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Ecosystem services and associated concepts†

Jan McP. Dick[a*], Rognvald I. Smith[a] and E. Marian Scott[b]

In this paper, we explore the practicality and limitations of the ecosystem services concept. The enthusiasm for the analytical investigation of services delivered by ecosystems is driven by the realisation that local, national and international policies are not protecting ecosystems and the full range of services they deliver to humans. We briefly review the history of the term and consider a range of analytical frameworks proposed to study ecosystem services. The problem of understanding ecosystems across varying spatial and temporal scales is a recurring theme and we argue that systems analysis such as world-systems and panarchy analysis is useful in this context. Translating any one of these frameworks to an operational definition presents some challenges, which are briefly discussed in terms of measurement and quantification.
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Keywords: panarchy; world-systems analysis; ISSE; Environmental Change Network

This paper explores the status of ecosystem services, a topic that has become an active research area in recent years. By ecosystem, we mean all the organisms living in a particular area and the physical components of the environment with which the organisms interact, and ecosystem services are considered to be the benefits that humans obtain from ecosystems (Table 1).

Man has been evaluating the goods and services delivered by ecosystems even before *Homo sapiens* replaced *Homo neanderthalensis* some 27 000–30 000 years ago (Caramelli *et al*., 2008). Human settlements historically are often where rivers join the sea thereby combining the ecosystem services delivered by marine, terrestrial and aquatic ecosystems (food, water, transport, aesthetic, recreation, etc.). This tendency persists to the present day with 17 of the world's 25 largest cities being situated close to the mouth of a river; this represents 70% of the 322 million citizens in the world's 25 largest cities.

It is however only recently that the term has become a recognised topic of scientific study. The concept of 'ecosystem services' delivered by a landscape is clearly embedded in other associated concepts which consider ecosystems in a wider context (Table 1). An analysis of the peer reviewed literature using the internationally recognised web-based search facility Web of Science was used to explore the connectivity of ecosystem service research with other such concepts. Limiting the analysis to peer reviewed journals is restrictive but it does provide a tightly bound study indicative of the wider research community. We fully acknowledge the omission of the significant contribution to the dynamic thinking in this area made by many reports from international organisations such as The World Bank, FAO, World Wildlife Fund, Nature Conservation, etc. We are therefore not claiming that the following data fully reflect the evolution or connectivity of the concepts; rather they simply illustrate the progression of the concepts in the peer reviewed literature and the increasing level of interest in the concept of ecosystem services within the scientific community.

Searching the Web of Science database using the search 'topic' function and keywords returned the total numbers of records which were then further refined using other terms which we consider were linking terms (Table 1). We captured the number of papers published each year by topic (Figure 1) and refined our search with other terms in a matrix approach to obtain the number of papers which mentioned more than one of the search terms (Figure 2). We chose search terms which appeared in the literature connected to ecosystem services and reflected the holistic management of ecosystems yet were relatively discrete. Some terms reflect the analytical approach to ecosystems, e.g. ecological footprint, natural capital, environmental payment while others consider a more systems approach such as panarchy and world-systems concepts.

Focusing on the search term 'ecosystem service*' reveals that since the early 1980s there was a period of around 15 years when there were only one or two papers published each year including the terms ecosystem service(s) but since the late 1990s the number of papers have grown exponentially (Figure 1). The publication of the Millennium Ecosystem Assessment (MA, 2005) based on over 13,000 scientists' input and structured overtly around the concept of ecosystem services added considerably to the published literature with 60 papers published with the key terms 'millennium ecosystem assessment' since 2003.

Papers reporting research into the concept of ecosystem services fall roughly into two schools (i) the economic discipline (35% in our search with 'ecosystem service*AND econom*') and (ii) the conservation/biodiversity discipline (54% in our search with 'ecosystem

* *Correspondence to: J. McP. Dick, Centre for Ecology, Hydrology, Bush Estate, Penicuik, Midlothian EH26 0QB, U.K. E-mail: jand@ceh.ac.uk*

a *J. McP. Dick, R. I. Smith*
Centre for Ecology, Hydrology, Bush Estate, Penicuik, Midlothian EH26 0QB, U.K.

b *E. M. Scott*
Department of Statistics, University of Glasgow, Glasgow G12 8QW, U.K.

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Table 1. Explanation of the terms used in this paper

Term	Explanation
Ecosystem approach	The ecosystem approach is human-centric focusing on the services that ecosystems deliver to *Homo sapiens* (Daily, 1997; Ehrlich and Mooney, 1983)
Ecosystem services	The benefits that humans obtain from ecosystems that support, directly or indirectly, their survival and quality of life. They include provisioning, regulating and cultural services that directly benefit people, and supporting services that are necessary for the production of all other services (MA, 2003)
Natural capital	Natural capital is the extension of the economic notion of capital to goods and services relating to the natural environment. Natural capital is thus the stock of natural ecosystems that yields a flow of valuable ecosystem goods or services into the future (Costanza *et al*., 1997)
Ecological footprint	An accounting framework, to measure the extent of humanity's current demand on the planet's bioproductive capacity (Wackernagel *et al*., 2002). It represents the amount of biologically productive land and sea area needed to regenerate the resources a human population consumes and to absorb and render harmless the corresponding waste. Using this assessment, it is possible to estimate how much of the Earth (or how many planet Earths) it would take to support humanity if everybody lived a given lifestyle
Environmental payments	Payments for Ecosystem Services, also known as Payments for Environmental Services (or Benefits) broadly defined, as the practice of offering incentives to farmers or landowners in exchange for managing their land to provide some sort of ecological service (http://en.wikipedia.org/wiki/Payment_for_ecosystem_services)
Panarchy	Ecological and social-ecological systems forming nested sets of adaptive cycles (Gunderson and Holling, 2002)
World-systems theory	A world system is composed not only of intersocietal interactions, but the totality of interactions that constitute the whole social, economic and political system (Chase-Dunn *et al*., 2000)

service*' AND 'conservat*' or 'biodiver*'). The first peer reviewed paper identified by Web of Science to use the term 'ecosystem services' (Ehrlich and Mooney, 1983) was written by conservation biologists consolidating previous research. They recognised the damage done globally by humans concentrating on the extraction of provisioning services from ecosystems which had resulted in local mass extinction of species within ecosystems (e.g. agriculture, deforestation and strip mining). They argued that such practices seriously degrade other 'ecosystem services' such as water provision by disrupting aquifers and polluting water streams. Their work was not primarily linked to the economic value of these services. However, Westman (1977), an eminent researcher in the field of science, humanity and the environment, did argue in terms of economic valuation of the 'free services' delivered by nature 5 years earlier when discussing 'nature's services'. The economic discipline has long argued the utility of using money to value ecosystem services pointing out that society at the local, national and

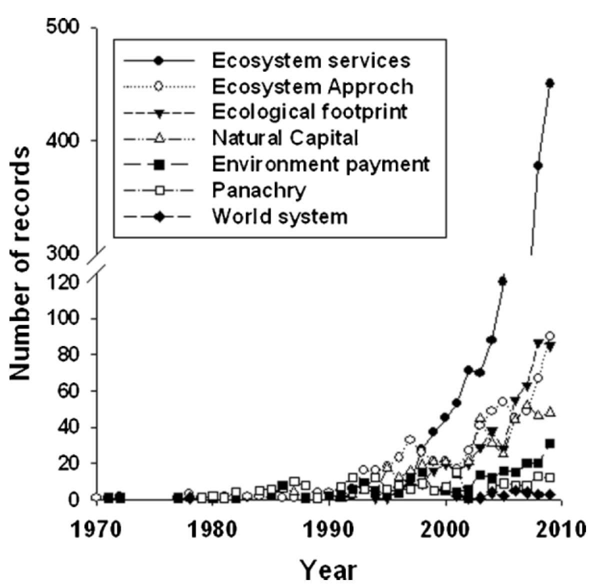

Figure 1. Number of records each year 1970–2009 by keyword searches in Web of Science (accessed 29 April 2010) exact search terms were: ecosystem service = 'ecosystem* service*'; ecological footprint = 'ecological footprint*'; natural capital = 'natur capital*'; panarchy = 'panarch*'; world-system = 'world-system* analys*' OR 'world system* theor*' OR 'world system analys*'; environ payment = 'envir* pay*' or 'envir* credit*' or 'bio* credit' or 'bio* offset*' or 'envir* bank*'

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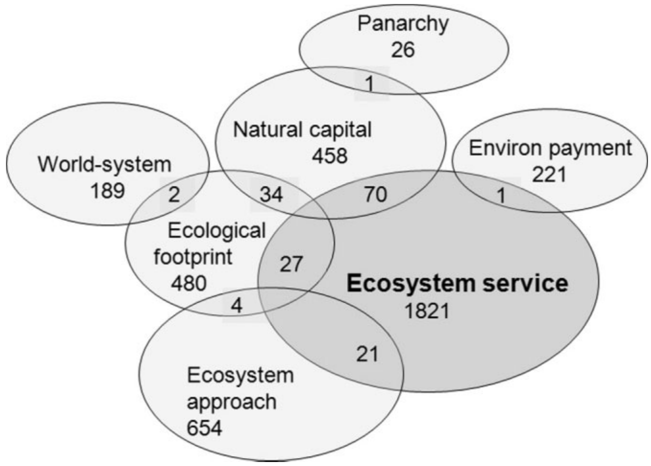

Figure 2. Number of records returned by keyword searches in Web of Science (accessed April 29 2010) and the number of records which shared two search terms (see Figure 1 for exact search terms)

international scales recognise this unit. However to date they have failed to convince a significant proportion of the scientific community that it is possible to place a monetary value on all services accrued by humans from ecosystems (Norgaard, 2008).

Researchers have also considered ecosystem dis-services either as a natural result of the ecosystem function, i.e. pest damage which reduces productivity but is increased in a monoculture agricultural ecosystem (Zhang *et al*., 2007) or as 'environmental ''bads'' borne by one party without compensation as result of actions (or inaction) by another party', e.g. fly tipping in woodland ecosystems (Agbenyega *et al*., 2009).

Although the number of papers using the key words 'natural capital', 'ecological footprint' and 'ecosystem approach' have all increased in the last 10 years, the rise has not been as dramatic as in the field of 'ecosystem service(s)' research (Figure 1). The overlap of the concepts can be roughly judged by the number of peer reviewed papers which mention both terms (Figure 2). Papers reporting studies related to the concept of natural capital were found to also mention ecosystem services most often (15%) representing in total 4% of all papers counted in the Web of Science search using the search term 'ecosystem service*'. The concept of natural capital is most often associated with the economic (63%) and policy (32%) aspects of environmental management. Papers reporting studies related to ecological footprint and ecosystem approach also overlapped with the search term 'ecosystem service*' and were also often associated with economics and policy issues. Interestingly some researchers have viewed ecological footprints simplistically as the opposite of the ecosystem services because ecological footprints are the consumption of ecosystem services by societies (Jenerette *et al*., 2006). Given the interest of economic researchers in the concept of ecosystem services it was surprising that so few papers which concentrated on environmental payments used the term ecosystem services as key words. The two systems analysis approaches considered in this review, i.e. panarchy and world-systems analysis shared no common papers and though they were linked to the concept of natural capital in the case of the former and ecological footprints in the case of the latter it is clear that few researchers have explicitly linked these systems approaches to studying ecosystem services of a landscape. We will use these concepts to explore ecosystem services delivered by an example landscape later in the paper.

The issue of spatial and temporal scale is often discussed in relation to ecosystem service research as defining the boundaries of the study are important and sometimes problematic (MA, 2003; Dick *et al*., 2011). The suite of terms investigated above encompassed a wide range on both scales. Plotting the outline of the concepts on a schematic graph reveals their inter-relationship (Figure 3). The world-systems concept is inherently concerned with the largest scale both temporally and spatially as it covers thousands of years and the whole world (Figure 3). Ecological footprints on the other hand although often encompassing activities and products which cover or travel over many 1000's of kilometers tend to consider usage over relatively short time scales (e.g. typically 1 year). Environment payments on the other hand have a tendency to operate over a similar spatial scale as ecological footprints, but tend to have a longer time scale as payments are frequently on a 10–100 years time span. Natural capital by definition is often concerned with capital which has accumulated over a very long temporal scale but is mined or harvested over a more moderate spatial scale (although we appreciate the products of the mining or harvesting can be transported over the whole world). The concept of a nested set of adaptive cycles, i.e. panarchy (represented by one cycle in Figure 3 for simplicity) can be applied over a whole range of scales with flows and influences moving between scales. Similarly, studies reporting ecosystem services tend to have relatively specific boundaries but different studies may be conducted over widely varying scales. We have sketched four studies from this volume in Figure 3 for illustrative purposes. Dick *et al.* (2011) limited their study to 1 year and the 11 sites reported varied in size from 200 to 1500 ha. Mangi *et al.* (2011) reports the carbon dioxide fixation of sea kelp around the waters of the Sicily Islands in the UK over a 10-year temporal scale while Smart *et al*. (2011) report studies on the effects of ammonia on biodiversity and climate regulation over the whole UK but on a similar time horizon to Mangi. Morse-Jones *et al*. (2011) reports studies on the economics of ecosystem services on a temporal scale of 10–50 years for a coastal realignment project in eastern England.

All these concepts require identifying and analysing data from a wide variety of sources. Few papers in this review used statistical terms in either there title, abstract or keywords making it difficult to directly analyse the use of statistical tools used in these concepts. It is clear however that the ecosystem services concept in particular overtly requires an understanding of the environmental, economic and socio-cultural aspects of the landscape. Historically, there has been a different approach taken to the collection and analysis of these data types. The analysis of the environmental aspects often follows the scientific paradigm of process understanding combined with data

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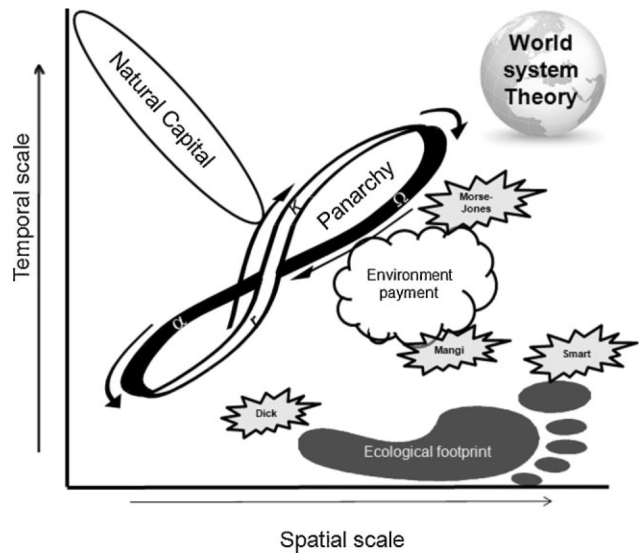

Figure 3. Schematic representation of the temporal and spatial scale coved by the concepts considered in this paper. The shaded stars represent ecosystem service studies reported in this volume (insert is name of first author)

collection, and is generally amenable to standard statistical methods to determine model parameters, to identify interactions between ecosystem components and to propagate uncertainty, e.g. Bayesian statistical methods, multivariate techniques, extreme value analyses, sampling strategies, etc. The economic analysis of ecosystem service delivery is typically considered by placing all elements on a single monetary valuation system to allow for quantification and analysis similar to the measurements of environmental aspects. A major issue is that it is difficult to quantify some aspects of landscapes on a single monetary scale (Norgaard, 2008) and the uncertainty introduced by this process puts limits on the applicability of the models. The socio-cultural assessments in contrast typically analyse opinion, relative value and influences on behaviour patterns. Traditionally there are many more qualitative assessments and the cause-effect linkage is either much more difficult or even impossible to determine. In the face of substantial narratives and often contradictory signals, ontologies become very important and analyses using mind maps and fuzzy logic commonly used (Nasiri and Huang, 2007).

Achieving the balance between the different components of an ecosystem services assessment is a challenge. Many statistical techniques bridge the gulf between detailed quantitative measurements, uncertain qualitative assessments and expert opinion. The concept of feedbacks in ecological models has led to analyses of qualitative data using Levin's loop analysis (Justus, 2006) which also has application in other parts of an ecosystem service assessment. In a more linear situation, Bayesian Belief Networks have been used to characterise ecosystem function (Cyr *et al*., 2010) and this can lead directly to decision and graphical theory approaches in socio-economics. Further discussion of the contribution of statistical methods to ecosystem services assessment is developed in Smith *et al*. (2011).

It can be seen therefore that the concept of ecosystem services delivered to humans by a landscape is an important and expanding area of research and is linked to other similar concepts which operate at varying spatial and temporal scales. There is however no agreed methodology to obtain a robust assessment of the ecosystem services delivered by a landscape. In the next section, we discuss a number of frameworks and illustrate three with an example terrestrial landscape.

1. PRACTICALITIES AND LIMITATIONS OF THE ECOSYSTEM SERVICE CONCEPT

All ecosystem approaches to management require that we synthesise diverse physical, biological, social and economic data and think critically about the ways in which our decisions affect the full range of ecosystem services we value. As noted above a major issue when numerating the ecosystem services delivered by a landscape is that ecosystems do not have 'inherent' geographic or temporal boundaries; rather practitioners (i) select the spatial and temporal extent of their study, (ii) select the parameters of analysis depending on the problem and analytical framework chosen, (iii) conduct studies which are constrained by the need to obtain 'appropriate' data and (iv) are usually further constrained by tightly time bound project deadlines (Norgaard, 2008). Many studies utilise routinely collected data (often collected for a different purpose and often designed to meet regulatory directives (e.g. the EC Water Framework Directive, http://ec.europa.eu/environment/water/water-framework/index_en.html). Linking these different data sources (either spatially or temporally) can present considerable challenges and there have been a number of recent papers which while not dealing with ecosystem services have encountered similar problems in other areas [e.g. linking air quality and population health, or atmospheric deposition and vegetation (Sahu *et al*., 2010)].

In addition to these problems, another major problem with assessments of ecosystem services provided to humans is that humans neither have a universal opinion nor an agreed set of values. It must be recognised that all assessments which seek to assess the social dimension of the value of ecosystem services are dependent on the history, current interests and the immediate, past and future needs of the individuals who are surveyed.

These constraints are limitations of the ecosystem service concept but there are a number of tools and associated concepts which may be useful when practically assessing the ecosystem services delivered by a landscape.

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2. ECOSYSTEM SERVICE FRAMEWORKS

In this section, we will consider a number of frameworks [ecological, economic, millennium assessment, integrative science for society and the environment (ISSE) framework, world-systems and panarchy] reported by researchers in the literature to understand the ecosystem and the services delivered to humans. We will use one example landscape to illustrate the latter three holistic frameworks.

2.1. Ecological focused frameworks

Some studies have focused on particular aspects of ecosystem services, e.g. the concept of 'service-providing units' (SPUs) (Luck *et al.*, 2003). The SPU concept arose from studies of biodiversity and an SPU was defined simply as the components of biodiversity necessary to deliver a given ecosystem service at the level required by the service beneficiaries. This concept effectively limited the study to a management unit. It has been used in marine ecosystems (Cognetti and Maltagliati, 2009) and, at a different scale, to group ants into SPUs, defined in that context as a group of organisms and their populations that perform specific ecosystem services (Sanford *et al.*, 2009). The concept of the SPU was taken further (Kremen, 2005) by identifying key ecosystem service providers (ESPs) and characterising the functional traits and functional importance of populations, communities, guilds and interacting networks of organisms that deliver services. This idea of the SPU-ESP continuum, was further refined and called simply the 'service provider' concept (Luck *et al.*, 2009). Luck *et al.* argue strongly from an ecological perspective recognising the limitation of their approach in relation to the social, economic and cultural services provided by landscapes.

2.2. Economic focused frameworks

Economic studies, on the other hand, often champion that monetary value of services is a simple approach universally understood around the world which integrates social, cultural and provisioning services. Such frameworks tend to have relatively linear structures (Wallace, 2007) with the end output the total economic evaluation of the system. However, many argue that not all services can be valued in monetary terms and hence these studies are severely limited (Norgaard, 2008).

2.3. Millennium Ecosystem Assessment

In contrast to the above, the MA carried out between 2001 and 2005 took a more holistic approach and attempted to provide a practical protocol to fully assess ecosystems considering social, economic and cultural services provided by landscapes (MA, 2003). The overall analytical approach used to achieve the goals of the MA has nine major tasks (Table 2) which collectively provide a view of the ecosystem from different perspectives. The first aspects of the MA approach, i.e. to identify and categorise ecosystems and their attendant services is illustrated in the paper describing the ecosystem services delivered by 11 Environmental Change Network terrestrial sites (Dick *et al.*, 2011).

2.4. Integrative Science for Society and the Environment framework

A major issue which many studies face is enumerating aspects of ecosystem service delivery. Frequently there is insufficient data for rigorous analysis and therefore data is utilised as part of a narrative approach (see Smith *et al.* (2011) for a discussion of the statistical implications). The ISSE framework outlined by Collins (2007) is an example of such a narrative approach. It recognises both short- and long-term events which influence the biotic structure and ecosystem function and directly links ecosystem services with human outcomes and human cognition, behaviours and institutions. At the core of this framework is the recognition that humans are embedded in Earth's ecological systems and studying ecosystem services without consideration of the sociological system is incomplete, like studying the carbon and nitrogen cycle without considering the role of water. Operationally the framework is supported by six key questions linking the elements of the framework:

Q1: How do long-term press disturbances and short-term pulse disturbances interact to alter ecosystem structure and function?
Q2: How can biotic structure be both a cause and consequence of ecological fluxes of energy and matter?
Q3: How do altered ecosystem dynamics affect ecosystem services?

Table 2. Task which define the Millennium Ecosystem Assessment protocol

	Millennium Ecosystem Assessment task
1	Identify and categorise ecosystems and their attendant services
2	Identify links between services and human societies
3	Identify indirect and direct drivers
4	Select indicators of ecosystem conditions, services, human well-being and drivers
5	Assess historical trends and the current state of ecosystems, their services and driver
6	Evaluate impact on human well-being
7	Develop scenarios
8	Evaluate possible responses
9	Analyse and communicate uncertainty

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Q4: How do changes in vital ecosystem services alter human outcomes?

Q5: How do perceptions and outcomes affect human behaviour?

Q6: Which human actions influence the frequency, magnitude, or form of press and pulse disturbance regimes across ecosystems, and what determines these human actions?

To illustrate the value of this framework we will use an example landscape, the Environmental Change Network terrestrial site of the Allt a'Mharcaidh catchment in the Cairngorm mountain range, Scotland (Dick *et al*., 2008) owned by Scottish Natural Heritage (SNH). The area is primarily utilised for conservation and recreation with no permanent habitation. The catchment extends to about 10 km^2 and in form is a hanging valley with a main stream, the Allt a'Mharcaidh, into which drain the Allt nan Coileach and two other un-named smaller streams. The site is predominantly north facing, and rises from 320 to 1110 m. The character of the landscape within the catchment is semi-natural, with areas of mature pine forest on the lower slopes, colonising trees and heather on intermediate slopes, and sub-montane and montane plant communities above the climatic treeline (about 750–800 m). The current economic value restricted to the catchment is zero as SNH receives no income from the land although the wider community receives considerable benefit through tourism.

In the example of the Allt a'Mharcaidh catchment, flash floods and summer droughts are perceived as two important environmental short-term pulses (Figure 4), while climate change manifested as increased temperature and reduced snow cover and duration are identified as the primary environmental presses which influence ecosystem function and to a lesser extent ecosystem structure (Q1). There has been a significant increase in temperature over a 7-year period since 2000 (Morecroft *et al*., 2009) and a consequent reduction in snow cover. The stream flow regime has historically reflected the influence of snow melt with a tendency for high flows to occur in late winter and early spring. Absence of snow leads to low spring and low early summer base flows (Soulsby *et al.*, 1997). The hydrological budget, an important ecosystem function of the catchment, is influenced directly by changing climate (Q1). The soils on the steeper slopes tend to be freely draining whilst the peat soils in the valley bottom are often waterlogged which is reflected in the vegetation cover (Q2). In addition to increased torrential rainfall there has been a perceived reduction in summer rainfall which results in stress to these wetter habitats. Summer droughts also increase the risk of wild fire. A long-term human induced disturbance press on the site is reduced grazing and cessation of managed burns which has led to changes in the ecosystem structure. Since the site was purchased in 1957 by a government conservation department, no burning of the vegetation has been permitted. In addition, since 1976 there has been a policy of reducing deer numbers to a level that permits tree regeneration (Mathews, 1990) which is considered the most significant policy press (Q6). Recent vegetation surveys have noted a change in vegetation cover (increased distribution of pine seedlings to the higher slopes) but it is unclear if this is due to climate change or reduced grazing pressure. The increase in flash floods which has been reported by local residents (a result of the increased frequency of torrential rain) increases the level of dissolved organic carbon in the stream water which has implications for the downstream whisky and salmon industries (Q3). The lack of winter snow has possibly resulted in a decreased number of people walking in the catchment in the winter months (Q4). In addition, the enjoyment of the site from a distance is thought to have been reduced because it has been noted that there are now seldom views of the snow capped mountains.

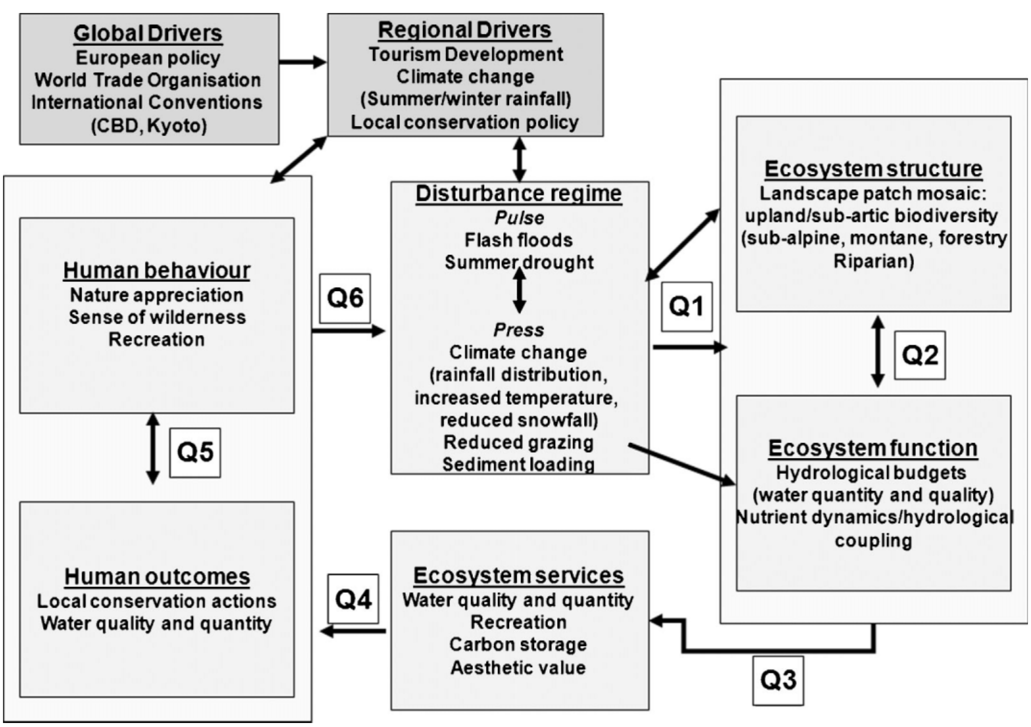

Figure 4. Examples of a socio-ecological centred analysis describing the change in economic, ecological and social assessment of the Allt a'Mharcaidh catchment in Cairngorms, Scotland following the land purchase by the SNH Government body responsible to Scottish Government Ministers (adapted from Collins, 2007)

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The site has been extensively used for research since 1984 by, amongst others, SNH, the Centre for Ecology and Hydrology and the Macaulay Land Use Research Institute. Often the site was chosen because there is little human impact. As noted the land owner has reduced grazing on the site and stopped the age old practise of muirburning. Reduced management is resulting in increased fuel loading and is very probably encouraging the spread of trees to higher elevations. Increased tree cover will increase the risk of fire but opinion is divided as to whether it will increase or reduce the value of the site for recreation (Q5).

In terms of provisioning ecosystem services there is only a limited amount of occasional wild fruit gathering in the autumn and 20–30 deer which are culled annually by Forestry Commission staff. Economically, therefore, there is little direct monetary value from the ecosystem although there is considerable income to the local region through activity tourism and research tourism. This example highlights that by taking an integrative and iterative approach the user is forced to consider the landscape from a wide range of aspects.

In conclusion, this analysis reveals that there is a dichotomy of uses for the ecosystem services of the site (Q4) with (i) local conservation initiatives which encourage biodiversity to thrive without human disturbance and (ii) the use of the ecosystem for recreational purposes (Q5) and this has implications for site management. The analysis also alludes to the underpinning monitoring data available for the site, including temperature and river flow records, but not directly to the measurement of quality of these components. The narrative highlights the often qualitative description of some of the ecosystem components. Interestingly this catchment is also included in the statistical analysis of ecosystem services reported by Dick *et al.* (2011). The comparison of the narrative and statistical approaches are highlighted by these two studies.

The ISSE approach is more systems oriented than the statistical approach adopted by Dick *et al.* (2011) as it implicitly includes an element of temporal scale through its separation of pulses and pressures but does not explicitly address the issue of spatial scale. However, spatial scale can be incorporated by assessing the services for a range of nested areas, e.g. the Allt a'Mharcaidh catchment, the larger area of the Invereshie and Inshriach National Nature Reserve and the district covered by the Cairngorm National Park (Dick *et al*., 2008). Understanding of the ecosystem services currently delivered via the ISSE approach allows the researcher to postulate future changes to the management of the landscape and the potential effect on the delivery of ecosystem services. The narrative approach to future scenarios could be linked to a numerical approach, e.g. a Bayesian Belief Network (see Smith *et al*., 2011).

2.5. World-systems theory framework

The holistic approach of Collins (2007) and the linking of scales leads to the logical consideration of systems models and analysis such as world-systems approach (Chase-Dunn and Hall, 1997).

In this paper, we consider the world-systems theory in essence as the flows and stocks of ecosystem goods and services within a global context and argue that using historical information we can learn about the linkages between ecosystem services and the wider global system through time (Figure 5). The flow of ecosystem goods and services between states and regions within the hierarchical concept of core, semi-core and peripheral regions has been a recurring theme in human history (Chew, 2001).

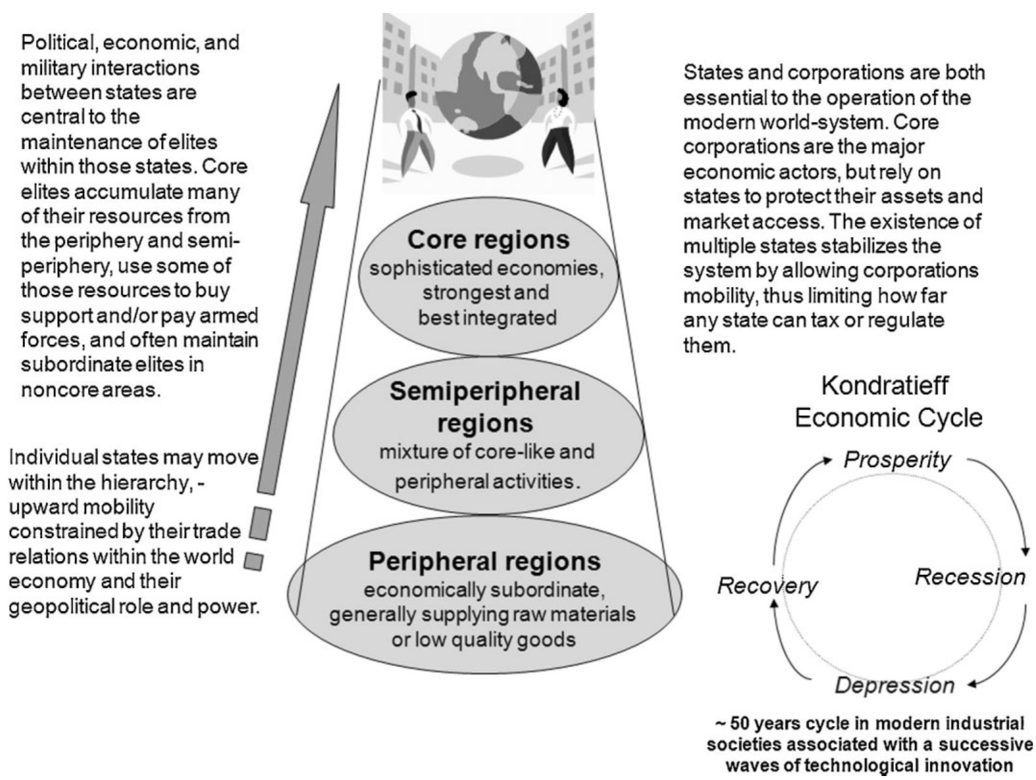

Figure 5. Schematic of the world-system analysis highlighting the main elements of core to peripheral countries and the cyclic Kondratieff economic cycle.

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Analysing the landscape described above using world-systems analysis encourages us to consider wider spatial and temporal scales. The vegetation of the Allt a'Mharcaidh catchment and surrounding area seen today is a direct result of over 2000 years of systematic and organised exploitation of natural resources by humans conducting farming and forestry activities (Holl and Smith, 2007). Prior to the Highland clearances the annual carrying capacity of the land was limited by the winter carrying capacity which resulted in long distance transhumance activity into the Cairngorms from the Morayshire plains with cattle moved to the summer hill pastures (shielings) since at least the 11th century. The population of the Cairngorm mountain range was dramatically reduced when major changes in the economy of the region resulted in the creation of extensive sheep farms and the enclosure of large tracts of hill land for hunting sports, in essence the region was semi-peripheral at this time in world-systems theory terms (Figure 5). These factors, together with a series of poor harvests, bouts of disease and famine, caused many thousands of people to abandon their farms between 1770 and the late 1800s because the provisioning services of the landscape were no longer sufficient (Holl and Smith, 2007). It is the realisation of this previous influence of humans on the landscape which goes some way to explain the current range of ecosystem services delivered by the landscape. For example the extensive sheep grazing resulted in the heather covered hills with few trees which are marketed today as a tourist attraction, particularly in the autumn when the heather flowers. The current support system to local farmers which is primarily driven by European Common Agricultural Policy has resulted in significantly reduced sheep numbers over the last half decade and there is already a worry that this may have a negative influence on the area as a tourist attraction as the hills revegetate with shrubs and trees and reduce the vista.

World-systems analysis is also relevant to the case study used in this paper as the area was semi-peripheral in the mid 1600s when the natural forests were cut to supply England and the continent with wood products. In the 1800s with the advent of the railway to the local villages of Aviemore and Ballater the area become popular as a holiday destination for the elite of the country including Queen Victoria and Walter Scott who visited regularly. The development of Aviemore as a ski resort in the 1960s increased the number of visitors substantially but the reduced snow cover associated with climate warming and the economic crises of 2008 have significantly reduced the number of visitors to the area.

A historical understanding of a landscape we feel is very important to both understand the current rate and range of ecosystem service delivered by a landscape and to predict the delivery of future ecosystem services which may be delivered following policy or societal changes. The world-system framework we argue is therefore a useful tool.

2.6. Panarchy framework

In contrast to the world-systems framework with its roots in the humanities, panarchy analysis stems from the ecological resilience community. It is useful in conjunction with world-systems ideas as it provides a visualisation of hierarchies across social, economic and ecological disciplines and across geographic and temporal scales. A panarchy as defined by Holling (2001) is a representation of a hierarchy as a nested set of adapted cycle. It has been used to position an ecosystem within a panarchy of temporal and spatial scales (Fraser, 2003; Dorren *et al*., 2004; Zurlini *et al*., 2007). Although Holling (2004) favourably assessed the possibility of using panarchy at the global scale, Gotts (2007) concluded that it was not possible to assign the planetary social-ecological system convincingly to any phase of the adaptive cycles. He considered that panarchy is better suited to the regional scale with the idea of global events working outside the system.

The adaptive cycle is commonly represented by a three-dimensional circle (Figure 3) with four ecosystem function phases: conservation (K), release (Ω), reorganisation (α) and exploitation (r). Each phase of those cycles creates the condition for the next phase. A pattern of two phases of growth, followed by two phases of reorganisation are proposed. The first two (r and K) form a familiar, slow, fairly predictable pattern of growth called the 'forward loop'; the second two Ω and α constitute a less familiar, unpredictable, more rapid 'back loop' of reorganisation (Figure 3). The three scales of the adaptive cycle, i.e. potential, connectedness and resilience can be related to meaningful ecological or social data. While it is easy to consider in a narrative approach where exactly an ecosystem is within an adaptive cycle it is not so easy to determine data for each of the three axes (Carpenter *et al*., 1999).

The value of assigning an ecosystem to its relative position in a panarchy is illustrated using the Allt a'Mharcaidh catchment at one point in time 2009 (Figure 6). The catchment can be considered as the fine or local scale in the framework proposed by Kinzig *et al*. (2006). Following the reduction in grazing after the land was purchased by the SNH in 1957 the ecological system started climbing to a mature state in the adaptive cycle. The catchment has no economic or social-cultural state directly—rather it can only be considered by looking at the wider panarchy. The next natural level we consider is the Cairngorm National Park which we consider has been generally ecologically and economically stable for the last 50 years following the end of the Second World War. The socio-cultural adaptive cycle on the other hand is only just emerging from the alpha or reorganisation phase due to the creation of the national park in 2004. Institutions active in the area (local authority, Forestry Commission, etc) are adapting to the new institution of the National Park Authority. Further, both the Allt a'Mharcaidh catchment and the Cairngorm National Park are part of the country adaptive cycle. Scotland has been part of the United Kingdom since the Union of the Parliaments in 1707. In 1999, Scotland was granted a devolved parliament, an event which very significantly changed how Scotland was governed. Before that, although much of Government in Scotland was decentralised administratively, all legislative responsibility rested with the UK Parliament at Westminster, England and the Ministers in the Scottish Office who ran much of Scotland's domestic policy were answerable to it (Calman, 2009). Since 1999 Scottish Ministers have been accountable to a Scottish Parliament in Edinburgh, composed of 129 MSPs directly elected by the people of Scotland. The Parliament has the power to make laws across a wide range of domestic policy in Scotland—including crime and justice, education, health, agriculture and the environment, transport, economic development and local government.

This major political change has understandably resulted in the country adaptive cycle entering a less familiar, unpredictable, and often more rapid 'back loop' of reorganisation (Figure 6). After 10 years with changing political structures, the authors feel the country may be commencing the typically slower forward loop of the adaptive cycle rising towards the conservation (K) phase. Unfortunately, the economic adaptive cycle is currently very unstable following the economic crash of 2008. In our case study, economic development of the Cairngorm National Park is strongly linked to human capital and the three recognised drivers of economic development (i) productivity (skills,

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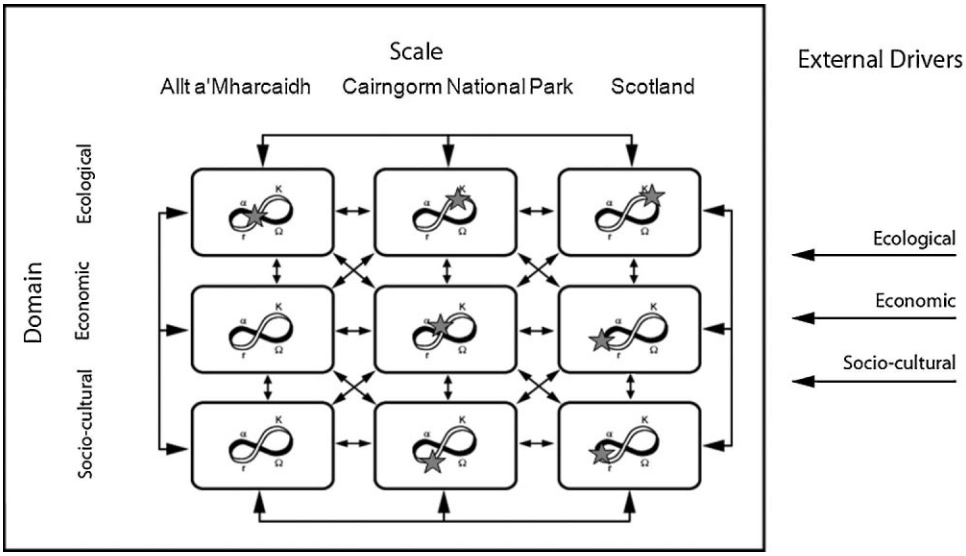

Figure 6. The estimated position in 2009 of the Allt a'Mharcaidh catchment, Cairngorm National Park and Scotland in the panarchy (marked by a star) of ecological, economic and socio-cultural adaptive cycles at three spatial scales (after Kinzig 2006)

investment and enterprise), (ii) spatial factors (peripherality and accessibility) and (iii) policy (economic structure, government infrastructure and road infrastructure). These have all been shown to be significant determinants of economic performance in rural areas (Agarwal *et al*., 2009) but are not currently stable in the case study areas considered in this paper.

By examining the adaptive cycles of the wider ecosystem, further information can be assembled which can help managers and policy makers evaluate the risk of management practices to the delivery of ecosystem services of the Allt a'Mharcaidh catchment and help predict future delivery.

3. CONCLUSION

Over the last 40 years there has been a growing realisation amongst ecologists, environmental policy makers and managers that human-ecological systems are complex, dynamic and unpredictable across space and time but little agreement on the best way to manage ecosystems has emerged (Moore *et al*., 2009). The concept of ecosystem services is useful to explore and helps understand the connectedness of social and ecological processes while providing transparent evidence for policy formulation.

However, we would argue that there are complimentary philosophies which may be relevant and we have given examples in this paper. The different perspectives of ecosystem services delivered by the ISSE, world-systems or panarchy viewpoints brings some clarity to the spatial and temporal scales of the assessment including the boundaries of the study and the levels of detail that are desirable. Identifying the correct spatial and temporal scales will be crucial in determining the most appropriate ecosystem service framework for a given undertaking.

As seen in the illustrative development of the approaches in the preceding text, there are challenges remaining in the application of these frameworks in terms of deciding what is necessary or economically possible to measure to populate the frameworks. It is easily seen that the evidence required to populate any ecosystem services framework will come from a variety of sources and be of differing standards consequently a range of statically techniques will be required to fully analyse the data.

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