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Valuing ecosystem services

Theory, practice, and the need for a transdisciplinary synthesis

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The concept of ecosystem services has shifted our paradigm of how nature matters to human societies. Instead of viewing the preservation of nature as something for which we have to sacrifice our well-being, we now perceive the environment as natural capital, one of society's important assets. But ecosystem services are becoming increasingly scarce. In order to stop this trend, the challenge is to provoke society to acknowledge the value of natural capital. Ecosystem services valuation (ESV) is the method to tackle such a challenge. ESV is the process of assessing the contributions of ecosystem services to sustainable scale, fair distribution, and efficient allocation. It is a tool that (1) provides for comparisons of natural capital to physical and human capital in regard to their contributions to human welfare; (2) monitors the quantity and quality of natural capital over time with respect to its contribution to human welfare; and (3) provides for evaluation of projects that will affect natural capital stocks. This review covers: (1) what has been done in ESV research in the last 50 years; (2) how it has been used in ecosystem management; and (3) prospects for the future. Our survey of the literature has shown that over time, there has been movement toward a more transdisciplinary approach to ESV research which is more consistent with the nature of the problems being addressed. On the other hand, the contribution of ESV to ecosystem management has not been as significant as hoped nor as clearly defined. Conclusions drawn from the review are as follows: first, ESV researchers will have to transcend disciplinary boundaries and synthesize tools, skills, and methodologies from various disciplines; second, ESV research has to become more problem-driven rather than tool-driven because ultimately the success of ESV will be judged on how well it facilitates real-world decision making and the conservation of natural capital.

Keywords: natural capital; environmental decision making; ecosystem valuation

Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services, such as food and water; regulating services, such as regulation of floods, drought, and disease; supporting services, such as soil formation and nutrient cycling; and cultural services, such as recreational, spiritual, and other nonmaterial benefits.[1–4] On the supply side, ecosystems are experiencing serious degradation in regard to their capability of providing services. At the same time, the demand for ecosystem services is rapidly increasing as populations and standards of living increase.[5]

Ecosystem services are becoming increasingly scarce. This trend is partially due to the lack of valuation because it is impossible to manage what we do not value.[6] Evidence of this is easily seen whereby we use words, such as "priceless" and "invaluable," when discussing the environment and yet this has proven woefully insufficient in terms of reducing or halting ecosystem degradation. The challenge then is to provoke society to acknowledge the value of ecosystem services.[7] Ecosystem services valuation (ESV) is the tool that can tackle such a challenge.

Definition and triple goals of ecosystem services valuation

The concept of ecosystem service is anthropogenic, as is the process of ESV. For this reason, ESV efforts, particularly monetary valuation, have been

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criticized for conserving ecosystems only for the sake of humans.[8] This argument is misleading for two reasons.

First, it is important to differentiate ends and means. Monetary valuation, and ESV in general, is only a means to communicate the concept of difference between the two schools of thought concerning ecosystem conservation—for the benefit of man or the benefit of the entire Earth—is mostly theoretical. In the end, the well-being of people and ecosystems are interdependent, which is in accord with conservation practices today where pluralism between the two schools is often the norm.[9]

In addition, the fact that ecosystem services have an economic value does not mean that economic benefits are the only focus for ESV. On the contrary, nature is vital to human survival and well-being for a myriad of reasons and, therefore, forcing all values into a single economic indicator is not realistic. Recognizing the existence of multiple values and encouraging open and pluralistic discussion of values will lead to new solutions for conservation practice.[10]

Ecosystems have both intrinsic and utilitarian values.[a] We acknowledge the importance of intrinsic value, yet it is beyond the scope of this paper. This is because ESV is anthropogenic whereas intrinsic value is not.

According to a utilitarian framework, *valuation* is the process of assessing the contribution of a particular object or action to meeting a particular goal, whether or not that contribution is fully perceived by the individual. A baseball player is valuable to the extent he contributes to the goal of the team's winning. In evolutionary biology, a gene is valuable to the extent it contributes to the survival of the individuals possessing it and their progeny. In neoclassical economics, a commodity is valuable to the extent it contributes to the goal of individual welfare as assessed by willingness to pay. The point is that one can not state a value without stating the goal being served.[13]

ESV is then the process of assessing the contribution of ecosystem services to meeting a particular goal or goals. In neo-classical economics this goal is efficient allocation, that is, to allocate scarce ecosystem services among competing uses, such as development and conservation. But other goals, and thus other values, are possible. There are at least three broad goals that have been identified as important to managing economic systems within the context of the planet's ecological life support system:[18]

1. assessing and ensuring that the scale or magnitude of human activities within the biosphere are ecologically sustainable;
2. distributing resources and property rights fairly, both within the current generation of humans and between this and future generations, and also between humans and other species; and
3. efficiently allocating the resources constrained and defined by 1 and 2 above (including both market and nonmarket resources, and especially ecosystem services) for the purpose of maximizing utility or human welfare.

Because of these multiple goals, valuation must be performed from multiple perspectives, using multiple methods (including both subjective and objective), and against multiple goals.[13] Furthermore, it is important to recognize that the three goals are not "either–or" alternatives. Instead, they are in some sense independent multiple criteria which must all be satisfied in an integrated fashion to allow human life to continue in a desirable way.[19]

However, basing valuation on current individual preferences and utility maximization alone does not necessarily lead to ecological sustainability or social fairness,[20] or to economic efficiency for that matter, given the severe market imperfections involved. ESV provides a tool that enhances the ability of decision makers to evaluate tradeoffs between alternative ecosystem management regimes in order to meet a set of goals, namely, sustainable scale, fair distribution, and efficient allocation.[21]

Framework for ESV

Figure 1 shows an integrated framework developed for ESV (adapted from Ref. 3). It exhibits the pivotal link served by ecosystem services between human and ecological systems. Ecosystem structures and processes are influenced by biophysical drivers, which in turn create the necessary conditions for providing the ecosystem services

[a] In the ESV arena, discussion has been focused on the difference between intrinsic and utilitarian values and its implication to environmental decision making.[5,8,11–17]

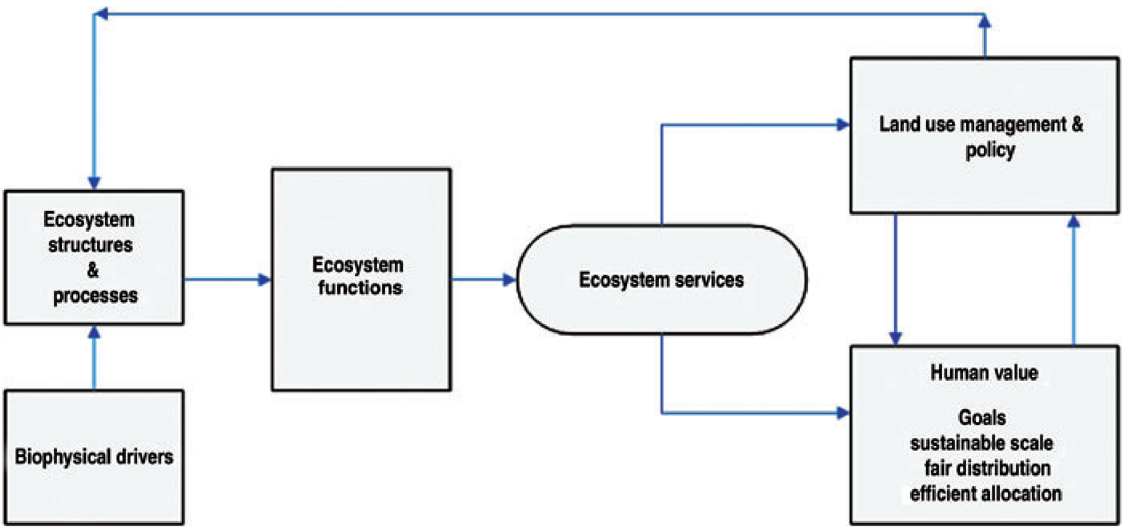

Figure 1. **Framework for integrated assessment and valuation of ecosystem goods and services (adapted from de Groot *et al.*[3]) (In color in *Annals* online.)**

that support human welfare. Through land use management and policy decisions, individuals and social groups make tradeoffs. In turn, these land use decisions directly modify the ecological structures and processes through engineering and construction activities and/or indirectly by modifying the physical, biological, and chemical structures and processes of the landscape.

Methodology for ESV

Many ecosystem services are neither rival nor excludable, so they are subject to market failure in which the market can not send the correct price signals to determine the appropriate provision of ecosystem services.[22] A spectrum of non-market valuation techniques have been developed to value ecosystem services, including both non-monetary valuation methods and environmental economic techniques based on a monetary metric (Box 1[23–26]).

The use of a monetary metric assumes that individuals are willing to trade the ecosystem service being valued for other services represented by the metric. The purpose of monetary valuation is to allow the measurement of the costs or benefits associated with changes in ecosystem services by calculating a shadow price. However, caution must be taken when using this price mechanism to allocate ecosystem services, and it has been argued that conservation needs should be price-determining, not price-determined.[27]

Box 1. Ecosystem service valuation methods

Monetary valuation (adapted from Farber *et al.*[15])

Revealed-preference approaches

- **Market methods**: Valuations are directly obtained from what people must be willing to pay for the service or good (e.g., timber harvest).
- **Travel cost**: Valuations of site-based amenities are implied by the costs people incur to enjoy them (e.g., cleaner recreational lakes).
- **Hedonic methods**: The value of a service is implied by what people will be willing to pay for the service through purchases in related markets, such as housing markets (e.g., open-space amenities).
- **Production approaches**: Service values are assigned from the impacts of those services on economic outputs (e.g., increased shrimp yields from an increased area of wetlands).

State-preference approaches

- **Contingent valuation**: People are directly asked their willingness to pay or accept compensation for some change in ecological service (e.g., willingness to pay for cleaner air).

- **Conjoint analysis**: People are asked to choose or rank different service scenarios or ecological conditions that differ in the mix of those conditions (e.g., choosing between wetlands scenarios with differing levels of flood protection and fishery yields).

Cost-based approaches

- **Replacement cost**: The loss of a natural system service is evaluated in terms of what it would cost to replace that service (e.g., tertiary treatment values of wetlands if the cost of replacement is less than the value society places on tertiary treatment).
- **Avoidance cost**: A service is valued on the basis of costs avoided, or of the extent to which it allows the avoidance of costly averting behaviors, including mitigation (e.g., clean water reduces costly incidents of diarrhea).

Benefit transfer: The adaptation of existing ESV information or data to new policy contexts that have little or no data (e.g., ecosystem service values obtained by tourists viewing wildlife in one park used to estimate that from viewing wildlife in a different park).

Nonmonetizing valuation or assessment[34]

Measures of attitudes, preferences, and intentions
Civic valuation
Decision science approaches
Ecosystem benefit indicators
Biophysical ranking methods

For an environmental economist, the principle distinction among monetary valuation methods is based on the data source, that is, whether it derives from observations of human behavior in the real world (i.e., *revealed-preference approaches*) or from human responses to hypothetical questions (*state-preference approaches*) such as, "How much would you be willing to pay for. . .?" or "What would you do if. . .?"

When an ecosystem service is difficult to value using the above two approaches, researchers—mainly ecologists—have resorted to the method of *replacement or avoided cost*. However, economists believe that such a cost-based approach should be used only with great caution.[25,28,29] For them, any value estimate derived from this approach is not a measure of economic value because it is not based on preferences. As a result these cost figures should not be on the benefit side of a benefit-cost balance sheet.[b]

Conducting original valuation research is expensive and time-consuming. *Benefit transfer* has been applied as a "second-best" strategy, where decision makers seek a timely and cost-effective way to value ecosystem services.[30] It involves obtaining an estimate for the value of ecosystem services through the analysis of a single study or group of studies that have been previously carried out to value "similar" goods or services in "similar" locations. The transfer itself refers to the application of derived values and other information from the original "study site" to a "policy site," which can vary across geographic space and/or time.[31,32]

The ability to transfer values from one context to another is service-specific. Some ecosystem services, such as carbon sequestration, may be provided at a scale for which benefits are easily transferable. By contrast, values of local-scale services, such as flood control, may have limited transferability. Table 1 provides guidance for transferring service values from one context to another.[33]

Similarly, Table 1 also illustrates some valuation tools that are more appropriate for some ecosystem services than for others. For example, Travel Cost (TC) is primarily used for calculating recreation values while Hedonic Pricing (HP), for estimating property values, is associated with the aesthetic qualities of natural ecosystems. Contingent Valuation (CV) and Conjoint Analysis (CA) are the only methods by which measurements can be obtained for nonuse values, such as the existence value of wildlife.

Finally, nonmonetary methods do not require valuation results expressed in a single monetary unit.[34] For instance, group valuation (GV), a type of civic valuation, is a more recent addition to the valuation literature and addresses the need to measure social values directly in a group context.[35,36] Another novel approach has emerged which estimates individuals' subjective happiness as a function of factors, such as ecosystem services and income.[26]

[b]Similarly, one should differentiate the concept of Cost of Policy Inaction and the value of ecosystem services. The former is the economic loss in the absence of additional policy or policy revision.[6]

Table 1. Categories of ecosystem services and economic methods for valuation (Farber *et al.*[33])

Ecosystem service	Amenability to economic valuation	Most appropriate method for valuation	Transferability across sites
Gas regulation	Medium	CV, AC, RC	High
Climate regulation	Low	CV	High
Disturbance regulation	High	AC	Medium
Biological regulation	Medium	AC, P	High
Water regulation	High	M, AC, RC, H, P, CV	Medium
Soil retention	Medium	AC, RC, H	Medium
Waste regulation	High	RC, AC, CV	Medium to high
Nutrient regulation	Medium	AC, CV	Medium
Water supply	High	AC, RC, M,TC	Medium
Food	High	M, P	High
Raw materials	High	M, P	High
Genetic resources	Low	M, AC	Low
Medicinal resources	High	AC, RC, P	High
Ornamental resources	High	AC, RC, H	Medium
Recreation	High	TC, CV, ranking	Low
Aesthetics	High	H, CV, TC, ranking	Low
Science and education	Low	Ranking	High
Spiritual and historic	Low	CV ranking	Low

AC, avoided cost; CV, contingent valuation; H, hedonic pricing; M, market pricing; P, production approach; RC, replacement cost; TC, travel cost.

History of ESV research

This section provides an historical perspective on ESV research. The initial impetus for ESV was the emergence of environmentalism in the 1960s. However, this is not to say that the foundations of ESV were not present before that. For instance, Hotelling's discussion of the value of parks implied by travel costs signaled the start of the travel cost valuation era.[37] Similarly, suggestions by Ciriacy-Wantrup in the late 1940s led to the use of stated preference techniques.[38] Such early efforts demonstrate that economists started to consider evaluating the contribution of nature to human well-being, even though the concept of ecosystem services was not developed for almost another 50 years.

Our approach to the history of advances in ESV will not be a method by method literature review.[c] Rather, we focus on how people faced the challenge presented by the transdisciplinary nature of ESV research. In the 1960s, for instance, there was relatively little work that transcended disciplinary boundaries on ESV. In later years, this situation gradually improved. *Transdisciplinary* approaches are required for ESV in which practitioners (1) perceive disciplinary boundaries as academic constructs irrelevant outside of the university, and (2) allow the problem being studied to determine the tools, rather than vice versa.

We frequently see ESV research in which teams of researchers trained in different disciplines separately tackle a single problem and then strive to combine their results. This is known as *multidisciplinary* research, but the result is much like the blind men who examine an elephant, each describing the elephant according to the single body part they touch. The difference is that the blind men can readily pool their information, while different academic disciplines lack even a common language with which their practitioners can communicate.[42] *Interdisciplinary* research, in which researchers from different disciplines work together from the start to

[c]Several reviews of the published ESV literature have been developed elsewhere.[23,24,39–41]

jointly tackle a problem and reduce the language barrier as they go, is a step in the right direction toward the transdisciplinary path.

Discussions in this paper focus primarily on the United States due to the comparative wealth of case studies. It could be true that the development of ESV research and practice are quite different in other parts of the world.[43]

We arbitrarily divide the last 50 years (1960 to present) into four periods. Influential contributions during each period are marked as milestones in Figure 2. The chart is meant to be illustrative, not comprehensive, as space prohibits showing all important contributions and milestones.

1960s—Common challenge, separate answers

The 1960s are remembered as the decade of early environmentalism. Main social events include publication of Rachel Carson's *Silent Spring* in 1962, passage of the 1970 Clean Air Act, and formation of the U.S. Environmental Protection Agency (EPA) in that same year.

In response to increasing public interest in environmental problems, such as pollution and dramatic population increase, economists began rethinking the role of the environment in their production models and identified new types of surplus for inclusion in their welfare measure.[44]

Economist Kenneth Boulding compared the "cowboy economy" model, which views the environment as a limitless resource, with the "spaceship economy" view of the environment's essential limits.[45] His work included recognition of the ecosystem service of waste assimilation to the production model, where before, ecosystems had mainly been regarded as a source of provisioning services.

Consideration of cultural services in an economic analysis began with Krutilla's seminal observation that many people value natural wonders simply for their existence. Krutilla argued that these people obtain utility through vicarious enjoyment of natural areas and, as a result, had a positive willingness to pay for the government to exercise good stewardship of the land.[46]

In addition to *existence value*, other types of economic value were also considered. These include *option value*, or the value of avoiding commitments that are costly to reverse.[47] There is also *quasi-option value*, or the value of maintaining opportunities to learn about the costs and benefits of avoiding possibly irreversible future states.[48]

In most cases, willingness to pay for these newly recognized values could not be derived via market transactions because most of the ecosystem services in question are not traded in actual markets. Thus, new valuation methods were also proposed, including *travel cost*,[49] *contingent valuation*,[50] and *hedonic pricing*.[51]

In the meantime, ecologists also proposed their own valuation methods. For example, "*energy analysis*" is based on thermodynamic principles in which solar energy is considered to be the only primary input to the global ecosystem.[52] This biophysical method does not assume that value is determined by individual preferences, but rather attempts a more "objective" assessment of ecosystem contributions to human welfare.

1970s—Breaking the disciplinary boundary

The existence of "limits to growth" was the main message in the environmental literature during the 1970s.[53] The Arab oil embargo in 1973 emphasized this message.

"*Steady-state economics*" as an answer to the growth limit was proposed by economist Herman Daly, who emphasized that the economy is only a subsystem of the finite global ecosystem.[54] Thus, the economy can not grow forever, and ultimately a sustainable steady state is desired. Daly was inspired by his graduate-school mentor, Nicholas Georgescu-Roegen. In *The Entropy Law and the Economic Process*, Georgescu-Roggen elaborates extensively on the implications of the entropy law for economic processes and how economic theory could be grounded in biophysical reality.[55]

Georgescu-Roegen was not the only scientist to break the disciplinary boundary in the 1970s. Ecologist H. T. Odum published his influential book *Environment, Power, and Society* in 1971, where he summarized his insights from studying the energetics of ecological systems and applying them to social issues.[56]

Along with these early efforts, a heated debate between ecologists and economists highlighted their differences regarding concepts of value. The economists of the day objected strenuously to the energetic approach. They contended that value and

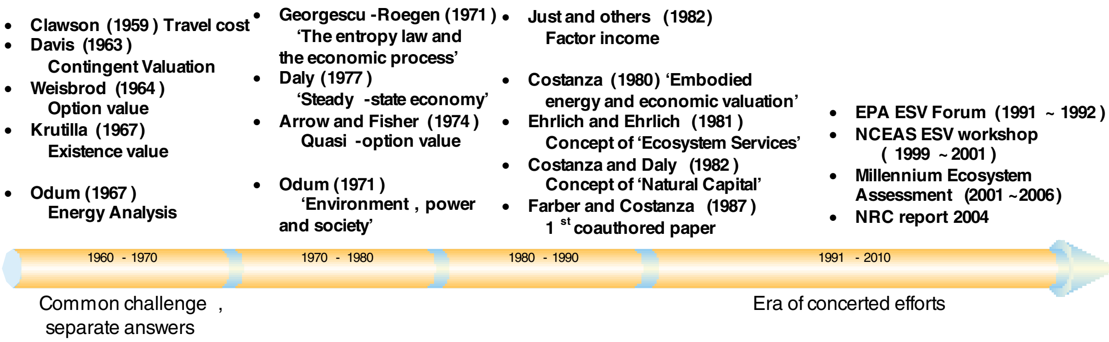

Figure 2. Milestones in the history of ecosystem service valuation. (In color in *Annals* online.)

price were determined solely by people's "willingness to pay" and not by the amount of energy required to produce a service. H. T. Odum and his brother E. P. Odum and economists Leonard Shabman and Sandra Batie engaged in a point–counterpoint discussion of this difference in the pages of the *Coastal Zone Management Journal*.[28,57,58]

Though unrealized at the time, a new method called the *production function* approach became one way to bring together the views of ecologists and economists. This method is used to estimate the economic value of ecosystem services that contribute to the production of marketed goods. It is applied in cases where ecosystem services are used, along with other inputs, to produce a market good.[59,60]

Early contributions in the area include works from Anderson,[61] Schmalensee,[62] and Just and Hueth.[63] Just and his colleagues provided a rigorous analysis of how to measure changes in welfare due to price distortions in factor and product markets. These models provide a basis for analyzing the effects of productivity-induced changes in product and factor prices.[64]

The field of environmental and resource economics grew rapidly from the beginning of the 1970s. The field became institutionalized in 1974 with the establishment of the *Journal of Environmental Economics and Management* (JEEM). The objects of analysis for natural-resource economists have typically been resources, such as forests, ore deposits, and fish species, that provided provisioning services to the economy. On the other hand, the environment itself is viewed more as a medium tainted by the externalities associated with air, noise, and water pollution, as well as the source of amenities. However, in later years this distinction between natural resources and the environment has been challenged as artificial and thus no longer meaningful or useful.[23]

1980s—Moving beyond multidisciplinary ESV research

In the 1980s, two government regulations created a tremendous demand for valuation research. The first was the 1980 *Comprehensive, Environmental Responses, Compensation and Liability Act* (CERCLA), commonly known as *Superfund*, which established liability for damages to natural resources from toxic releases. In promulgating its rules for such Natural Resource Damage Assessments (NRDA), the U.S. Department of Interior interpreted these damages and the required compensation within a welfare–economics paradigm, measuring damages as lost consumer surplus. The regulations also describe protocols that are based on various economic valuation methods.[65]

The role of ecosystem valuation increased in importance in the United States with President Reagan's Executive Order 12911, issued in 1981, requiring that all new major regulations be subject to a cost-benefit analysis (CBA).[66]

As shown in Figure 3,[d] the 1980s witnessed dramatic increases in the number of publications,

[d]The search was conducted for four general types of entities relevant to ecosystem services, including ecological functions, extractive uses, nonextractive uses, and passive uses. We excluded valuation publications on human health and the built environment from EVRI because they are not relevant to ESV.

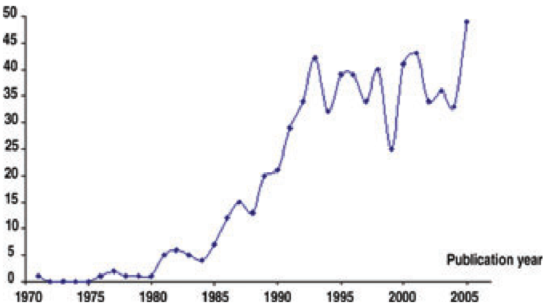

Figure 3. **Number of ESV publications in EVRI over time (accessed Feb. 10, 2007). (In color in *Annals* online.)**

including peer-reviewed papers, book chapters, governmental reports, and theses on the topic of ecosystem valuation.[e] These results are based on a search of the Environmental Valuation Reference Inventory™ (EVRI), the world's largest online valuation database (http://www.evri.ca/).

The 1989 *Exxon Valdez* oil spill was the first case where nonuse value estimated by *contingent valuation* was considered in a quantitative assessment of damages. In March of that year, the *Exxon Valdez* accidentally spilled 11 million gallons of oil into Alaska's pristine Prince William Sound. Four months later, the District of Columbia Circuit of the U.S. Court of Appeals held that nonuse value should be part of the economic damages due to releases of oil or hazardous substances that injure natural resources. Moreover, the decision found that CV was a reliable method for undertaking such estimates. Prior to the spill, CV was not a well-developed area of research. After the widely publicized oil spill, the attention given to the conceptual underpinnings and estimation techniques for nonuse value increased dramatically.[68] In the same year, two leading researchers, Mitchell and Carson, published their substantive work on CV.[69]

At the same time, ecologists began to compare their results based on energy analysis with conventionally derived economic values. For example, Costanza[70] and Costanza and Herendeen[71] used an 87-sector input–output model of the U.S. economy for 1963, 1967, and 1973, modified to include households and governments as endogenous sectors, to investigate the relationship between direct and indirect energy consumption (*embodied energy*[f]) and the dollar value of output by sector. They found that the dollar value of sector output was highly correlated with embodied energy, though not with direct energy consumption or with embodied energy calculated excluding labor and government energy costs.

Differences of opinion between ecologists and economists still existed in the 1980s in terms of the relationship between energy inputs, prices, and values.[72] But the decade also witnessed the first paper coauthored by an ecologist and an economist on ecosystem valuation.[73] Though the idea of the paper was simply to compare the results from two separate studies using different methods, the paper also represented the first instance of an ecologist and economist overcoming their disciplinary differences and working together.

The term e*cosystem services* first appeared in Ehrlich and Ehrlich's work (1981[74]). The creation of the concept represents an attempt to build a common language for discussing linked ecological and economic systems. Using "ecosystem services" and "environmental services" as key words, a search in the ISI Web of Knowledge shows the total number of papers published and the number of disciplinary categories in which they occur over time (Fig. 4). For example, the curves indicate that by July 2007, more than 200 papers per year were being published on ecosystem services in about 50 subdisciplines. The two exponential curves show the increasing use of the term over time and the fact that it has been embraced quickly by many different disciplines, including those that appear at first glance to be not so relevant, such as computer science, pharmacy, business, law, and demography.

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[e] The drop of the number of publications in some recent years is probably due to artificial effect, i.e., EVRI has not included all the publications. According to a similar analysis by Adamowicz, the amount of peer-reviewed literature in environmental valuation has increased over time.[67]

[f] The energy embodied in a good or service is defined as the total direct energy used in the production process plus all the indirect energy used in all the upstream production processes used to produce the other inputs to the process. For example, auto manufacturing uses energy directly, but it also uses energy indirectly to produce the steel, rubber, plastic, labor, and other inputs needed to produce the car.

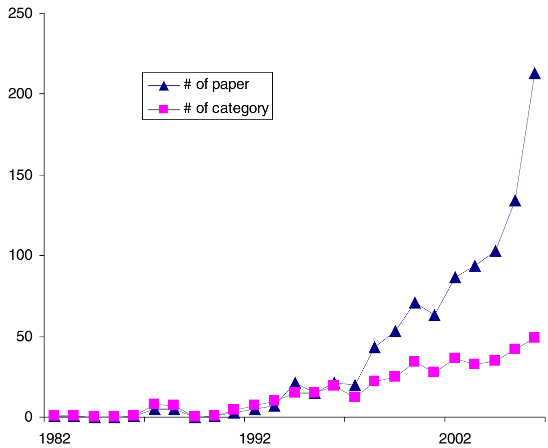

Figure 4. **Number of peer-reviewed ecosystem service papers and their related sub-categories over time listed in the ISI Web of Science (accessed June 29, 2007). (In color in *Annals* online.)**

The concept of ecosystem services and the related concept of "*natural capital*[g]" have enhanced our understanding of how the natural environment matters to human societies. It is now believed that the natural environment and the ecosystems within can be defined as natural capital, and along with physical, human, and social capital, these four together comprise society's precious assets.

1990s ∼ present: Moving toward transdisciplinary ESV research

Not only attention but also controversy was drawn to the CV approach after its application to the *Exxon Valdez* case, when it became known that a major component of the legal claims for damages was likely to be based on CV estimates of lost nonuse or existence value. The concerns about the reliability of the CV approach led the National Oceanic and Atmospheric Administration (NOAA) to convene a panel of eminent experts co-chaired by Nobel Prize winners Kenneth Arrow and Robert Solow to examine the issue. In January 1993, the panel issued a report which concluded that "CV studies can produce estimates reliable enough to be the starting point of a judicial process of damage assessment, including lost passive-use values" (p. 64)[75] (i.e., nonuse value).

At the same time, the controversy about CV also stimulated a substantial body of transdisciplinary ESV research. Highlights include conjoint analysis, Meta-Analysis (MA), group valuation, and Multiple Criterion Decision Analysis (MCDA).

Insights from psychology have proven fruitful in structuring and interpreting CV studies.[76] A new approach that gained popularity in the 1990s was *conjoint analysis*. This technique allowed researchers to identify the marginal value of changes in the *characteristics* of environmental resources, as opposed to asking direct CV questions. Respondents are asked to choose the most preferred alternative (or, to rank the alternatives in order of preference, or to rate them on some scale) among a given set of hypothetical alternatives, each depicting a different bundle of environmental attributes. Responses to these questions can then be analyzed to determine the marginal rates of substitution between any pair of attributes that differentiate the alternatives. If one of the characteristics has a monetary price, then it is possible to compute the respondent's willingness to pay for the other attributes.[77–80]

While subject to the same concern as CV regarding the hypothetical nature of valuation, the conjoint analysis approach offers some advantages.[81] For example, it creates the opportunity to determine tradeoffs in environmental conditions through its emphasis on discovering whole preference *structures* and not just monetary valuation. This may be especially important when valuing ecosystems, which provide a multitude of joint goods and services. In addition, it more reasonably reflects multi-attribute choice than the typical one-dimensional CV.

A well-developed approach in psychological, educational, and ecological research, MA was introduced to the ESV field by Walsh and colleagues in the late 1980s and early 1990s.[82–84] MA is a technique that is increasingly used to understand the influence of methodological and study-specific factors on research outcomes and to synthesize past research. Recent applications include MA of air quality,[85] endangered species,[86] and wetlands.[87,88] A more recent use of MA is the systematic utilization of the existing value estimates from the source literature for the purpose of value transfer.[89–91]

[g]Natural capital is defined as the *stock* of ecosystem structure that produces the *flow* of ecosystem goods and services.

Mainly derived from political theory, *discourse-based valuation* is founded on the principles of deliberative democracy and the assumption that public decision making should result, not from the aggregation of separately measured individual preferences, but from a process of open public debate.[92,93] This method is extremely useful in ESV as it can address the fairness goal of ESV.[35,36]

MCDA techniques originated over three decades ago in the fields of mathematics and operations research and are well-developed and well-documented.[94] These provide a structured framework for decision analysis, which involves definition of goals and objectives, identification of the set of decision options, selection of criteria for measuring performance relative to objectives, determination of weights for the various criteria, and application of procedures and mathematical algorithms for ranking options.

Compared to CBA, MCDA has at least these three advantages[95,96]: (1) by definition MCDA is multidimensional and can consider different and incommensurable objectives, such as sustainability, equity, and efficiency at the same time; (2) MCDA is much more flexible in structure as well as aggregation procedures. For instance all indicators do not have to be valued in monetary terms. Instead, the original measurement units could be kept or normalized in different ways, which makes room for subjective components of the analysis; and (3) MCDA has the capacity to take into account qualitative variables. This is especially useful when uncertainty is an issue. For instance, the effect of global warming on species diversity is uncertain but can be expressed qualitatively. Of course, MCDA also has it own limitations, such as (1) a multicriteria problem is by definition mathematically ill-structured, i.e., it has no objective solution. This is also the primary reason for proliferation of so many different theories and models; and (2) various aggregation procedures exist for MCDA which could make the valuation process less transparent.

The emergence of these new interdisciplinary methods can be attributed in part to two workshops in the 1990s which brought together ESV researchers from different disciplines (EPA 1991 and National Center for Ecological Analysis and Synthesis (NCEAS) 1997, summarized in special issues of *Ecological Economics* in 1995 and 1998, respectively). The organizers of the first workshop believed that "the challenge of improving ecosystem valuation methods presents an opportunity for partnership—partnership between ecologists, economists, and other social scientists and policy communities. Interdisciplinary dialogue is essential to the task of developing improved methods for valuing ecosystem attributes" (p. 90).[42] In a paper comparing economics and ecological concepts for valuing ecosystem services, participants from the second workshop concluded that "there is clearly not one 'correct' set of concepts or techniques. Rather there is a need for conceptual pluralism and thinking 'outside the box' " (p. 390). [15]

This call for cross-disciplinary research is echoed by a recent National Research Council study on assessing and valuing the ecosystem services of aquatic and related terrestrial ecosystems. In their final report[h] a team composed of 11 experts from the fields of ecology, economics, and philosophy offered guidelines for ESV including: "Economists and ecologists should work together from the very beginning to ensure the output from any an ecological model is in a form that can be used as input for an economic model" (p. 220).[25]

Two interdisciplinary publications drew widespread attention to ESV and stimulated a continuing controversy between ecological economists and traditional "neoclassical" economists. Costanza and his colleagues (ecologists and economists) published an often-cited paper in *Nature* on valuing the services provided by global ecosystems. They estimated that the annual value of 17 ecosystem services for the entire biosphere was US$33 trillion.[1] The journal *Ecological Economics* contributed a special issue in 1998, which included a series of 13 commentaries on the *Nature* paper.

The first book dedicated to ecosystem services was also published in 1997.[2] *Nature's Services* brought together world-renowned scientists from a variety of disciplines to examine the character and value of ecosystem services, the damage that has been done, and the consequent implications for human society. Contributors including Paul R. Ehrlich, Donald Kennedy, Pamela A. Matson, Robert Costanza, Gary Paul Nabhan, Jane Lubchenco, Sandra

[h]Their report titled "Valuing ecosystem services: toward better environmental decision-making" is available online at http://books.nap.edu/books/030909318X/html.

Postel, and Norman Myers present a detailed synthesis of the latest understanding of a suite of ecosystem services and a preliminary assessment of their economic value.

As of April 2001, more than 2000 experts have been involved in a 4-year effort to survey the health of the world's ecosystems and the threats posed by human activities. The Millennium Assessment[i] has fundamentally changed the landscape in ecosystem service research by switching attention from ecological processes and function to the service itself.[97]

ESV in practice

In the area of ESV research and application, most demands originate from policy makers and public agencies.[j] To what extent, however, is ESV actually used to make real environmental decisions?

The answer to this question is contingent upon the specific areas of environmental policy which are of concern. There are a few areas in which ESV is well established. These include NRDA cases, CBA of water and forest resource-use planning in the United States.[67] In a number of European countries CBA has been used as a decision tool in public work schemes, especially in road construction.[98] In other areas, however, there have been relatively few documented applications of ESV whereby it was used as the sole or even the principal justification for environmental decisions, and this is especially true in the natural resources planning area (though cf. McCollum[99] for some examples). A recent survey of 14 case studies showed the interaction of ESV research and policy ranging from "no action" all the way to "influencing federal policy design" (p. 2064).[100]

A number of factors have limited the use of ESV as a major justification for environmental decisions. These include methodological problems that affect the credibility of the valuation estimates, legislative standards that preclude consideration of cost-benefit criteria, and lack of consensus about the role that efficiency and other criteria should play in the design of environment regulations (see later section for details on debates on ESV). However, while environmental decisions may not always be made solely or mainly on the basis of net benefits, ESV has a strong influence in stimulating awareness of the costs and gains stemming from environmental decisions and often plays a major role in influencing the choice among competing regulatory alternatives.[104,105]

In Europe, the extent of both research and applied work in ESV is much more limited than in the United States. Usually, environmental effects are not valued in monetary terms within the European Union. Up until around 1990 the European Commission did not use CBA or related procedures in its formulation of new directives.[105,106]

Next we will focus on ESV's roles in (1) NRDA, (2) CBA/CEA (cost-effectiveness analysis), (3) natural capital accounting, and (4) payment for ecosystem services (PES). Because there are no specific mechanisms that track the process of how and when research becomes policy, we have to rely on examples and, therefore, offer an anecdotal overview.

ESV in Natural Resource Damage Assessments

NRDA is the process of collecting, compiling, and analyzing information to determine the extent of injuries to natural resources from hazardous substance releases or oil discharges, and to determine appropriate ways of restoring the damaged resources and compensating for those injuries. Two environmental statutes provide the principal sources of federal authority over natural resource damages: the *Comprehensive Environmental Response*, CERCLA, and the *Oil Pollution Act* (OPA). Although other examples of federal legislation addressing natural resource damages do exist, these two statutes are the most generally applicable and provide a consistent framework in which to discuss natural resource damage litigation.

Under the Department of Interior regulations, valuation methodologies are used to calculate "compensable values" for interim lost public uses. Valuation methodologies include both market-based methods (e.g., market price and/or appraisal) and nonmarket methodologies (e.g., factor income, travel cost, hedonic pricing, and CV). Under the OPA, trustees for natural resources base damages for interim lost use on the cost of "compensatory restoration" actions. Trustees can determine the scale of these actions through methodologies that measure the loss of services over time or through

[i]The synthesis report is now available at http://www.millenniumassessment.org/en/index.aspx.
[j]Other reviews of the use of ESV in policy include Refs. 67,98,99,101–103.

valuation methodologies. In any case, NRDA poses a big challenge for ESV as a dollar value estimate of total damages is required and valuing multiple ecosystem services typically multiplies the difficulty of evaluation.

Although statutory authorities existed prior to the 1989 *Exxon Valdez* oil spill, the spill was a singular event in the development of trustee NRDA programs. In the years following the spill, NRDA has been at the forefront of ESV use in litigation. The prospect of extensive use of nonmarket methods in NRDA has generated extensive controversy, particularly among potentially responsible parties (cf. Hanemann[107] and Diamond and Hausman[108] for differing viewpoints on the reliability of the use of CV in NRDA as well as in CBA in general).

In the *Exxon Valdez* case, a team of CV researchers was hired by the State of Alaska to conduct a study of the lost "passive use value" caused by the spill, and the team produced a conservative assessment of 2.8 billion dollars.[k,109] Exxon's own consultants published a contrasting critical account of CV arguing that the method can not be used to estimate passive-use values. Their criticism mainly focused on situations where respondents have little experience using the ecosystem service that is to be altered and when the source of the economic value is not the result of some in-site use.[l,110]

This argument led to the previously mentioned NOAA panel, which, after a lengthy public hearing and review of numerous written submissions, issued a report that cautiously accepted the reliability of CV.[75]

In the context of the wide-ranging public debate that continued after the *Exxon Valdez* case, NOAA reframed the interim lost value component from a monetary compensation measure (*how much money does the public require to make it whole?*) to a resource compensation measure (*how much compensatory restoration does the public require to make it whole?*). By recovering the costs of compensatory restoration actions (costs of resource compensation) rather than the value of the interim losses (monetary compensation), the revised format deflects some of the public controversy about economic methods. However, some researchers argue, for instance, that money can not be removed from NRDA for the simple reason that failure to consider money leaves trustees unable to judge the adequacy of compensating restoration.[111]

ESV in a Cost Benefit Analysis–Cost Effectiveness Analysis framework

CBA is characterized by a fairly strict decision making structure that includes defining the project, identifying impacts that are economically relevant, physically quantifying impacts as benefits or costs, and then calculating a summary monetary valuation.[112] CEA has a rather similar structure, although only the costs of alternative means of achieving a previously defined set of objectives are analyzed. CBA provides an answer to "whether to do," and CEA answers "how to do."

When the Reagan administration came to power, it attempted to change the government's role in the private affairs of households and firms. Regulatory reform was a prominent component of its platform. President Reagan's Executive Order No. 12291 required a CBA for all new major regulations whose annual impact on the economy was estimated to exceed $100 million.[66] The aim of this Executive Order was to develop more effective and less costly regulation. It is believed that the impact of EO 12291 fell disproportionately on environmental regulation.[98]

President Bush Sr. used the same executive order. President Clinton issued Executive Order 12866, which is similar to Reagan's order but changes some requirements. The order requires agencies to promulgate regulations if the benefits "justify" the costs. This language is generally perceived as more flexible than Reagan's order, which required the benefits to "outweigh" the costs. Clinton's order also places greater emphasis on distributional concerns.[m,113]

[k] This compares to the 1 billion dollars in natural resource damages and restitution for injuries settled in court and over 2 billion dollars Exxon spent on oil-spill response and restoration.[68] In 2008, however, a divided high court cut punitive damages in the case to $507.5 million.

[l] Much of this debate could be reconciled if the critiques distinguished concerns about the CV itself from a belief that CV estimates do not measure economic values because they are not the result of an economic choice.[40]

[m] As one reviewer pointed out, the policy change with Clinton's order indicated a switch to a social welfare function that differs from Bergson-Sammelson function of individualistic welfare maximization, on which a CBA is based.[106]

The use of CBA analysis in environmental policy making under the George W. Bush administration remains controversial. At the core of the controversy was the growing influence of the White House and its perceived responsibility for cost-benefit review: the Office of Information and Regulatory Affairs (OIRA), within the Office of Management and Budget. Traditionally, OIRA has had fairly minimal interaction with submitting agencies as they prepared CBAs. But under administrator John Graham, OIRA became intimately involved in all aspects of the cost-benefit process. During the 8 years of the Clinton administration, OIRA sent 16 rules back to agencies for rewriting. In his first year alone, Graham sent back 19 rules (not all of which were environmental).

Originally, CBAs primarily reflected market benefits such as, job creation and added retail sales. More recently, attempts have been made to incorporate the environmental impacts of projects and policies within CBA to improve the quality of government decision making. The use of ESV allows CBA to be more comprehensive in scope by incorporating environmental values and placing them on the same footing as traditional economic values.

The EPA's National Center for Environmental Economics' online library has been an integral resource in the CBAs conducted over the years. The most common ESV application by the EPA involves analyses of the benefits of specific regulations as part of Regulatory Impact Analyses (RIAs). Although RIAs—and hence ESV—have been done on numerous regulations, the scope and quality of the ESV in these RIAs has varied widely. A review of 15 RIAs performed by the EPA between 1981 and 1986 found that only six of the 15 RIAs addressed by the study presented a complete analysis of monetized benefits and net benefits.[114] The 1987 study notes that many regulations were improved by the analysis of benefits and costs, even where benefits were not monetized and net benefits were not calculated.

One famous example of the use of CEA is the 1996 New York Catskills Mountains Watershed case where New York City administrators decided that investment in restoring the ecological integrity of the watershed would be less costly in the long run than constructing a new water filtration plant. New York City invested between $1 billion and $1.5 billion in restoratory activities in the expectation of realizing cost savings of $6–$8 billion over 10 years, giving an internal rate of return of 90–170% and a payback period of 4–7 years. This return is an order of magnitude higher than is usually available, particularly on relatively risk-free investments.[115]

ESV in natural capital accounting

Though closely related, "Green" gross domestic product (GDP) accounting and natural capital accounting are different. GDP aggregates all sources of well-being, including all market goods and services, into a single index. Green GDP adds missing ecological elements to conventional GDP by including nonmarket contributions to welfare. Natural capital accounting, in contrast, usually separately accounts for *all* of nature's contributions to welfare, including those captured in GDP as intermediate products, such as pollination's contribution to increased agricultural output. Proposals have been made to integrate the results of natural capital accounting into Green GDP, although researchers have cautioned against double accounting and the simple add-up approach.[116] So far, a handful of studies have attempted to plug ESV results into Green GDP accounting—[117,118] for example, using the supply side of the input–output model to avoid double accounting.[119]

This paper will focus only on natural capital accounting, which was popularized by the effort to value the ecosystem services and natural capital on a global scale.[1] Since then, there have been numerous studies to value natural capital at a national level[120] and at the state/regional levels.[121–123] Attempting to include the value of all ecosystem services, these studies used benefit transfer of results from the empirical valuation literature. Recent trends include combining the transferred results with Geographical Information Systems (GIS) and ecosystem modeling.

GIS has been used to increase the context specificity of value transfer.[124,125] The value-transfer process is augmented with a set of spatially explicit factors so that geographical similarities between the policy site and the study site are more easily detected. In addition, the ability to present and calibrate economic valuation data in map form offers a powerful means for expressing environmental and economic information on multiple scales to stakeholders.

The EcoValue Project,[n] for example, draws from recent developments in ESV, database design, internet technology, and spatial analysis techniques to create a web-accessible GIS decision support system. The site uses empirical studies from the published literature which are then used to estimate the economic value of ecosystem services. Using watersheds as the primary unit of spatial aggregation, the project provides ecosystem service value estimates for the State of Maryland and the four state Northern Forest regions, including New York, Vermont, New Hampshire, and Maine. The end result is a GIS value transfer platform capable of providing the best available valuation data to researchers, decision makers, and public stakeholders throughout the world.

In a study using a similar technique, Constanza and colleagues estimated the value of ecosystem services in New Jersey using benefit transfer techniques.[123] The aggregate total for the state ranged from \$11.6 to \$19.6 billion/year depending on the criteria used. In addition to calculating the range, mean and standard deviation for each of 12 ecosystems services for 11 Land Use/Land Cover (LULC) types, they also mapped these values by assuming an average value for each LULC in GIS.

Recognizing the value of ecosystem services, decision makers have started to adopt *ex ante* ESV research linked with computer modeling. An example of this was an integrated modeling and valuation study of fynbos ecosystems in South Africa.[126] In this example, a cross-section of stakeholders concerned about the invasion of fynbos ecosystems by European pine trees worked together to produce a simulation model of the dynamics and value of the ecosystem services provided by the system. The model allowed the user to vary assumptions and values for each of the services and observe the resulting behavior and value of the ecosystem services from the system. This model was subsequently used by park managers to design and justify containment and removal of the pine trees.

In a more recent example, the city of Portland's Watershed Management Program sponsored a Comparative Valuation of Ecosystem Services (CVES) analysis in order to understand the tradeoffs between different flood control plans. Integrated with ecosystem modeling, an ESV study under CVES concluded that a proposed flood abatement project in the Lent area could provide more than \$30 million in public benefits over a 100-year timeframe. And five ecosystem services would increase in productivity as a result of floodplain function improvements and riparian restoration.[127]

Modeling has also been combined with GIS to understand and value the spatial dynamics of ecosystem services. An example of this application was a study of the 2352 km^2 Patuxent River watershed in Maryland.[128,129] This model was used to address the effects of both the magnitude and spatial patterns of human settlements and agricultural practices on hydrology, plant productivity, and nutrient cycling in the landscape, and the value of ecosystem services related to these ecosystem functions. Several historical and future scenarios of development patterns were evaluated in terms of their effects on both the biophysical dynamics of ecosystem services and the value of those services. A recent effort[o] involves the use of spatially explicit dynamic modeling to integrate our understanding of ecosystem functioning, ecosystem services, and human well-being across a range of spatial scales.

ESV in payment for ecosystem services

PES is "a voluntary transaction where a well-defined environmental service is being bought by a service buyer from a service provider if and only if the service provider secures service provision" (p. 664).[130] There are multiple ways to classify PES. In terms of the ecosystem commodities conserved, PES could be grouped as payments in the carbon market, water market, biodiversity market, and bundled service market. According to payment types, most PES falls into one of these three categories: voluntary, compliant, or government mediated.[131] By function, PES programs are divided into those for pollution control, for conservation, and for generating environmental amenities. Finally, from the perspective of service providers, a distinction is made between land diversion and working-land PES[p.] programs.[132]

[n]http://ecovalue.uvm.edu.

[o]http://www.uvm.edu/giee/mimes/.

[p]The term *PES* has been used, especially by practitioners, in a much boarder sense for any kind of

PES is a field fast expanding both inside and outside academia. In 2008 alone, two special issues of *Ecological Economics* and *Environment and Development Economics* were dedicated to PES. Recently, the U.S. Department of Agriculture also established an Office of Ecosystem Services and Markets to develop "new technical guidelines and science-based methods to assess environmental service benefits which will in turn promote markets for ecosystem services including carbon trading to mitigate climate change."[134]

Indeed, one would imagine that ESV, the process of assessing the benefits of environmental services, must have been applied widely to guide PES. By definition a buyer offers payments to those who provide ecosystem services, which benefit the buyer. Naturally, the amount of the payment should be determined on the basis of the ecosystem service delivered (output based) and how much the buyer has benefited (benefit based).

In practice, however, ESV results have rarely been applied in setting payment amounts. An input-based (or cost-based) approach is dominant, and most PES programs base payments on the cost of the seller's adoption of particular land uses or management activities.[130] In the former case, it is sufficient to compensate service providers for the opportunity cost of foregoing alternative land uses. When additional management activities, such as reforestation are involved, the PES payment equals the sum of opportunity cost, transaction cost, and conservation cost.[135]

Benefit-based PES program do exist, but they are exceptions rather than the rule.[130] Proxies of benefits, such as land cover type,[136,137] spatial location of service providers' land,[138] and level of management activities (e.g., area reforested combined with a minimum tree-survival rate[139]), are used instead. Yet the linkages between such proxies and the ecosystem services conserved are often uncertain, and the degree of uncertainty varies depending on the service.[139]

So why have ESV estimates rarely been applied in PES programs? Several reasons may factor into the equation, including the uncompetitiveness of the market, equity concerns in program design, and lack of information on benefit estimates.

First, the market for ecosystem services is often not competitive. In theory, the price for an ecosystem service is determined by the buyer's willingness to pay and the service provider's willingness to accept. In reality, potential supply often outstrips demand in markets for ecosystem services, which results in low prices.[140]

For voluntary markets, price is negotiated and the PES programs are more tailored to local conditions. For instance, the Vittel PES program developed customized pricing for each farm.[141] By contrast, in government-mediated markets, prices are often set at the average cost of producing the service, as opposed to marginal cost, which means that service providers do not make any profit. Most government-mediated programs for land diversion have a fixed payment per land unit and are designed to attract the least profitable lands while maximizing the area enrolled.[132]

Second, equity concerns partially explain the reason why government-mediated PES programs pay uniform rates; in this sense they can be difficult to differentiate from traditional subsidy programs.[139] However, PES programs can not always serve the goals of equity and conservation at the same time.[142,143] Alix-Garcia *et al.* found that the most egalitarian approach—paying a flat rate per hectare per year with a cap on the number of allowable hectares per recipient—was the least efficient strategy in terms of environmental benefits per dollar spent.[144]

The third reason for the popularity of the cost-based approach is the lack of information on benefit estimates.[137] Conducting original ESV research often requires a great amount of time and resources, and existing studies are often not designed and reported with benefit transfer in mind. For instance, the payment amount per unit land area is more useful for PES purposes, yet most CV estimates are reported in per household or per individual terms. By contrast, costs are more straightforward to estimate.

A major problem with the cost- or input-based approach is underpayment, whereby the payment is not high enough to attract potential providers to the most important areas of ecosystem service conservation. In the United Kingdom's Environmentally Sensitive Areas program, for instance, the payment,

market-based mechanism for conservation including eco-labeling certified forest product, conservation easements, ecotourism—even entrance fees to national parks.[133]

which is smaller than ESV estimates based on CV, did not offer enough incentives to attract enrollment in the intensive farming areas.[145] Similarly, U.S. farmers enrolled in the Conservation Reserve Program spurned guaranteed annual payments to cash in during the recent commodity market boom because the government payments were no longer comparable to what they could make by working their land.[146]

A future direction for PES is to establish benefit and output-based systems supported by ESV. Lacking guidance from ESV research, many PES programs are based on a shaky scientific foundation. One example is for similar activities programs that pay for multiple services do not pay more than those paying for a single service.[139] The benefit and output-based approach could possibly eliminate uncertainty between the input (e.g., land and labor) and the output of ecosystem services. It is also more efficient to pay farmers per unit of ecosystem services provided rather than per area of land regardless of the services provided.[147]

Debate on the use of ESV

There are multiple policy purposes and uses of ESV. These uses include:

1. to provide for comparisons of natural capital to physical and human capital in regard to their contributions to human welfare.
2. to monitor the quantity and quality of natural capital over time with respect to its contribution to human welfare
3. to provide for evaluation of projects that propose to change (enhance or degrade) natural capital.

Much of the debate about the use of ESV has to do with not appreciating this range of purposes. In addition, there are a range of other obstacles and objections to the use of ESV. In summarizing experiences of ESV use from six countries, Barde and Pearce mentioned three main categories of obstacles: (1) ethical and philosophical, (2) political, and (3) methodological and technical. Below we discuss each of these in greater detail.[148]

Ethical and philosophical debate

Ethical and philosophical obstacles arise from a criticism of the neoclassical welfare economics foundations of ESV. In particular, "monetary reductionism," illustrated by the willingness-to-pay criterion, is strongly rejected by those who claim that ecosystems are not economic assets and that it is therefore immoral to measure them in monetary terms.[8,149] Based exclusively on an individual's preferences, the principle of utility maximization is judged to be too reductionist a basis on which to make decisions involving environmental assets, irreversibility, and future generations.[150,151]

Practitioners of ESV argue that the ESV concept is much more complex and nuanced than these objections acknowledge. Monetization is simply a convenient means of expressing the relative values that society places on different ecosystem services. If these values are represented solely in physical terms—so much less provision for clean water, perhaps, and so much more for production of crops—then the classic problem of comparing apples and oranges applies. The purpose of monetary valuation is to simply create a setting whereby the disparate services provided by ecosystems are able to be compared to each other using a common metric. Alternative common metrics exist (including energy units and land units, i.e., the "ecological footprint"), but in the end, the choice of metric is not critical because, given appropriate conversion factors, one could always translate results of the underlying tradeoffs from one metric to another.

The key issue here comes down to tradeoffs. *If* one does not have to make tradeoffs between ecosystem services and other things, *then* valuation is not an issue. *If* however, one does have to make such tradeoffs, *then* valuation will occur, whether it is explicitly recognized or not.[152] Given this, it seems better that the tradeoffs be made explicit.

The practicality lies in the fact that ESV uses easily understood and accepted rules to reduce complex clusters of effects and phenomena to single-valued commensurate magnitudes—that is, to dollars. The value of the benefit-cost framework lies in its ability to organize and simplify certain types of information into commensurate measures.[153]

While we believe that there is a strong case in favor of monetary valuation as a decision aid to help make tradeoffs more explicit, we also recognize that there are limits to its use. Expanding ESV toward sustainability and fairness goals (on top of the traditional efficiency goal) will help expand the boundaries of those limits.[21] An MCDA system that incorporates the triple goals might appear to alleviate the limitations of monetary valuation, but in fact it does not. If there are real tradeoffs in the system, those tradeoffs will have to be evaluated one way or the other. An MCDA facilitates greater public participation and collaborative decision making, and allows consideration of multiple attributes,[154] but it does not eliminate the need to assess tradeoffs, and, as we have said, conversion to monetary units is only one way of expressing these tradeoffs and all forms of value may and should ultimately contribute to decisions regarding the environment.[155]

Political debate

The very objective and virtue of ESV is to make policy objectives and decision criteria explicit, e.g., what are the actual benefits of a given course of action? What is the best alternative? Is the government making efficient use of environmental resources and public funds? Introducing a public debate on such issues is often unattractive to technical experts and decision makers and may significantly reduce their margin of action and decision autonomy. Therefore, there may be some reluctance to introduce ESV into political or regulatory debates.

Notwithstanding this, humanity will have to make choices and tradeoffs concerning ecosystem services, and, as mentioned above, this implies and requires "valuation" because any choice between competing alternatives implies that the one chosen is more highly "valued." Practitioners of ESV argue that society can make better choices about ecosystems if the valuation issue is made as explicit as possible. This means taking advantage of the best information available, making the uncertainties in that information explicit, and developing new and better ways to make good decisions in the face of uncertainties. Ultimately, it means being explicit about our goals as a society, both in the short and the long term, and understanding the complex relationships between current activities and policies and their ability to achieve these goals.[13]

As Arrow and colleagues argued, valuation should be considered as a framework and a set of procedures to help organize available information.[153] Viewed in this light, benefit-cost analysis does not dictate choices, nor does it replace the ultimate authority and responsibility of decision makers. It is simply a tool for organizing and expressing certain kinds of information from a range of alternative courses of action. The usefulness of value estimates must be assessed in the context of this framework for arraying information.[23]

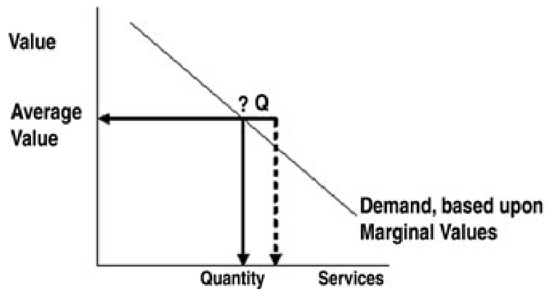

Figure 5. A model of ecosystem service valuation.

The more frank and open decision makers are about the problems of making choices and the values involved, and the more information they have about the implications of their choices, the better their choices are likely to be.

Methodological and technical debate

ESV has also been criticized on methodological and technical grounds. There are a range of issues here which are covered in detail elsewhere.[29,152] For the purposes of this discussion, we will focus on two major issues which seem to underlie much of the debate: purpose and accuracy.

One line of criticism aimed at ESV is it can only be used to evaluate *changes* in ecosystem service values. For example, Bockstael *et al.* contended that assessing the total value of global-, national-, or state-level ecosystem services is meaningless because it does not relate to *changes* in services, and one would not really consider the possibility of eliminating the entire ecosystem at these scales.[29] But, as mentioned earlier, there are at least three purposes for ESV, and this critique has to do with confusing purpose #3 (assessing changes) with purpose #1 (comparing the contributions of natural capital to human welfare with those of physical and human capital).

To better understand this distinction, the following is helpful (Fig. 5):

The Demand for Services reflects the Marginal Valuations of increasing service levels. The Quantity of Services available determines the Average Valuation of that service over its entire range. Consequently, Average Value *x* Quantity would represent a "Quasi-market Valuation" of that service level. In a restricted sense, if there were a market for the service, this would be the revenue obtained from the service, comparable to an indicator like the sales volume of the retail sector. It would be directly comparable and analogous to the valuation of income flows from physical capital, and could be capitalized to reflect the market value of natural capital and compared to similarly capitalized values for physical investment. Furthermore, changes in the volume or value of this service could be capitalized to reflect the value of new natural capital investment/disinvestment, just as we measure new investment and depreciation in physical capital at the macro level.[156]

This "quasi-market value" has a restricted meaning. Of course, it does not reflect the "full value" of the service to human welfare because full value is the sum of marginal values; i.e., the area under the demand curve. However, the more substitutes there are available for the service, the less the difference between "full value" and this quasi-market value. In addition, this quasi-market value is more directly comparable with the quasi-market value of the physical and human capital contributors to human welfare as measured in aggregate indicators like GDP. So, if one's purpose is to compare contributions of natural capital to human welfare with those of physical and human capital (as estimated in GDP, for example), then this is an appropriate (albeit not perfect) measure.

Furthermore, if there really were a market for the service, and economies actually had to pay for it, the entire economics of many markets directly or indirectly impacted by the service would be altered.[152] For example, electricity would become more costly, altering its use and the use of energy sources, in turn altering the costs and prices of energy using goods and services. The changes in markets would likely reflect back onto the demand for the ecosystem service, increasing or decreasing it, depending on the service and its economic implications. The "true market value" could only be determined through full scale ecologic-economic modeling. While modeling of this type is under way,[157] it is costly and difficult, and meanwhile decisions must be made. "Quasi-market value" is thus a reasonable first-order approximation for policy and public discourse purposes if we want to compare the contributions of natural capital to the contributions of other forms of capital to human welfare.

ESV can also be used to assess the impact of specific changes or projects. Balmford *et al.* is a recent example of the use of ESV at global scale. In this study, the costs and benefits of expanding the global nature reserve network to encompass 15% of the terrestrial biosphere and 30% of the marine biosphere were evaluated, concluding that the benefit-cost ratio of this investment was approximately 100:1.[158] In these circumstances, Average Value x ΔQ is likely to be a reasonable measure of the economic value of the change in services; an overestimate of benefits for service increases, and an underestimate of costs for service decreases. The degree of over- or underestimation depends again on the replaceability of the service being gained or lost.

Beyond the confusion concerning purposes, the *accuracy* of ESV is also sometimes questioned. Diamond and Hausman, for instance, asked the question, "[In] *contingent valuation–is some number better than no numbers?*" (p. 45).[108]

The answer to this question depends on the intended use of the ESV result and the corresponding accuracy required.[31,32] As Figure 6 shows, we can think of accuracy as existing along a continuum whereby the minimum degree of accuracy needed is related to the cost of making a wrong decision based on the ESV result.

For example, using ESV to assist an environmental policy decision maker in setting broad priorities for assessment and possible action may require a moderate level of accuracy. In this regard, any detriment resulting from minor inaccuracies is

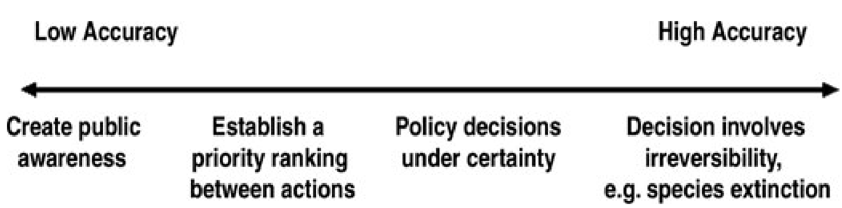

Figure 6. Accuracy continuum for the ESV (adapted from Desvousges *et al.*[165]).

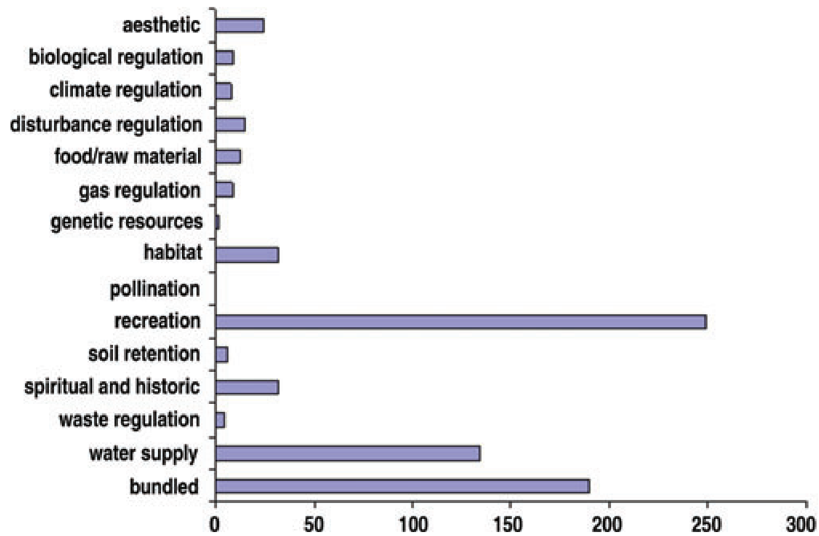

Figure 7. **EVRI peer-reviewed valuation data by ecosystem services (total data point = 730, accessed Feb. 10, 2007). (In color in *Annals* online.)**

adequately offset by the potential gains. This use of ESV represents an increase of knowledge which costs society relatively little if the ESV results are later found to be inaccurate. However, if ESV is used as a basis for a management decision which involves irreversibility, the costs to society of a wrong decision can be quite high. In this case, it can be argued that the accuracy of a value transfer should be very high.

Findings and directions for the future

ESV is multidimentional and socially contentious. In contrast, traditional ESV research involves the work of experts from separate disciplines, and these studies often turn out to be overly simple, unidimensional, and "value-free." Our survey of the literature has shown that over time there has been movement toward a more transdisciplinary approach to ESV research, an approach more consistent with the nature of the problems being addressed.

The truly *transdisciplinary* approach ultimately required for ESV is one in which practitioners must accept that disciplinary boundaries are academic constructs irrelevant outside of the university, and must also allow the problem being studied to determine the appropriate set of tools, rather than vice versa.

What is needed are ESV studies which encompass all the components mentioned earlier in Figure 1, including ecological structures and processes, ecological functions, ecosystem services, human welfare, land-use decisions, and the dynamic feedback between them. To our knowledge, there have been few such studies to date, although several recent projects are moving in this direction, including Valuing the Arc,[q] Nature Capital Project,[r] and Multi-scale Models of Ecosystem Services. It is just this type of study that is of greatest relevance to decision makers and it looks to be the way forward.[159]

Figure 7 indicated how little effort has gone into understanding the linkages between ecological functions, services, and human welfare. Among 675 peer-reviewed ESV studies (with a total of 730 data points) published in the past 35 years, most effort has gone into the understanding of human preferences for ecosystem services which are directly consumed, including 34% valuing recreation benefits and 18% valuing water quality change. In comparison, most supporting and regulating services are undervalued if they are valued at all.

Obviously there has been great progress in ecology and in understanding ecosystem processes and functions, and in the economics of developing and

[q]http://valuingthearc.org/about˙us/index.html.
[r]http://www.naturalcapitalproject.org/joinourteam.html.

applying nonmarket techniques for valuation; however, there remains a gap between the two. To quote a recent ESV report by an interdisciplinary group of ecologists, economists, and philosophers, "...the fundamental challenge of valuing ecosystem services lies in providing an explicit description and adequate assessment of the links between the structure and functions of natural systems, the benefits (i.e., goods and services) derived by humanity, and their subsequent values" (pp. 2–3).[25]

Nevertheless, some useful integrated studies are emerging to bridge the gap between ecosystem functions and services, including those valuing biological control[160] and pollination services.[161–163]

This paper also attempted to quantify ESV's contribution to environmental policy making by answering questions, such as "to what extent is ESV actually used to make real decisions?" However, it was soon realized that this goal was too ambitious. Instead, along with other reviewers,[64,102] it was found that the contribution of ESV to ecosystem management has not been as large as hoped nor as clear as imagined. This requires ESV researchers to do more than simply develop good ideas to influence policy. They need to understand how the political process affects outcomes and actively market the use of appropriate and feasible methodologies for promoting environmental policy. In other words, ESV research has to become more problem driven rather than tool driven.[113]

We discussed the three types of obstacles to the use of ESV in policy making. While there is a strong case in favor of monetary valuation as a decision aid, we also recognize that there are limits to its use. These limitations are due to the complexity of both ecological systems and values, which could be more adequately incorporated by the triple-goal ESV system. Valuing ecosystem services with not only efficiency, but also fairness and sustainability as goals, is the next step needed to promote the use of ESV in ecosystem management and environmental policy making. This new system can be well supported by current transdisciplinary methodologies, such as participatory assessment,[164] group valuation,[35,36,92] and the practice of integrating ESV with GIS and ecosystem modeling.[128,129,157]

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Conflicts of interest

The authors declare no conflicts of interest.

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