rural landscapes, these ideas are equally applicable to urban and other predominantly cultural systems. Planning and decision-making generally involve ecosystems with a mixture of natural and cultural elements. Therefore, the classification of services was deliberately designed here to allow decisions concerning natural and cultural resources to be integrated in the same decision process.

Effective decision-making also entails a number of other characteristics beyond the scope of this paper. Most importantly, the goals driving decisions, including their spatial and temporal aspects, must be clearly stated. Other prerequisites for successful decision-making include identifying and involving those who should be represented in the evaluation process, and incorporating measures of management feasibility and risk in assessments.

Finally, in western societies a major challenge is reconciling short-term private desires with the long-term needs of both individuals and communities (Hay, 2002). The effective classification of ecosystem services and human values is a foundation step in this process. However, it is acknowledged that the relative weighting of different values and services is ultimately a socio-political process. Science may inform and assist this process, but it is not a scientific process.

Acknowledgements

Discussions with colleagues and critiques from reviewers have been an essential component of testing and developing the ideas in this paper. In particular, comments, references and suggestions from: Nick Abel, John Bartle, Margaret Byrne, Steve Cork, David Freudenberger, Carol Lacroix, Cliff Lloyd, Michael Lockwood, Richard McKellar, Ryan Vogwill and Brian Walker were particularly helpful.

Appendix. Explanation of definitions

Asset

The Oxford Dictionary definition of the term asset as denoting a "thing or person of use or value" is the general meaning used here. Given the specific explanation of value below, natural assets are defined here as the natural abiotic and biotic elements of ecosystems that are considered to be of use to humans. (See also biodiversity asset, defined below.) The terms natural resources and natural assets are taken here to be synonymous. Both terms are also synonymous with 'natural capital' as defined by De Groot et al. (2003).

It may be argued that all abiotic and biotic elements of ecosystems are of use to humans, and that all the natural elements of ecosystems are therefore assets. Given that others will argue that some ecosystem elements, such as disease organisms, are not of human use, a conservative approach is adopted in this document which allows for natural assets to be considered as a sub-set of the natural biotic and abiotic elements of ecosystems.

Biodiversity

Biodiversity is the variety of life forms including the different plants, animals, fungi, microorganisms, etc. It is generally seen as encompassing genetic, species (taxonomic), structural and assemblage (or biological community) diversity. While ecosystem diversity is also often included, the approach here is that the term biodiversity should be confined to a description of living elements, and that ecosystem processes and abiotic components should be excluded. Support for this view is provided in Angermeier and Karr (1994), Callicott et al. (1999), and Wallace et al. (2003).

Although culturally derived biodiversity, such as domestic animals, may be excluded from the definition of biodiversity (Angermeier and Karr, 1994), here the term is taken to include all biological elements in ecosystems so that decision-makers may identify the synergies and trade-offs at the level of whole systems. However, throughout this document the term biodiversity is used as shorthand for natural biodiversity unless otherwise stated.

Biodiversity asset

In this document, a biodiversity asset is defined as a living entity, or group of living entities, that are useful to humans. Although some people express considerable disquiet that such an economic and anthropomorphic approach is used in the environmental arena (Hay, 2002), it is consistent with the human, value-centred approach taken with ecosystem services (for example, De Groot et al., 2003; Millennium Ecosystem Assessment, 2005), and other philosophical positions and beliefs may be accounted for within the socio-cultural services for human well-being described in Table 3. Throughout this document the term biodiversity asset refers to natural biodiversity assets unless otherwise stated.

Ecosystem

The term ecosystem is used here in the sense of Tirri et al. (1998) as "a functional entity or unit formed locally by all the organisms and their physical (abiotic) environment interacting with each other". This definition encompasses those elements of the biotic and abiotic environment that are culturally derived – such as domestic animals, buildings, roads and humans themselves – as well as natural elements. Often the term ecosystem is used in a way that implies only the natural elements of ecosystems. Given that this paper deals with ecosystem services from natural assets, all the ecosystems considered here contain at least some natural elements.

Ecosystem function

The term ecosystem function has been variously used, sometimes to describe the actual functioning of ecosystems, such as energy fluxes and nutrient recycling; and sometimes to describe the benefits obtained by humans from ecosystems (De Groot et al., 2002; De Groot, 2006). It is common to find the terms ecosystem function and ecosystem process used as synonyms within the same document.

While one approach is to more specifically define ecosystem function (De Groot et al., 2002; De Groot, 2006), in the development of this paper, it was found that the term is not required provided ecosystem services, processes, structure and composition are suitably defined. Therefore, given that parsimony of terms generally leads to greater clarity, the term ecosystem function is treated here as a synonym of ecosystem processes, and it is not used.

Ecosystem processes and services are defined separately below. With regard to ecosystem structure and composition, Noss (1990, pp. 356–7) has stated that "composition has to do with the identity and variety of elements in a collection" and structure "is the physical organization or pattern of a system". For an ecosystem, these terms are interpreted here as follows. Composition of an ecosystem is taken as comprising the types and abundance of biotic and abiotic elements in a defined ecosystem; and structure refers to their distribution and arrangement.

Ecosystem processes

Process is defined by Tirri et al. (1998) as "a series of events, reactions or operations, achieving a certain definite result". Ecosystem processes are, therefore, defined here as the complex interactions (events, reactions or operations) among biotic and abiotic elements of ecosystems that lead to a definite result. In broad terms, these processes involve the transfer of energy and materials (Lyons et al., 2005).

Key processes include energy, nutrient, oxygen and water cycles and fluxes. It is important to note that these processes occur both within and outside organisms, and involve geochemical (such as volcanism and plate tectonics) and cosmic (sunlight) processes that occur at least partly outside the biosphere. Also, this definition of processes includes sociocultural processes.

An important distinction between ecosystem elements (both biotic and abiotic) and processes is that the former are generally tangible entities described in terms of amount, while the latter are operations and reactions and generally described in terms of rates (for example, change or production per unit time).

Ecosystem services

Such services are defined in the Millennium Ecosystem Assessment (2005, p. 1) as "the benefits people obtain from ecosystems." These benefits include food, water, timber, leisure, spiritual benefits, etc. Given the above definition of ecosystem, these services may be obtained from either natural or cultural elements of ecosystems, or some combination of both. However, in the literature it is generally implied or stated that ecosystem services are those derived from natural elements of ecosystems. The narrower meaning is used throughout this document, which concentrates on ecosystem services derived from natural elements. However, in planning urban and rural systems with few natural elements the broader meaning is valid, and the principles outlined in this document are equally applicable.

Alternative definitions of ecosystem services were investigated. For example, Binning et al. (2001, see Table 2, p. 21) have defined ecosystem services as one of the means by which ecosystem goods are produced, rather than as the goods and services themselves. However, neither this nor alternative approaches investigated developed effective separation of means and ends within their typologies.

It is also acknowledged that although in everyday language there is a general differentiation between goods (such as food, furniture, timber) and services (such as health services, aesthetic provision); in the ecological and related economic literature the term services is sometimes used to include both goods and services, and at other times not. The definitions in Eatwell et al. (1987) show that both terms are variously used in the economics literature. Thus, it may ultimately prove preferable to introduce a new term, such as ecosystem benefit, for ecosystem services. Nevertheless, the definition used by the Millennium Ecosystem Assessment (2005) is generally consistent with current usage in the literature examined, and was adopted in this work.

Value

Many different approaches have been used to define and describe natural resource values, particularly in relation to biodiversity conservation (see, for example, Brown, 1984; Norton, 1986; Hampicke, 1994; Noss and Cooperrider, 1994; Burgman and Lindenmayer, 1998; Edwards and Abivardi, 1998; Lockwood, 1999; Chee, 2004; Worboys et al., 2005; Fischer and van der Wal, 2007).

In relation to ecological resources, Straton (2006) discusses values from a variety of ecological and economic perspectives, and this underlines the potential complexity of the term. Lockwood's (1999 p. 382) comment that "At present, we only have limited understanding of individuals' values, the ways that they are expressed, and means of appropriately incorporating them into our decision making processes" remains highly relevant.

Rokeach (1973, p. 5) defines the term value thus: "A value is an enduring belief that a specific mode of conduct or end-state of existence is personally or socially preferable to an opposite or converse mode of conduct or end-state of existence". This is a relevant starting point given that here we are particularly concerned with end-states of existence, or terminal values. Rokeach lists 18 terminal values including freedom, inner harmony, a comfortable life and family security. Although he (p. 14) conceptualises these as "supergoals beyond immediate, biologically urgent goals"; values such as a comfortable life would seem to be inextricably linked to adequate resources, such as food and shelter.

Rokeach also states that he opposes the view held by many, particularly Maslow (1954), that values and needs are synonymous. However, he does note (p. 20) that "Values are the cognitive representations and transformations of needs" and that "when a person tells us about his values he is surely also telling us about his needs".

Given that current classifications of environmental values invariably list resources such as food and water as important, and that the biological requirements of humans are planned over long timeframes, not just as urgent biological requirements, needs are considered here to constitute important end-states or terminal values. Thus, the definition of values used in Table 1 and followed in Table 3 (proposed classification of services) is that they are the preferred end-states of existence, including those required for human survival and reproductive success, which taken together circumscribe human well-being.

The above discussion takes an anthropomorphic approach to values. The concept of intrinsic values, that non-human organisms and/or inanimate things have value independent of their value to humans is not directly dealt with here, except that some aspects of intrinsic value and related ethical positions are incorporated within the spiritual/philosophical service listed in Table 3. It is assumed that this will cover most circumstances where values are actually assigned within a particular decision process; however, it is understood that this will not be acceptable to all.

REFERENCES

Abel, S., Cork, S., Gorddard, R., Langridge, J., Langston, A., Plant, R., Proctor, W., Ryan, P., Shelton, D., Walker, B., Yialeloglou, M., 2003. Natural Values: Exploring Options for Enhancing Ecosystem Services in the Goulburn Broken Catchment. CSIRO Sustainable Ecosystems, Canberra.

Andrewartha, H.G., 1971. Introduction to the Study of Animal Populations, second ed. The University of Chicago Press, Chicago.

Angermeier, P.L., Karr, J.R., 1994. Biological integrity versus biological diversity as policy directives. Bioscience 44, 690–697.

Anielski, M., Wilson, S., 2005. Counting Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystems. The Pembina Institute, Drayton Valley. <http://www.pembina.org/pdf/publications/Boreal_FINAL.pdf>.

Binning, C., Cork, S., Parry, R., Shelton, D., 2001. Natural Assets: An Inventory of Ecosystem Goods and Services in the Goulburn Broken Catchment. CSIRO Sustainable Ecosystems, Canberra. <http://www.ecosystemservicesproject.org/html/publications/index.htm>.

Brooks, T., DA Fonseca, G.A.B., Rodrigues, A.S.L., 2004. Species, data, and conservation planning. Conservation Biology 18, 1682–1688.

Brown, T.C., 1984. The concept of value in resource allocation. Land Economics 60, 231–246.

Burgman, M., 2005. Risks and Decisions for Conservation and Environmental Management. Cambridge University Press, Cambridge.

Burgman, M.A., Lindenmayer, D.B., 1998. Conservation Biology for the Australian Environment. Surrey Beatty, Chipping Norton, Sydney.

Callicott, J.B., 1986. On the intrinsic value of nonhuman species. In: Norton, B.G. (Ed.), The Preservation of Species: The Value of Biological Diversity. Princeton University Press, Princeton, New Jersey, pp. 138–172.

Callicott, J.B., Crowder, L.B., Mumford, K., 1999. Current normative concepts in conservation. Conservation Biology 13, 22–35.

Chee, Y.E., 2004. An ecological perspective on the valuation of ecosystem services. Biological Conservation 120, 549–565.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The values of the world's ecosystem services and natural capital. Nature 387, 253–260.

De Groot, R., 2006. Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. Landscape and Urban Planning 75, 175–186.

De Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41, 393–408.

De Groot, R., Van der Perk, J., Chiesura, A., van Vliet, A., 2003. Importance and threat as determining factors for criticality of natural capital. Ecological Economics 44, 187–204.

Eamus, D., Macinnis-Ng, C.M.O., Hose, G.C., Zeppel, M.J.B., Taylor, D.T., Murray, B.R., 2005. Turner Review No. 9: Ecosystem services: an ecophysiological examination. Australian Journal of Botany 53, 1–19.

Eatwell, J., Milgate, M., Newman, P., 1987. The New Palgrave: A Dictionary of Economics. The Macmillan Press Limited, London.

Edwards, P.J., Abivardi, C., 1998. The value of biodiversity: where ecology and economy blend. Biological Conservation 83, 239–246.

Farber, S., Costanza, R., Childers, D.L., Erickson, J., Gross, K., Grove, M., Hopkinson, C.S., Kahn, J., Pincetl, S., Troy, A., Warren, P., Wilson, M., 2006. Linking ecology and economics for ecosystem management. Bioscience 56, 121–133.

Fischer, A., van der Wal, R., 2007. Invasive plant suppresses charismatic seabird – the construction of attitudes towards biodiversity management options. Biological Conservation 135, 256–267.

Groffman, P.M., Driscoll, C.T., Likens, G.E., Fahey, T.J., Holmes, R.T., Eagar, C., Aber, J.D., 2004. Nor gloom of night: a new conceptual model for the Hubbard Brook ecosystem study. Bioscience 54, 139–148.

Hampicke, U., 1994. Ethics and economics of conservation. Biological Conservation 67, 219–231.

Harris, L.D., 1988. The nature of cumulative impacts on biotic diversity of wetland vertebrates. Environmental Management 12, 675–693.

Hay, P., 2002. Main Currents in Western Environmental Thought. University of New South Wales Press, Sydney.

Hein, L., van Koppen, K., De Groot, R.S., van Ierland, E.C., 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecological Economics 57, 209–228.

Hooper, D.U., Chapin III, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setala, H., Symstad, A.J., Vandermeer, J., Wardle, D.A., 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological Monographs 75, 3–35.

Kinnear, J.E., Sumner, N.R., Onus, M.L., 2002. The red fox in Australia – an exotic predator turned biocontrol agent. Biological Conservation 108, 335–359.

Kremen, C., 2005. Managing ecosystem services: what do we need to know about their ecology? Ecology Letters 8, 468–479.

Lockwood, M., 1999. Humans valuing nature: synthesising insights from philosophy, psychology and economics. Environmental Values 8, 381–401.

Lyons, K.G., Brigham, C.A., Traut, B.H., Schwartz, M.W., 2005. Rare species and ecosystem functioning. Conservation Biology 19, 1019–1024.

Main, A.R., 1981. Ecosystem theory and management. Journal of the Royal Society of Western Australia 4 (Pt 1), 1–4.

Main, A.R., 1992. The role of diversity in ecosystem function: an overview. In: Hobbs, R.J. (Ed.), Biodiversity of Mediterranean Ecosystems in Australia. Surrey Beatty & Sons, Chipping Norton, pp. 77–93.

Maslow, A.H., 1954. Motivation and Personality. Harper & Row, New York. Cited in Rokeach, M., 1973. The Nature of Human Values. The Free Press, New York.

Maslow, A.H., 1970. Motivation and Personality. second ed. Harper & Row, New York.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC.

Naiman, R.J., Decamps, H., McClain, M.E., 2005. Riparia: Ecology, Conservation, and Management of Streamside Communities. Elsevier Academic Press, London.

Norton, B.G. (Ed.), 1986. The Preservation of Species: The Value of Biological Diversity. Princeton University Press, Princeton, New Jersey.

Noss, R.F., 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4, 355–364.

Noss, R.F., Cooperrider, A.Y., 1994. Saving Nature's Legacy: Protecting and Restoring Biodiversity. Island Press, Washington DC.

O'Neill, J., 1992. The varieties of intrinsic value. Monist 75, 119–133.

Pimm, S.L., 1991. The Balance of Nature? Ecological Issues in the Conservation of Species and Communities. The University of Chicago Press, Chicago.

Rokeach, M., 1973. The Nature of Human Values. The Free Press, New York.

Sinden, J.A., Thampapillai, D.J., 1995. Introduction to Benefit-Cost Analysis. Longman, Melbourne.

Straton, A., 2006. A complex systems approach to the value of ecological resources. Ecological Economics 56, 402–411.

Tirri, R., Lehtonen, J., Lemmetyinen, R., Pihakaski, S., Portin, P., 1998. Elsevier's Dictionary of Biology. Elsevier, Amsterdam.

Walker, B., Holling, C.S., Carpenter, S.R., Kinzig, A., 2004. Resilience, adaptability and transformability in social-ecological systems. Ecology and Society 9, 5. URL:http://www.ecologyandsociety.org/vol9/iss2/art5.

Wallace, K.J., 2006. A decision framework for natural resource management: a case study using plant introductions. Australian Journal of Experimental Agriculture 46, 1397–1405.

Wallace, K.J., Beecham B.C., Bone, B.H., 2003. Managing Natural Biodiversity in the Western Australian Wheatbelt: A Conceptual Framework. Department of Conservation and Land Management, Perth. http://www.naturebase.net/component/option,com_docman/task,doc_download/gid,756/.

Worboys, G.L., Lockwood, M., De Lacy, T., 2005. Protected Area Management: Principles and Practice. Oxford University Press, South Melbourne.