



Ecosystem services: Foundations, opportunities, and challenges for the forest products sector

Trista M. Patterson*, Dana L. Coelho¹

USDA Forest Service, PNW Research Station, 204 Siginaka Way, Sitka, AK 99835, United States

ARTICLE INFO

Article history:

Received 23 January 2008

Received in revised form 10 November 2008

Accepted 11 November 2008

Keywords:

Ecosystem services

Natural resource management

Forest products

ABSTRACT

The ecosystem service concept has been proposed as a meaningful framework for natural resource management. In theory it holds concomitant benefit and consequence for the forest product sector. However, numerous barriers impede practitioners from developing concrete and enduring responses to emerging ecosystem service markets, policies, and initiatives. Principle among these barriers is that the ecosystem service concept has a complex history, numerous definitions in use, and an astounding diversity in rationale and application. This article provides a conceptual review of ecosystem services and its economic foundations, distinguishes among several current definitions of the term and their relatedness to strategies in practical application, discusses diverse approaches to valuation, and explores potential for future relevance in forest product and other sectors.

Published by Elsevier B.V.

1. Introduction

Ecosystem services can be broadly defined as those processes of ecosystems that support (directly or indirectly) human wellbeing (MEA, 2005). In forest product application, common ecosystem services to be listed are timber, non-timber forest products, wildlife habitat, water quantity and quality, carbon sequestration and storage, and recreation opportunities.² Between 1960 and 2000, while the world's population doubled and the global economy increased sixfold, the Millennium Ecosystem Assessment documented a decline in over 60 percent of the world's ecosystem services (MEA, 2005). Future challenges are likely to be more profound, driven in large part by population growth, affluence, and technology (Ehrlich and Ehrlich, 1990; Haberl et al., 2007). Because a large portion of global ecosystem service flows originate within forests, and because the life cycles³ of forest products affect ecosystem service flows, forest product specialists are important contributors to addressing declines in flows of ecosystem services.

At the same time, the valuation of ecosystem services and the development of markets offer opportunities for landowners and investors within the forest products sector to explore alternative revenue streams.

Important opportunities exist to engage new perspectives in provisioning forest ecosystem services, whether through governance (Gibson et al., 2000, 2005), payment systems and markets (Engel et al., 2008; Johnson et al., 2001), adjustments to life cycle processes (Ghertner and Fripp, 2007), or other means. We review concept origins, definitions in current use, and the economic properties of ecosystem services. We focus on three general application strategies relevant to forest product specialists: emerging markets in ecosystem services, managing for ecosystem services on forests as a whole, and raising awareness for ecosystem services through accounting and valuation. The paper concludes with a discussion of further and potential applications of the ecosystem service concept within the forest products sector.

2. Conceptual review

The modern concept of ecosystem services is a tapestry of accumulated knowledge and perspective stemming from the finite nature of natural resources (Marsh, 1864) and the study of ecosystems (Lindeman, 1942). Multiple disciplines have contributed to the evolution of the term, with ecology and economic lines of reasoning at times appearing more separate than related.

Krutilla's work on the "present and future amenities associated with unspoiled natural environments, for which the market fails to make adequate provision" (Krutilla, 1967, p. 778) stands out as a

* Corresponding author. Tel.: +1 907 7381205.

E-mail addresses: tmpatterson@fs.fed.us (T.M. Patterson), dcoelho@fs.fed.us (D.L. Coelho).

¹ Tel.: +1 907 7474249.

² As will be covered later in the article, definitions and scope of ecosystem services differ widely.

³ The life cycle of a forest product includes everything from planting, to forest treatment applications, harvest, manufacture, sale, consumption, and recycling or disposal; life cycle analysis considers all material and energy inputs and outputs of the production process (Seppälä et al., 1998).

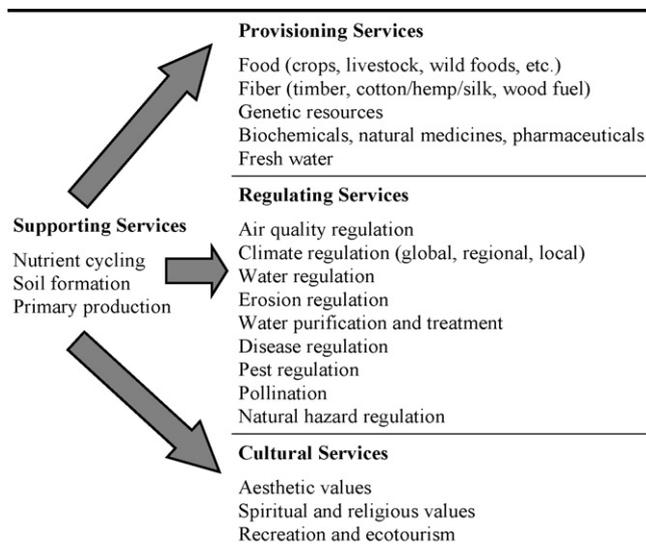


Fig. 1. Broad categories of ecosystem services (adapted from MEA, 2005).

particularly concise, early, and influential characterization of the issue. Meanwhile, an MIT Study of Critical Environmental Problems (SCEP, 1970) was among the first to identify a suite of environmental services that faced decline if ecosystem function were impaired or lost. Specific references to “public-service functions of the global environment”/“global ecosystem”, “nature’s services”, and finally “ecosystem services” (Holdren and Ehrlich, 1974; Ehrlich et al., 1977; Westman, 1977; Ehrlich and Ehrlich, 1981; respectively) soon followed.

Schumacher (1973) and Daly (1977, 1991, 1996) drew attention to the increasing likeliness of ecosystem service declines, pointing out that the world’s growing “man made economy” would one day bump up against immutable laws of physics,⁴ as economic growth consumed and affected the “biosphere”. Thus, today’s ecological economists are not only addressing the value of ecosystems as life support (Folke et al., 1991; Deutsch et al., 2003), but are asking questions such as to how ecosystem services relate to quality of life (Collados and Duane, 1999; Bridgewater, 2002; Daily, 1997), whether we are over-weighting those resources which have market value in decision making (Costanza et al., 1997), whether current rates of energy and resource use exceed the planet’s ability to replenish itself (Wackernagel and Rees, 1996; Wackernagel et al., 2002). Other lines of inquiry question whether social resource use is excessive (Ehrlich and Goulder, 2007), if social-ecological relationships are less than resilient (Holling, 2001; Folke et al., 2002) and what role social institutions play if any of these is the case (Ostrom, 1990; Dietz et al., 2003).

These lines of research have come together in an ecosystem service concept that broadly recognizes ecosystems as a fundamental basis of production. Consequently, economists are increasingly using ecosystems as the organizing structure of the benefits people receive, while ecologists are becoming more versed in explaining management choices in terms of benefit tradeoffs (Kline et al., 2008). These tradeoffs have both a spatial and temporal variation. Ecosystem services originate from, and extend to users at, different scales—from local to global. They are often described using four broad categories: provisioning (direct), cultural (direct), regulating (indirect), and supporting services (indirect) which create a foundation for the first three (Fig. 1) (MEA, 2005).

This broad definition arose from and remains in the company of various, more specific definitions, as covered in the next section. We use this information later in the article in discussing the appropriateness of market-based tools (according to economic

properties of the ecosystem services at hand) and three methods of applying the ecosystem service concept within the forest products sector.

3. Definitions currently in use

Considering the long history of the ecosystem service concept and its now frequent appearance in the literature, the diversity in definitions may be surprising (see for review, de Groot et al., 2002; Kline, 2007; Costanza, 2008; Fisher and Turner, 2008). The broadest interpretations are often used to raise awareness of the pervasive yet often intangible benefits that people receive from healthy ecosystems (MEA, 2005; Daily, 1997; Collins and Larry, 2007). Other, more specific definitions are intended to relate ecosystem function to social activities, or estimate replacement cost of lost ecosystem services (Costanza et al., 1997; US EPA, 2006). Others employ more narrow definitions for specific accounting and decision making (Boyd and Banzhaf, 2007) (Fig. 2). Each definition varies in its emphasis on supply- and/or demand-side issues, recognition of market and non-market values, consideration of temporal and spatial scale, units of measurement, and the tracking of services from origin to user.

The decision of how to define ecosystem services for a given ecosystem service project places important bounds on it. Assumptions that cooperators already share agreement on definition can undermine the ability of those cooperators to be as specific as may be needed to produce tangible project outcomes. Should the project deal with multiple services, or just one? Should it deal with markets only, non-marketable services only, or a mix of both? On one hand, as research and practice strive for greater specificity, the need for empirical data increases. The need for quantification may lead to assessments which intentionally exclude non-market values and qualitative data. On the other hand, a more inclusive definition may be chosen to intentionally facilitate consideration of supporting, regulating, and cultural ecosystem services which would otherwise not be counted.

More general references are generally regarded as more appropriate for education and raising awareness, stakeholder discussions, and broadening the scope of existing studies or projects. Allowing for both quantitative and qualitative information from a full spectrum of ecosystem services can provide the basis for a more culturally inclusive and complex system description. More narrow definitions of ecosystem services may be the most practical way to avoid issues of joint production and double counting, to distinguish ecological structure from function, or to estimate a discrete service or multiple services within a geographically limited area (Brown et al., 2007; Boyd and Banzhaf, 2007). A more refined definition will be warranted for any study involving quantification of flows of ecosystem services or the use of data in models and other decision tools. Estimates of market value will require great attention to definition, as that will determine the structure of calculations and resulting values (Boyd and Banzhaf, 2007), appropriateness for wider application (Costanza, 2008), and whether or not markets can support the ecosystem service under consideration (Johnson et al., 2001).

Defining the scope of a project is also important to understanding the complex perspectives encompassed when using the term ‘valuation’. If an ecosystem service valuation project has publicized a dollar value for ecosystem services, an individual land owner seeking payment for ecosystem services may be surprised when even the most effective payment for ecosystem service program is not expected to deliver this in returns. The difference is

⁴ Nicolis and Prigogine (1977) established the thermodynamic basis for these limits and was awarded the Nobel Prize in Chemistry for dissipative structures, complex systems, and irreversibility.

Citation	Definition	Principal uses
Daily, 1997	The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life	Awareness
MEA, 2005	The benefits people obtain from ecosystems	Awareness
Collins and Larry, 2007	Natural assets that support human health and well-being	Awareness
Costanza et al., 1997	Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human (est. of replacement cost) modeling populations derive, directly or indirectly, from ecosystem functions	Awareness, valuation,
US EPA, 2006	Outputs of ecological functions or processes that directly or indirectly contribute to social welfare or have the potential to do so in the future. Some outputs may be bought and sold, but most are not marketed	Valuation (Ecological Benefits Assessment*)
Boyd and Banzhaf, 2007	The ecological components directly consumed or enjoyed	Valuation (green accounting)

Fig. 2. Multiple definitions of ecosystem services and their principle uses in research and practical application. (*Ecological benefits assessments are used by the US EPA (2006) to estimate the benefits of a particular environmental policy and, where feasible and appropriate, to estimate the monetary values of those benefits in order to compare policy options.)

	Excludable	Non-excludable
Rival	Private goods	The commons
Non-rival	Club goods	Public goods

Fig. 3. Rivalness and excludability define the character of economic goods and services (adapted from Randall, 1993 see Daly and Farley, 2004 for extended discussion).

somewhat similar to as that between the replacement value estimate of a house's goods and services and the value expected if everything were instead sold at a garage sale. Valuation will be covered more extensively in Section 5.3.2, but as background we first describe how the basic economic properties of ecosystem services affect the ability (and often inability) of markets to provision them.

4. Economic properties of ecosystem services

Ecosystem services can be considered to have economic value because they contribute to human wellbeing and can be scarce. Yet, because many ecosystem service flows are not directly perceived or used, they include goods and services for which people have not developed clear preferences (Pritchard et al., 2000). This is true for a number of reasons, and in part explains why ecosystem services fit (or do not) into traditional markets. The economic characteristics of ecosystem services lend explanatory power in describing why one strategy for dealing with their provision and use may be preferred over another. This section addresses the basic qualities that distinguish between public and private goods and services, explores the tragedy of the commons, and introduces the concept of externalities.

4.1. Public and private goods

All economic goods and services have attributes which determine their rivalness and excludability (Fig. 3).

Rivalness refers to whether the use of a good or service by one person diminishes the enjoyment another can gain from it,⁵ while excludability refers to whether, if one pays for a good or service, it is

⁵ For example, a sunset is non-rival, while a piece of pizza is considered rival. We can both view the same sunset, but cannot eat the same piece of pizza. The existence value of species or unique habitats is non-rival, as is (up to a certain point) the waste assimilation capacity of the atmosphere or a wetland ecosystem.

feasible to prevent another from enjoying (free-riding on) it.⁶ Goods or services that are both rival and excludable are considered private goods, and are familiar because we buy and sell them in markets everyday. Pure public goods, on the other hand, are those that are non-rival, and non-excludable (Samuelson, 1954). When this is the case, a free marketplace will not provide effectively for their sustained provision (Daly and Farley, 2004). As forest product specialists increase the use and application of ecosystem service approaches, an understanding of these two attributes can assist in determining which strategy – fostering private markets, managing public lands, or raising awareness – is most appropriate for each situation, resource, and set of goals.

4.2. The commons

When a good or service is non-excludable but rival it is referred to as a common pool resource, as in the term “the commons”. A social trap⁷ is created when economic markets cannot efficiently or equitably deal with common pool resources (Hardin, 1968), which is often the case with ecosystem services. In the “Tragedy of the Commons”, Hardin (1968) described pasture lands which were available for exploitation by multiple sheep herd owners where (absent incentive to stop) they repeatedly added to their herd. The land, overgrazed as a result, could only support a fraction of the initial number of sheep. Hardin contrasted this with a fenced range land, the fences themselves adding the excludability which could provide the incentive for each owner to maintain herds at numbers which would not reduce the productivity of the land.

Assigning excludability characteristics is more difficult on other types of land cover, and for many ecosystem services. For example, harvest and restoration activities on a forest impact (positively or negatively) a larger watershed (wildlife habitat, public water supplies, etc.) as well as the atmospheric commons (via carbon emissions and sequestration, see Nordhaus, 1982; Baer et al., 2000; Burger et al., 2001). The provision of wildlife habitat, clean water,

⁶ One may find it easy to exclude others from drinking from a cup of coffee, while the creamer they leave in the office break room fridge may be non-excludable. The water filtration and carbon sequestration services of a forest occur locally, but one cannot exclude others from benefiting downstream.

⁷ Coined by John Platt (1973), the term “social trap” refers to situations in which individuals, organizations, or societies become ensnared by a decision which charts a dangerous path that is difficult to alter. The tragedy of the commons represents a particular kind of social trap in which individuals acting in self-interest create undesirable long-term effects for the group as a whole.

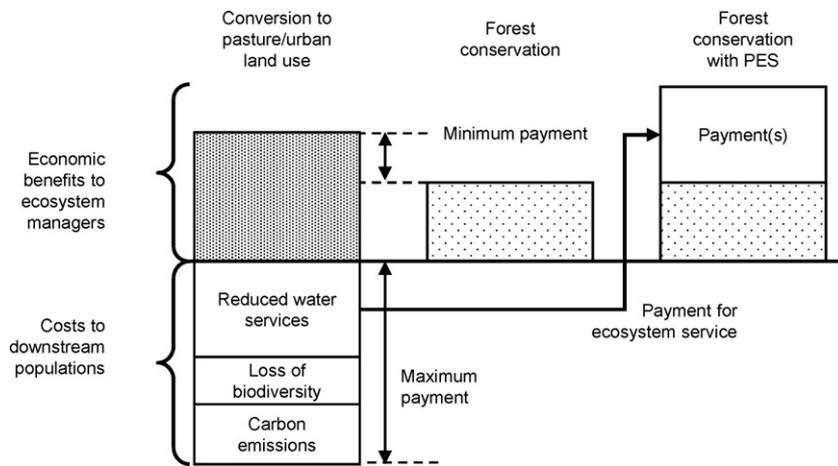


Fig. 4. How a PES transaction works when applied to forest conservation (adapted from Engel et al., 2008).

clean air, and climate regulation are ecosystem services (public goods), the full costs of which do not factor into traditional economic decisions related to the provision of forest products. As such, impacts to these systems and services are considered external to cost-benefit consideration, or *externalities*.⁸ Externalities have always been present in market interactions, but as populations and economies grow and resources become scarce, they become more critical (Dorfman and Dorfman, 1993).

In the case of private goods, price can serve as a proxy for how scarce a given good or service has become. In contrast, in the case of services bearing the qualities of public goods, price will not reflect scarcity and an over-reliance on the market will (e.g., through neglect, damage, or over harvest) lead to diminished ecological capacity to support them in the long-term. The broad consequences of this type of market failure include losses in ecosystem function and economic resilience (Gunderson and Folke, 2005), equity (Daly and Farley, 2004; Foley et al., 2007), and wellbeing (Pérez-Maqueo et al., 2007). Adjusting the market characteristics of ecosystem services or establishing alternate social institutions to provide for them are possible solutions, as we will describe in the next section. Using an ecosystem services approach to acknowledge and quantify the value of these services affords managers of both public and private forests the opportunity to base harvest and restoration decisions on longer term, more complete information.

5. Strategies for application

A number of strategies have emerged to address declining rates of ecosystem service provision. A strategy will be more or less effective based on how well the economic properties of the ecosystem services are accounted for, benchmarked, and measured over time. This section presents an overview of three broad strategies relevant to forest product application: fostering private markets, managing public lands, and raising awareness. This is not a definitive list, nor are the categories strictly exclusive.

5.1. Private markets and payment for ecosystem services

By manipulating the properties illustrated in Fig. 3 of public goods (non-rival and non-excludable) so that they become more

⁸ Externalities are unintended consequences or side effects (positive or negative) of an economic transaction borne by others who were not involved in the transaction. A positive externality is when someone gets a "free lunch", while a negative externality is when an "innocent bystander" is harmed by the actions of others.

like private goods (rival and excludable), payments for ecosystem services (PES) are an attempt to harness market forces to provide ecosystem services (see review in Engel et al., 2008). As price, quantity, time horizon, and willingness/ability to pay are all important factors of a PES transaction, the ecosystem services definition used requires a high degree of specificity. This section provides a contextual framing of the goals and indicators of success for PES transactions, and then describes the general architecture of two PES systems which may be relevant to forest product specialists.

Possibly the most critical, and overlooked aspect of early planning for an emerging market for ecosystem services is the concept of *additionality*. Additionality is the extent to which the action (e.g., reforestation, forest thinning, erosion mitigation), market, and payment at hand, increases the provision of ecosystem services above and beyond that which would have been provisioned under a business as usual scenario. Without a means of establishing a baseline and a quantified measure of ecosystem services following the payment or credit transaction, a payment system cannot demonstrate economic efficiency. While PES programs with available seed money may be able to initiate and stimulate initial transactions, additionality is the measure upon which a sustained and self-sufficient market for ecosystem services strictly depends.

Land use change has often been used as a proxy for additionality when changes to ecosystem service flows themselves have proved difficult to quantify (Waage et al., 2007; Engel et al., 2008). In this structure, government agencies, conservation organizations, or other entities provide funds to compensate landowners for retaining forest (as opposed to converting land for pasture or urban development) on their property. New York City, for example, decided to purchase or place easements on land in order to limit development and conserve the natural water regulation services of the watershed, avoiding a \$4–6 billion water filtration plant (de Groot et al., 2002; Echavarría and Lochman, 1999). A basic PES transaction of this kind functions as shown in Fig. 4. A landowner receives payment that represents at least some of the value of the conserved ecosystem services. This payment, if it surpasses the expected economic benefit from conversion, makes forest conservation the economically desirable choice (Ruddell et al., 2007).

A second form of PES does not involve changes in land cover, but rather changes in management practices (Fig. 5). The source or sources of revenue may result from direct payment for ecosystem services conserved and downstream impacts avoided. For example, compensation may be given for maintained or enhanced water quality through planting buffer strips around streams on

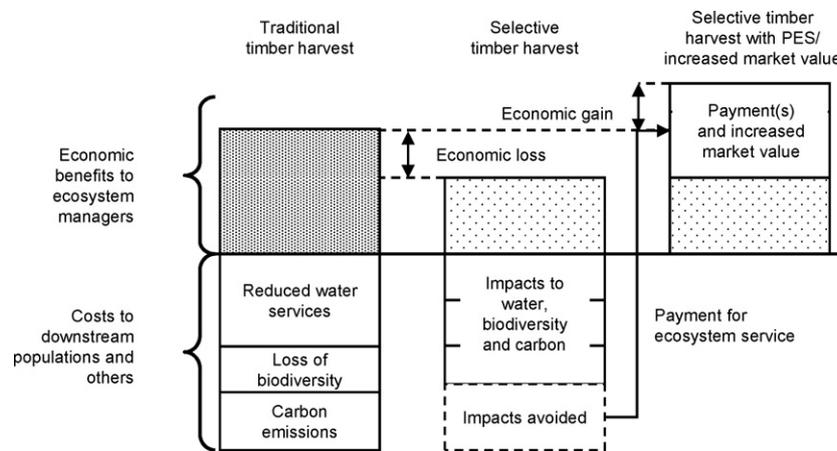


Fig. 5. How a PES transaction works when applied to selective or sustainable harvest of forest products (adapted from Engel et al., 2008).

agricultural land, treatments which enhance the forest's ability to support biodiversity, or replanting activity intended to stimulate additional carbon sequestration. However, little controlled experimentation has been done to examine the impact of various forestry and silvicultural practices on carbon sequestration over time. Nevertheless, private landowners and the forestry industry are increasingly being consulted as municipal and other entities look for creative ways to ensure clean, abundant water flows (Barnes et al., 2007), and may be called upon in the near future for the carbon sequestration and storage benefits of their forested land. One example in South Africa is the Working for Water program, which funds the removal of invasive species to increase water flows (van Wilgen et al., 1998; Richardson and van Wilgen, 2004).

A second source of revenue may come from increased market value of forest products. This would require marketing and/or certification (e.g., Forest Stewardship Council, USDA Organic) in conjunction with documented stewardship action undertaken on the land. Interest in this form of PES is expected to grow with market demand for "green" products and practices which support ecosystem service flows.

Whereas markets for biodiversity conservation have been slower to develop, markets for water services and carbon sequestration are rapidly being established. In 2007, 65 million tonnes of carbon dioxide equivalent (MtCO₂ e) worth US\$330.8 million were transacted in voluntary markets, up from 24.6 MtCO₂ e worth US\$96.7 million in 2006 (Hamilton et al., 2008). Forestry projects are among the most frequently engaged in carbon trading (37% and 15% of all documented projects in 2006 and 2007, respectively) (Hamilton et al., 2008). The engagement and commitment of forest products participants can affect the price of carbon; higher prices may be achievable by supporting buyer assessment of quality via additionality, verifiability,⁹ and public visibility (Hamilton et al., 2008). Where demand for timber is falling and development pressures are increasing, ecosystem service values may provide the necessary incentive to conserve forests.

Once established, PES systems are not a silver bullet (Landell-Mills and Porras, 2002; Wunder, 2005, 2007; Kline et al., in review). The extent to which additionality is sustained or the PES catalyzes other benefits depends upon how well market and non-market, ecological, social, and economic considerations have been inte-

grated into the project. Industrial and non-industrial private forest owners are well positioned to take advantage of payments for ecosystem services as markets expand, yet the challenges of quantification, benchmarking, and demonstrating additionality remain.

5.2. Public lands: ecosystem service provision in the commons

In the cases where markets are not suited for ecosystem service provision, governance and adaptive management that incorporates ecosystem services data is needed to address landscape level changes and declining ecosystem health (Patterson, 2007; Ranganathan et al., 2008). An ecosystem services approach taken on public (here, primarily federal) lands is complex because it involves valuation of multiple benefits simultaneously, and an understanding of how multiple ecosystem service bundles evolve over time. From communicating the diverse public values of ecosystem services on public lands to making project-specific decisions, the definition used by land managers may be broad in scope to allow for the inclusion of non-monetary values or very narrow to facilitate cost-benefit analysis.

There are direct and indirect benefits of better understanding ecosystem service provision on public lands. The knowledge gained through experimentation on federal lands may be disseminated to partners (public, nongovernmental, and private) to improve land management methods elsewhere. Research performed on public lands can also contribute to decision making by private, municipal, and nongovernmental partners who are not able to support studies of equal scope and complexity. For example, data from long-term studies on HJ Andrews Experimental Forest could be used by Seattle Public Water Utility to understand how different intensities of land management (i.e., thinning prescriptions) will affect water provision and carbon sequestration over time (Jones and Post, 2004; Chapin, personal communication 30 May 2008).

When public funds are limited, ecosystem service data can be used to prioritize geographic areas for research, restoration, and monitoring. Beier et al. (2008) used geospatial data to identify where ecosystem service provision (supply), use (harvest), and disturbance (present and historical human manipulation of the land) converged to indicate potential for vulnerability or higher marginal benefits from interventions (Fig. 6). The result was a series of maps of forested watersheds, which managers could use to weigh the tradeoffs among focusing restoration funds on many (230) or few (3) watersheds. The conceptual model of comparing production, consumption, and disturbance is applicable to a wide

⁹ A project must be verified by an independent third party for actual carbon emissions avoided in order to successfully trade in the voluntary carbon market (Hamilton et al., 2008).

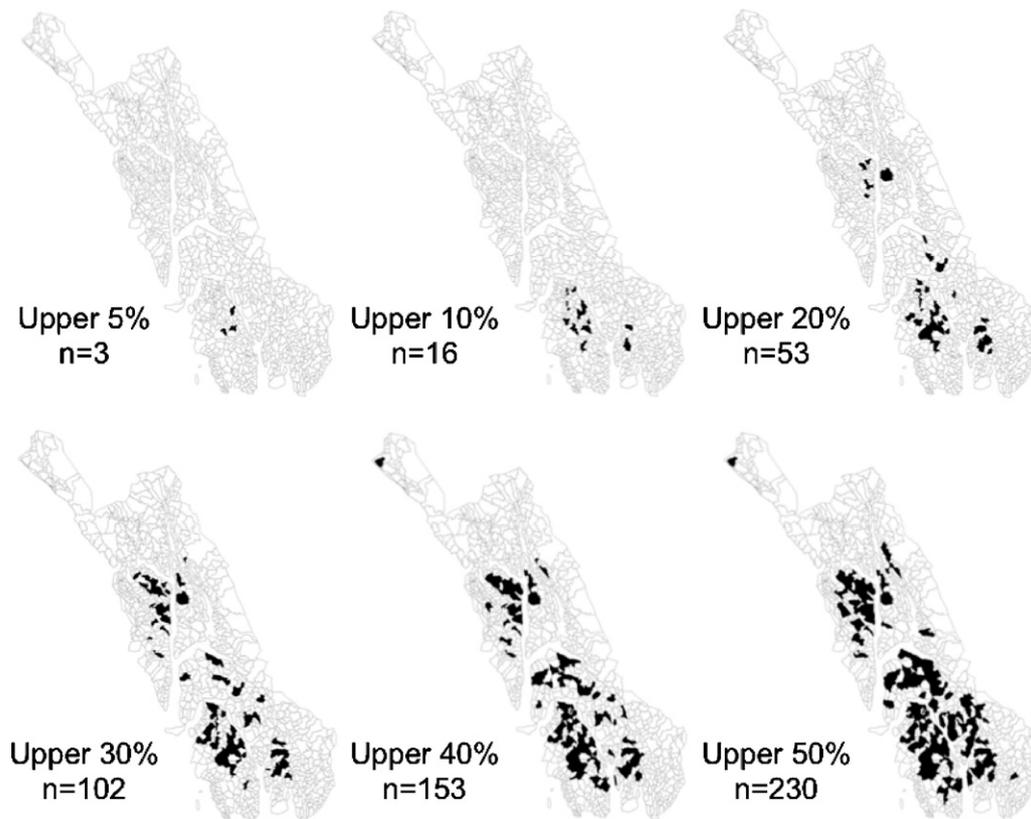


Fig. 6. An application of ecosystem services data to assist prioritization of ecosystem service restoration on the Tongass National Forest in southeast Alaska. Distinctions were made between data which indicated ecosystem service provision, use, and disturbance (from Beier et al., 2008).

variety of land management applications where ecosystem service losses are a concern.

5.3. Raising awareness

Stemming the loss of global ecosystem services (including those from forests) will require more than isolated actions to increase provision on private or public lands. Increased public awareness of ecosystem services has the potential to benefit the forest products sector in a number of ways. Public support can lead to institutional support (e.g., funding, partnerships) for forest product research, development, management, and market exploration. Awareness of ecosystem services and efforts by producers to conserve them can increase demand for a diversified range of sustainably harvested forest products, thus supporting a more stable economic base. Addressing ecosystem service losses in “the commons” will require deep and concerted social shifts. Individuals are more likely to respond to environmental problems when they are aware of the issues, believe the problem to be significant, and feel a responsibility to act (Story and Forsyth, 2008).

Attention to both supply- and demand-side approaches is warranted (Straton, 2006). Demand-side approaches include accounting methods that document and communicate how consumption choices impact the flow of ecosystem services. From the supply-side, studies are exploring ecosystem service replenishment rates, susceptibility to disturbance, replacement cost, and scenarios which track and value various combinations of ecosystem service flows over time. More broadly, public awareness for ecosystem services can raise public support for legislation that retains forested landcover, and funding for restoration. The ecosystem services definition for awareness raising purposes depends on the audience being addressed and the issue being communicated, but tends to be more general and inclusive in

nature. Awareness for ecosystem services can influence forest product purchasing decisions, build support for forest science research, and facilitate the use of indicators in public decision making.

5.3.1. Accounting methods

Various accounting methods have attempted to capture, in quantified form, human reliance on the biosphere. Ecological footprints, carbon calculators, sustainability indicators, and report cards are being used globally and by nations, states, cities, and individuals (e.g., Wackernagel et al., 2002; Patterson et al., 2007; McIntyre et al., 2007; San Mateo County, 2008). This type of accounting benchmarks rates of both resources used and wastes/emissions produced by a given population. This sum is converted to a common unit, a “global hectare” in the case of the ecological footprint, which represents the area of productive land and aquatic ecosystems demanded to produce resources (including energy) and assimilate waste (Wackernagel and Rees, 1996).

The ecological footprint is one accounting tool which can serve as a proxy for pressures on ecosystems and can be an important input into decision making. Patterson et al. (2007) calculated the relative ecological pressures due to the products consumed by an average Italian citizen (Fig. 7), which were then used by the provincial planning authority to encourage residents to reduce their ecological footprints and support restoration activities that would maintain the productivity of forests and agricultural systems (Tiezzi and Bastianoni, 2008). Seven percent of the ecological footprint was attributed to the consumption of forest products, comparable to the amount of resources consumed in marine products. Ecological pressures vary among countries and are determined by factors such as climate, land use, and cultural attributes, as well as available substitutes for energy, production processes, transport, and technology (Weisz et al., 2006).

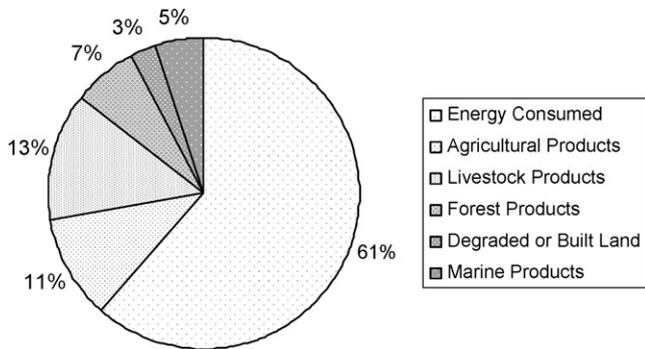


Fig. 7. The ecological footprint (EF) associates consumption patterns with environmental impact. While ecosystem services are not explicitly described, ecological footprint intensity impacts ecosystem services in each category of land and resource use. This figure depicts the EF according to products consumed annually by an average Italian citizen (Patterson et al., 2007).

Arguably most relevant at the national or global scale, the ecological footprint may be supplemented as a sustainability indicator with other accounting approaches such as Environmentally Weighted Material Consumption (EMC) and Land and Ecosystem Accounts (LEAC) (Best et al., 2008). Complementary approaches, such as the component ecological footprint (which focuses on the effects of transport, energy, water, and waste instead of the consumption of raw materials) and input–output analysis (which quantifies the indirect requirements of consumption) are being put forward as most relevant for local or regional analyses (Barrett, 2001; Munksgaard et al., 2005). Efforts to tie ecological footprints to ecosystem service values, supply, and demand more explicitly (Jenerette et al., 2006) offer even more comprehensive tools for decision makers, though few focus explicitly on forests or forest management.

Quantified indicators can also be used to inform consumers who wish to incorporate ecosystem service attributes into product selection, such as carbon labels appearing on forest and agricultural products throughout Great Britain (Carbon Trust, 2008a). Accounting and labeling has allowed businesses and local governments to demonstrate their commitment to managing and reducing their carbon footprint. For example, the Local Authority Carbon Management Programme is a group of 141 local authorities in Britain and Scotland who, in a single year, have seen energy bills reduced, on average, 20 percent, resulting in savings of more than \$135 million and 861,000 tons of avoided carbon dioxide emissions; information that can be passed on to voters (Carbon Trust, 2008b).

5.3.2. Valuation

The history of valuation of ecosystem services is long. Krutilla (1967) catalyzed an expansion of methodologies for economic valuation of natural resources.

Meanwhile Hammack and Brown (1974) and Krutilla and Fisher (1975) expanded the set of “goods and services” considered by economists to be of value to society. Valuation studies continued to flourish in the 1970s and 1980s and 1990s (see reviews in Freeman, 1979; Wilson and Carpenter, 1999) and today (US EPA, 2006; Boyd and Banzhaf, 2007; Brown et al., 2007; Kline, 2007; among others).

There are a number of reasons to value ecosystem services and methods to do so (Farber et al., 2002). The various motivations for the valuations studies, has resulted in a variety of methodologies. The varieties of methodologies have resulted in a wide range of dollar values. Explanations for this are often as unsatisfying for decision-makers as the economists involved. An analogy would be if, wanting to insure your house, you asked an estate appraiser to

come to your property to assess the replacement value of the house and everything in it. This approach is similar to the one taken by Costanza et al., 1997) who used prior studies to estimate that the value of the world’s ecosystem services was worth US\$33 trillion, annually. This kind of ‘value’ can be used to underscore the tremendous returns on investment when the public invests in protection and restoration of ecosystem services (e.g., Pritchard et al., 2000; Brouwer, 2000; Tol, 2005). However- the need for information about ‘value’ is not always alike! What if, instead, you wanted to run an estate sale at your house? In that case, the ‘value’ would be bounded by people’s willingness and ability to pay (Brouwer et al., 1999; Wilson and Carpenter, 1999), and would also include estimates of the ‘transaction cost’ (Whitten et al., 2003; Wunder, 2005, 2007). Imagine your surprise if you had expected a purchaser to give you the replacement cost, and instead someone offered the “street value” of whatever you were selling! This difference, can be a critical piece of information for someone creating a Payment for Ecosystem Service (PES) program, and also illustrates why some applications of ‘valuation’ allow for very large margins of error, while others must be much more specific. An area of emerging importance is in education (Spash and Vatn, 2006) and the use of deliberative techniques (Howarth and Wilson, 2006; Spash, 2007) to reconcile some of these differences.

There is also a history of efforts to evaluate and describe the public goods characteristics associated with multiple use management of public lands. For example, watershed restoration and maintenance (e.g., quantity and quality of the public water supply, flood protection, wildlife habitat) were primary drivers behind the creation of the US National Forest System (Sedell et al., 2000). Today, more than half of the water supply in the western United States is provided by national forests (Brown, personal communication 15 May 2008). A 193 million acre system, the marginal value of water flowing from national forest land has been estimated at between US\$3.7 and 7.2 billion per year (Sedell et al., 2000). These estimates should be seen as lower bounds, as they are projected to increase as population growth stimulates demand and capacity for water production remains limited (Brown, personal communication 15 May 2008). Haynes et al. (1997, 1998) estimated relative values among other uses within the Columbia River Watershed, including recreation (35%), timber (14%), rangelands (1%), and the existence value¹⁰ of road-less wilderness areas (49%). Whereas reliable marginal values for water will require a fairly narrow definition of ecosystem services, consideration of existence values, which are not marketable, requires use of a more inclusive definition of ecosystem services.

Today, tools such as UFORE (the Urban Forest Effects Model) and iTree, developed by the US Forest Service, are being used to raise awareness among city residents of the benefits (pollution removal, carbon storage and sequestration, energy conservation, etc.) of urban forests and street tree networks (Nowak and Crane, 2002; Nowak et al., 2002; Maco and McPherson, 2003). Analyses of several US cities have been performed, returning, for example, values between US\$164,000 and US\$779,000 per year for carbon storage, depending on the size and composition of the urban forest (Nowak et al., 2006a,b; Nowak et al., 2007a,b). Tools available for assessing ecosystem service (primarily carbon) values on more traditional forest landscapes, both public and private, include the Forest Service’s FORCARB2 model (Smith et al., 2006), the Carbon On-Line Estimator (COLE), and Forest Vegetation Simulator (FVS) (The Wilderness Society, 2008). Forest Inventory and Analysis (FIA) data are available from the US Forest Service as model inputs and

¹⁰ Existence value refers to the benefit received from knowing that a particular environmental resource, such as a wilderness area or its associated wildlife, exists. Quantification of existence values is itself a controversial issue (Kopp, 1992; Rosenthal and Nelson, 1992) not explored in this article.

have been used, for example, to estimate the annual value of carbon sequestration from the Tongass National Forest (based on a price of US\$20/Mg C) at \$4–7 million (Leighty et al., 2006).

6. Discussion and conclusions

To this point we have described the development of the ecosystem services concept, present day definitions, and applications. We underscored the importance of explicit and collaborative consideration of how specific or inclusive an ecosystem services project is to be, including attention for the economic characteristics (rival/excludable or not) of the services at hand. Data availability is often a principle factor in determining whether it will be feasible to raise awareness, initiate a market, or to incorporate ecosystem service information into forest and forest product management and decision making.

The enthusiasm for payments for ecosystem services can result in creative responses to long standing environmental problems (e.g., deforestation, climate change). However, to reduce false expectations, this paper took special care to discuss the differences between values derived from methods inclusive of market and non-market values and those calculated under a more restrictive definition of ecosystem services. Most ecosystem services are not suitable for trade in private markets or for direct payments. Other strategies were discussed such as management of ecosystem services on public and private lands, raising awareness to inform behavior and decision making. Sustained provision of ecosystem services is an important goal for natural resource management. Many of the examples in this paper have been chosen because they highlight contributions from forest management toward that goal, or they highlight how ecosystem service gains can feedback positive benefits to forest product objectives. These can include benefits to firms, industry, consumers, and communities.

6.1. From raising awareness to making decisions

Forest product specialists new to ecosystem services quickly realize that moving from a general understanding (provisioning, supporting, regulating, and cultural ecosystem services) to quantifiable and relatable measures is a substantial undertaking. Examples of successful application in forest management decision making is not as common as may be expected by the frequency of its mention. Lack of clarity in definition and market/non-market attributes of ecosystem services hinders the achievement of tangible outputs from case studies. However, some decisions about how, where, and when to harvest or restore the land in a manner that will provide an optimal return on investment, conserve productive capacity, and sustain ecological functions are being made. For example, Seattle Public Water Utility has used ecosystem service value estimates in the Cedar River watershed to construct its land management plan and is experimenting with use of these values to make decisions involving difficult tradeoffs (Chapin, personal communication 13 June 2008). Ecosystem service units are also providing the means to compare costs and benefits (e.g., increased habitat, biodiversity, water quantity and quality) of a forest restoration project with the goals (e.g., carbon sequestration) of the City of Seattle's Climate Action Plan.

Additional applications of valuation and accounting methods presented in this paper have the potential to be used more robustly in decision making. Cities that have raised awareness for urban forest benefits using tools like UFORE and iTree are poised to better prioritize future planting that maximizes ecosystem services.

Increased public awareness of ecosystem services may also have the potential to change consumption patterns generally (Marchand and Walker, 2007) and the kind and quantity of forest

products demanded, specifically. Change may come about through personal decisions, public policies, and can affect the market value of forest products that are produced. Communities and firms exploring their ecological or carbon footprints are increasingly using the awareness generated to create policies and programs that support reduced ecological impacts, increased wellbeing, and cost reduction. Ultimately, changes in demand will influence what products are supplied and how they are produced (Weber and Matthews, 2008).

6.2. Developing indicators of success

Scientific and policy interest in ecosystem services is growing rapidly. Research on actors, networks, institutions, organizations, emerging markets, and management is needed to respond to ecosystem service feedbacks, and to sustain and enhance flows of freshwater, food, forest products, and other ecosystem services.

It is important that beguilement with a particular concept or tool not distract us from the important task at hand—*supporting the continued provision and sustainable consumption of ecosystem services in the long run*. Exceptionally few indicators of success against this goal have been attempted at almost any scale. One effort to incorporate ecosystem service payments into benchmarks and indicators of sustainability is the recent addition of indicator 6.1c “Revenue from Forest Based Environmental Services” in the forthcoming 2010 National Report on Sustainable Forests, part of the Montreal Process Criteria and Indicators Assessment. However, growth in revenue (quantitative goal) is not the same as strengthened ecosystem services provision (qualitative goal). It may be quite plausible that ecosystem service payments are increasing, while the ecosystem service flows themselves continue to decline. Research is needed to articulate the nexus between the two objectives, where they deviate, and how they align with existing strategies in the resource management toolkit.

Relatively little is known about the demands of consumers who value forest ecosystem services, as they make decisions to purchase forest products. Exploring this line of research has implications for the entire life cycle of a product: harvest, production, transport, use, and disposal. A growing body of literature on forest product lifecycle analysis (e.g., Seppälä et al., 1998; Gertner and Fripp, 2007) and other quantified forest product information is poised to assist our understanding of how developments and trends in ecosystem services affect and can be affected by the forest products sector. This article has aimed to inform and clarify aspects of ecosystem service discussions which may be otherwise overlooked as numerous interested parties attempt to bring forest product perspectives to discussion, application, valuation, management and exchange.

Acknowledgements

The authors thank the numerous reviewers who contributed the thoughtful and constructive comments that led to this version of the text. Additionally, we thank Richard Haynes, Allen Brackley, Jeff Kline, Cynthia West, Ron Wolfe, Cynthia Glick, and Gardner Brown for their early draft suggestions and for engaging discussion throughout.

References

- Baer, P., Harte, J., Haya, B., Herzog, A.V., Holdren, J., Hultman, N.E., Kammen, D.M., Norgaard, R.B., Raymond, L., 2000. Climate change: equity and greenhouse gas responsibility. *Science* 289, 2287.
- Barnes, A., Ebright, M., Gaskin, E., Strain, W., 2007. Working for water: addressing social and environmental problems with payments for ecosystem services in South Africa. *Ecosystem Marketplace Case Studies*.
- Barrett, J., 2001. Component ecological footprint: developing sustainable scenarios. *Resource Management* 19, 107–118.

- Beier, C., Patterson, T., Chapin, S., 2008. Ecosystem services and emergent vulnerability in managed ecosystems: a geospatial decision-support tool. *Ecosystems* (online first).
- Best, A., Giljum, S., Simmons, C., Blobel, D., Lewis, K., Hammer, M., Cavalieri, S., Lutter, S., Maguire, C., 2008. Potential of the ecological footprint for monitoring environmental impacts from natural resource use: Analysis of the potential of the Ecological Footprint and related assessment tools for use in the EU's Thematic Strategy on the Sustainable Use of Natural Resources. Report to the European Commission, DG Environment.
- Boyd, J., Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics* 63, 616–626.
- Bridgewater, P.B., 2002. Biosphere reserves: special places for people and nature. *Environmental Science and Policy* 5, 9–12.
- Brouwer, R., 2000. Environmental value transfer: state of the art and future prospects. *Ecological Economics* 32, 137–152.
- Brouwer, R., Langford, I.H., Bateman, I.J., Turner, R.K., 1999. A meta-analysis of wetland contingent valuation studies. *Regional Environmental Change* 1 (1), 47–57.
- Brown, T.C., Bergstrom, J.C., Loomis, J.B., 2007. Defining, valuing and providing ecosystem goods and services. *Natural Resources Journal* 47, 329–376.
- Burger, J., Ostrom, E., Norgaard, R.B., Policansky, D., Goldstein, B.D., 2001. Protecting the Commons: A Framework for Resource Management in the Americas. Island Press, Washington, DC.
- Carbon Trust, 2008a. Monitoring and targeting - In-depth management guide. Carbon Trust Publication CTG008, 01 May 2008. <http://www.carbontrust.co.uk> (13 June 2008).
- Carbon Trust, 2008b. Creating a low carbon future with the public sector. Carbon Trust Publication PFL304, 01 February 2008. <http://www.carbontrust.co.uk/publications/publicationdetail?productid=PFL304> (13 June 2008).
- Chapin, D., 2008. PhD Aquatic/Riparian Ecologist, Seattle Public Utilities, with T. Patterson (30 May 2008).
- Chapin, D., 2008. PhD Aquatic/Riparian Ecologist, Seattle Public Utilities, with T. Patterson (13 June 2008).
- Collados, C., Duane, T.P., 1999. Natural capital and quality of life: a model for evaluating the sustainability of alternative regional development paths. *Ecological Economics* 30, 441–460.
- Collins, S., Larry, E., 2007. Caring for our natural assets: an ecosystem services perspective. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-733.
- Costanza, R., 2008. Ecosystem services: multiple classification systems are needed. *Biological Conservation* 141, 350–352.
- 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 value of the world's ecosystem services and natural capital. *Nature* 387, 253–260.
- Daily, G.C., 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC.
- Daly, H.E., 1977. Steady-state economics. In: Cahn, M.A., O'Brien, R. (Eds.), *Thinking about the Environment: Readings on Politics, Property, and the Physical World*. M.E. Sharpe, Inc., New York, NY, pp. 250–255.
- Daly, H., 1991. *Steady-State Economics: Second Edition With New Essays*. Island Press, Washington, DC.
- Daly, H., 1996. *Beyond Growth: The Economics of Sustainable Development*. Beacon Press, Boston, MA.
- Daly, H.E., Farley, J., 2004. *Ecological Economics: Principles and Applications*. Island Press, Washington DC.
- de Groot, R.S., Wilson, M.A., Boumans, R.M., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41, 393–408.
- Deutsch, L., Folke, C., Skanberg, K., 2003. The critical natural capital of ecosystem performance as insurance for human well-being. *Ecological Economics* 44, 205–217.
- Dietz, T., Ostrom, E., Stern, P.C., 2003. The struggle to govern the commons. *Science* 302, 1907–1912.
- Dorfman, R., Dorfman, N.S. (Eds.), 1993. *Economics of the Environment: Selected Readings*. third ed. W.W. Norton & Company, New York, NY.
- Echavarría, M., Lochman, L., 1999. Policy mechanisms for watershed conservation: Case studies. *Nature Conservancy*, Arlington, Virginia, USA.
- Ehrlich, P.R., Ehrlich, A.H., 1981. *Extinction: The Causes and Consequences of the Disappearance of Species*. Random House, New York, NY.
- Ehrlich, P.R., Ehrlich, A.H., 1990. *The Population Explosion*. Simon and Schuster, New York, NY.
- Ehrlich, P.R., Ehrlich, A.H., Holdren, J.P., 1977. *Ecoscience: Population, Resources, Environment*. W. H. Freeman, San Francisco.
- Ehrlich, P.R., Goulder, L.H., 2007. Is current consumption excessive? A general framework and some indications for the United States. *Conservation Biology* 21, 1145–1154.
- Engel, S., Pagiola, S., Wunder, S., 2008. Designing payments for environmental services in theory and practice: an overview of the issues. *Ecological Economics* 65, 663–674.
- Farber, S., Costanza, R., Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. *Ecological Economics* 41, 375–392.
- Fisher, B., Turner, R.K., 2008. Ecosystem services: classification for valuation. *Biological Conservation* 141, 1167–1169.
- Foley, J.A., Monfreda, C., Ramankutty, N., Zacks, D., 2007. Our share of the planetary pie. *Proceedings of the National Academy of Sciences* 104, 12585–12586.
- Folke, C., Hammer, M., Jansson, A.M., 1991. Life-support value of ecosystems: a case study of the Baltic Sea Region. *Ecological Economics* 3, 123–137.
- Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., Walker, B., Bengtsson, J., Berkes, F., Coling, J., Danell, K., Falkenmark, M., Gordon, L., Kasperson, R., Kautsky, N., Kinzig, A., Levin, S., Mäler, K.-G., Moberg, F., Ohlsson, L., Olsson, P., Ostrom, E., Reid, W., Rockström, J., Savenije, H., Svedin, U., 2002. Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations. Scientific Background Paper on Resilience for the process of The World Summit on Sustainable Development on behalf of The Environmental Advisory Council to the Swedish Government. Stockholm, Sweden.
- Freeman, A.M., 1979. *The Benefits of Environmental Improvement: Theory and Practice*. Johns Hopkins Press for Resources for the Future, Baltimore, MD.
- Ghertner, D.A., Fripp, M., 2007. Trading away damage: quantifying environmental leakage through consumption-based, life-cycle analysis. *Ecological Economics* 63, 563–577.
- Gibson, C., McKean, M.A., Ostrom, E., 2000. *People and Forests: Communities, Institutions, and Governance*. MIT Press, Cambridge.
- Gibson, C., Ostrom, E., Williams, J.T., 2005. Local enforcement and better forests. *World Development* 2, 273–284.
- Gunderson, L., Folke, C., 2005. Resilience—now more than ever. *Ecology and Society* 10, 22–26.
- Haberl, H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., Gingrich, S., Lucht, W., Fischer-Kowalski, M., 2007. Quantifying and mapping the human appropriation of net primary production in earth's terrestrial systems. *Proceedings of the National Academy of Sciences* 104, 12942–12947.
- Hamilton, K., Sjardin, M., Marcello, T., Xu, G., 2008. Forging a frontier: state of the voluntary carbon markets 2008. Ecosystem Marketplace and New Carbon Finance. http://www.ecosystemmarketplace.com/documents/cms_documents/2008_StateofVoluntaryCarbonMarket_ExecSumm.pdf (accessed 6-1-2008).
- Hammack, J., Brown Jr., G.M., 1974. *Waterfowl and Wetlands: Toward Bioeconomic Analysis*. Johns Hopkins University Press, Baltimore, MD.
- Hardin, G., 1968. The tragedy of the commons. *Science* 162, 1243–1248.
- Haynes, R.W., Horne, A.L., Reyna, N.E., 1997. Economic evaluation of the preliminary draft EIS alternatives, in: Quigley, T.M., Lee, K.M., Arbelbide, S.J. (Eds.), *Evaluation of the Environmental Impact Statement Alternatives by the Science Integration Team*. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-406, pp. 731–758.
- Haynes, R.W., Reyna, N.E., Allen, S.D., 1998. Social and economic systems. *Journal of Forestry* 96, 28–32.
- Holdren, J.P., Ehrlich, P.R., 1974. The human population and the global environment. *American Scientist* 62, 282–292.
- Holling, C.S., 2001. Understanding the complexity of economic, ecological and social systems. *Ecosystems* 4, 390–405.
- Howarth, R.B., Wilson, M.A., 2006. A theoretical approach to deliberative valuation: aggregation by mutual consent. *Land Economics* 82, 1–16.
- Jenerette, G.D., Marussich, W.A., Newell, J.P., 2006. Linking ecological footprints with ecosystem valuation in the provisioning of urban freshwater. *Ecological Economics* 59, 38–47.
- Johnson, N., White, A., Perrot-Maitre, D., 2001. *Developing Markets for Water Services From Forests: Issues and Lessons for Innovators*. Forest Trends, World Resources Institute, and The Katoomba Group, Washington, DC.
- Jones, J.A., Post, D.A., 2004. Seasonal and successional streamflow response to forest cutting and regrowth in the northwest and eastern United States. *Water Resources Research* 40, W052031–W0520319.
- Kline, J.D., Patterson, T., Mazotta, M., in review. Toward a rational exuberance for ecosystem services markets. *Journal of Forestry*.
- Kline, J.D., 2007. Defining an economics research program to describe and evaluate ecosystem services. USDA Forest Service, Pacific Northwest Research Station. Gen. Tech. Rep. PNW-GTR-700.
- Kline, J.D., Patterson, T., Spies, T., 2008. Toward a rational exuberance for ecosystem services markets. USDA Forest Service, Pacific Northwest Research Station. Presented at ACES: A conference for ecosystem services, Naples, FL, December 8.
- Kopp, R.J., 1992. Why existence value should be used in cost-benefit analysis. *Journal of Policy Analysis and Management* 11, 123–130.
- Krutilla, J.V., 1967. Conservation reconsidered. *The American Economic Review* 57, 777–786.
- Krutilla, J.V., Fisher, A.C., 1975. *The Economics of Natural Environments: Studies in the Valuation of Commodity and Amenity Resources*. Johns Hopkins University Press, Baltimore, MD.
- Landell-Mills, N., Porras, I.T., 2002. Silver bullet or fool's gold? A global review of markets for forest environmental services and their impact on the poor. *Institutes for Sustainable Private Sector Forestry Series*. International Institute for Environment and Development, London, UK.
- Leighty, W.W., Hamburg, S.P., Caouette, J., 2006. Effects of management on carbon sequestration in forest biomass in Southeast Alaska. *Ecosystems* 9, 1–20.
- Lindeman, R.L., 1942. The trophic-dynamic aspect of ecology. *Ecology* 23, 399–418.
- Maco, S.E., McPherson, E.G., 2003. A practical approach to assessing structure, function, and value of street tree populations in small communities. *Journal of Arboriculture* 29, 84–97.
- Marchand, A., Walker, S., 2007. Product development and responsible consumption: designing alternatives for sustainable lifestyles. *Journal of Cleaner Production* 16, 1163–1169.
- Marsh, G.P., 1864. *Man and Nature*. Reprint. Harvard University Press, Cambridge, MA, p. 1965.

- McIntyre, S.A., Peters, H.M., Christensen, M.H., Emmi, P.C., Martinson, W.M., Mielke, M., Senbel, M., Stark, D.O., 2007. The Ecological Footprint of Utah. Utah Vital Signs.
- MEA, 2005. Ecosystems and Human Well-being: Current State and Trends. Island Press, Washington, DC.
- Munksgaard, J., Wier, M., Lenzen, M., Dey, C., 2005. Using input–output analysis to measure the environmental pressure of consumption at different spatial levels. *Journal of Industrial Ecology* 9, 169–185.
- Nicolis, G., Prigogine, I., 1977. *Self-Organization in Non-Equilibrium Systems*. Wiley-Interscience, New York.
- Nordhaus, W., 1982. How fast should we graze the global commons? *The American Economic Review* 72, 242–246.
- Nowak, D.J., Crane, D.E., 2002. Carbon storage and sequestration by urban trees in the United States. *Environmental Pollution* 116, 381–389.
- Nowak, D.J., Crane, D.E., Dwyer, J.F., 2002. Compensatory value of urban trees in the United States. *Journal of Arboriculture* 28, 194–199.
- Nowak, D.J., Hoehn III, R.E., Crane, D.E., Stevens, J.C., Walton, J.T., Bond, J., Ina, G., 2006a. Assessing urban forest effects and values: Minneapolis' urban forest. USDA Forest Service, Northeastern Research Station, Resource Bulletin NE-166.
- Nowak, D.J., Hoehn III, R.E., Crane, D.E., Stevens, J.C., Walton, J.T., 2006b. Assessing urban forest effects and values: Washington, D.C.'s Urban Forest. USDA Forest Service, Northern Research Station, Resource Bulletin NRS-1.
- Nowak, D.J., Hoehn III, R.E., Crane, D.E., Stevens, J.C., Walton, J.T., 2007a. Assessing urban forest effects and values: New York City's urban forest. USDA Forest Service, Northern Research Station, Resource Bulletin NRS-9.
- Nowak, D.J., Hoehn III, R.E., Crane, D.E., Stevens, J.C., Walton, J.T., 2007b. Assessing urban forest effects and values: San Francisco's urban forest. USDA Forest Service, Northern Research Station, Resource Bulletin NRS-8.
- Ostrom, E., 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press, New York, NY.
- Patterson, T., 2007. The economic value of ecosystem services from and for wilderness. Wild Planet Project. *International Journal of Wilderness* (April), 27–30.
- Patterson, T.M., Niccolucci, V., Bastianoni, S., 2007. Beyond 'more is better': ecological footprint accounting for tourism and consumption in Val di Merse, Italy. *Ecological Economics* 62, 747–756.
- Pérez-Maqueo, O., Intralawana, A., Martínez, M.L., 2007. Coastal disasters from the perspective of ecological economics. *Ecological Economics* 63, 273–284.
- Platt, J., 1973. Social traps. *American Psychologist* 28, 641–651.
- Pritchard Jr., L., Folke, C., Gunderson, L., 2000. Valuation of ecosystem services in institutional context. *Ecosystems* 3 (1), 36–40.
- Randall, A., 1993. The problem of market failure. In: Dorfman, R., Dorfman, N. (Eds.), *Economics of the Environment*. third ed. Norton, New York, NY, pp. 144–161.
- Ranganathan, J., Bennett, K., Raudsepp-Hearne, C., Lucas, N., Irwin, F., Zurek, M., Ash, N., West, P., 2008. Ecosystem Services: A Guide for Decision Makers. World Resources Institute Publication. http://pdf.wri.org/ecosystem_services_guide_for_decisionmakers.pdf (13 June 2008).
- Richardson, D.M., van Wilgen, B.W., 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? *South African Journal of Science* 100, 45–52.
- Rosenthal, D.H., Nelson, R.H., 1992. Why existence value should not be used in cost-benefit analysis. *Journal of Policy Analysis and Management* 11, 116–122.
- Ruddell, S., Sampson, R., Smith, M., Giffen, R., Cathcart, J., Hagan, J., Sosland, D., Godbee, J., Heissenbuttel, J., Lovett, S., Helms, J., Price, W., Simpson, R., 2007. The role for sustainably managed forests in climate change mitigation. *Journal of Forestry* (September), 314–319.
- Samuelson, P.A., 1954. The pure theory of public expenditure. *The Review of Economics and Statistics* 36, 387–389.
- San Mateo County, 2008. Indicators for a Sustainable San Mateo County: Twelfth Annual Report Card April 2008. <http://www.sustainablesanmateo.org/indicators-report/reports/2008-indicators-report/>. (11 June 2008).
- SCEP (Study of Critical Environmental Problems), 1970. *Man's Impact on the Global Environment*. MIT Press, Cambridge, MA.
- Schumacher, E.F., 1973. *Small Is Beautiful: Economics As If People Mattered*. Hartley & Marks Publishers.
- Sedell, J., Sharpe, M., Dravnieks, D., Copenhagen, M., Furniss, M., 2000. Water and the Forest Service. USDA Forest Service, Policy Analysis, FS-660. <http://www.fs.fed.us/publications/policy-analysis/water.pdf> (accessed 6-1-2008).
- Seppälä, J., Melanen, M., Jouttijärvi, T., Kauppi, L., Leikola, N., 1998. Forest industry and the environment: a life cycle assessment study from Finland. *Resources Conservation and Recycling* 23, 87–105.
- Smith, J.E., Heath, L.S., Skog, K.E., Birdsey, R.A., 2006. Methods for calculating forest ecosystem and harvest carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service Northeastern Research Station. 216 pp.
- Spash, C.L., 2007. Deliberative monetary valuation (DMV): issues in combining economic and political processes to value environmental change. *Ecological Economics* 63, 690–699.
- Spash, C.L., Vatn, A., 2006. Transferring environmental value estimates: issues and alternatives. *Ecological Economics* 60, 379–388.
- Story, P., Forsyth, D., 2008. Watershed conservation and preservation: Environmental engagement as helping behavior. *Journal of Environmental Psychology* 28 (4), 305–317.
- Straton, A., 2006. A complex systems approach to the value of ecological resources. *Ecological Economics* 56, 402–411.
- The Wilderness Society, 2008. Measuring forest carbon: strengths and weaknesses of available tools. Ecology and Economics Research Department Science and Policy Brief. April 2008.
- Tiezzi, E., Bastianoni, S., 2008. Sustainability of the Siena Province through ecodynamic indicators. *Journal of Environmental Management* 86, 329–331.
- Tol, S.J., 2005. The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties. *Energy Policy* 33, 2064–2074.
- USEPA (US Environmental Protection Agency), 2006. Ecological Benefits Assessment Strategic Plan, EPA-240-R-06-001. Office of the Administrator, Washington, DC. <http://www.epa.gov/economics/> (accessed 5-12-2008).
- van Wilgen, B.W., Le Maitre, D.C., Cowling, R.M., 1998. Ecosystem services, efficiency, sustainability and equity: South Africa's Working for Water programme. *Trends in Ecology and Evolution* 13 (9), 378.
- Waage, S., Mulder, I., ten Kate, K., Scherr, S., Roberts, J.P., Hawn, A., Hamilton, K., Bayon, R., Carroll, N., 2007. Investing in the future: an assessment of private sector demand for engaging in markets & payments for ecosystem services. PESAL Papers Series No. 2. FAO, Rome, Italy and Forest Trends, Washington, DC.
- Wackernagel, M., Rees, W., 1996. *Our Ecological Footprint*. New Society Publishers, Philadelphia, PA.
- Wackernagel, M., Schulz, N.B., Deumling, D., Callejas Linares, A., Jenkins, M., Kapos, V., Monfreda, C., Loh, J., Myers, N., Norgaard, R., Randers, J., 2002. Tracking the ecological overshoot of the human economy. *Proceedings of the National Academy of Sciences* 99, 9266–9271.
- Weber, C.L., Matthews, H.S., 2008. Quantifying the global and distributional aspects of American household carbon footprint. *Ecological Economics* 66, 379–391.
- Weisz, H., Krausmann, F., Amann, C., Eisenmenger, N., Erb, K., Hubacek, K., Fischer-Kowalski, M., 2006. The physical economy of the European Union: cross-country comparison and determinants of material consumption. *Ecological Economics* 58, 676–698.
- Westman, W.E., 1977. How much are nature's services worth? *Science* 197, 960–964.
- Whitten, S., Salzman, J., Shelton, D., Proctor, W., 2003. Markets for ecosystem services: applying the concepts. CSIRO Sustainable Ecosystems. In: Paper Presented at the 47th Annual Conference of the Australian Agricultural and Resource Economics Society, Fremantle.
- Wilson, M.A., Carpenter, S.R., 1999. Economic valuation of freshwater ecosystem services in the United States: 1971–1997. *Ecological Applications* 9 (3), 772–783.
- Wunder, S., 2005. Payments for Environmental Services: Some Nuts and Bolts. CIFOR Occasional Paper No. 42, Center for International Forestry Research, Jakarta.
- Wunder, S., 2007. The efficiency of payments for environmental services in tropical conservation. *Conservation Biology* 21, 48–58.