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c0010 # Valuing Ecosystem Services

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s0010 ## Introduction

p0010 When choosing which patches of old-growth Douglas firs to harvest in the mountains of Oregon, a timber company might take note of the tree density or the slope, as these factors directly impact the profit of the company's operations. It is less likely that the company would voluntarily avoid harvesting trees from a steep hillside because the resulting increased release of sediment from the denuded hillside could increase costs for the reservoir operator downstream. Less likely still is the possibility that the timber company would factor in the impacts of extracting old-growth trees on the population viability of different forest-dwelling species.

p0015 In practice, the logging industry in the Pacific Northwest did not voluntarily adjust its operations in response to the negative environmental impacts associated with the clear-cut harvest of old-growth trees from the Pacific temperate rain forest. The clear-cut harvest of timber in Oregon, which began in the late 1820s, continued as the dominant management approach until the National Forest Management Act passed in 1976. The act did not prohibit clear-cutting, though it did restrict application of this harvest technique. In 1989, the US Fish and Wildlife Service designated the northern spotted owl as a threatened species in Washington, Oregon, and northern California, restricting land-use activities, including logging, on its habitat under the Endangered Species Act (ESA) of 1973. These pieces of legislation set the status quo operation of the timber industry at odds with efforts to ensure the viability and continued function of these forest ecosystems.

p0020 Many loggers in the region voiced their displeasure with enforcement of the ESA, as they felt that their way of life was being sacrificed for a cause that did not clearly benefit social well-being. Following the listing of the northern spotted owl as a species covered by the ESA, bumper stickers appeared in the Pacific Northwest in support of the loggers. Examples include "Kill a Spotted Owl – Save a Logger" and "I Like Spotted Owls – Fried" (Satchell, 1990). Though framed in the context of species protection, the ESA has been implemented as a means of conserving habitat, presumably out of the belief that habitat conservation provides value to society. That said, this value may not accrue to the individuals whose activities are regulated, and the salience of this value to beneficiaries may not be obvious when discussed in terms of species viability. These facts contribute to the tension between forces of conservation and forces of conversion. This tension is what may have motivated the reframing of the habitat conservation issue in terms of ecosystem services, which deal, by definition, with the value of nature to humans.

p0025 The potential benefits to society of conserving these temperate rain forests in Oregon include but are not limited to maintenance of water quality in coastal tributaries that are home to commercially important salmon species and are used for human recreation, retention of sediment that might impact downstream reservoirs regarding both hydropower production and flood-prevention functions, and the sequestration and storage of carbon whose release into the atmosphere is associated with expected damages. In addition to this sample of benefits from intact forests in the Pacific Northwest, these forests are also essential habitat to multiple species of animals and plants whose survival depends on their continued existence. None of this suite of benefits is as directly tangible as the consumption of timber from the harvest of Douglas firs or the income associated with this harvest; however, this lack of familiarity and tangibility does not imply a lack of social value.

The choice between the conservation and conversion of extant habitat that continues to play out in the Pacific Northwest and elsewhere around the globe illustrates the trade-off that exists between the private benefits of conversion and the social benefits of conservation. Ensuring that land- and resource-use decisions provide the greatest amount of benefit to society requires the identification and quantification of the trade-offs inherent in such decisions. To achieve this goal, we must be able to value the benefits of habitat conservation, which must generally be forgone to enjoy the benefits of intensive resource management. p0030

Under certain conditions, self-interested actors operating within a market system can achieve an efficient use and allocation of resources. However, several characteristics of land and other natural resources typically prevent markets for these goods from achieving their efficient use. There are external costs associated with habitat conversion, and several benefits provided by extant habitat are public goods: it is difficult to exclude downstream users from receiving the benefits of improved water quality (i.e., this good is nonexcludable), and carbon sequestration and storage by forests reduces the probability of climate change for every individual on the planet (i.e., this good is nonrival). These two features of land and resource use have contributed to inefficient habitat conversion across the globe. p0035

It would seem that regulatory and public policy mechanisms could increase social welfare through the increased protection of habitat and the provision of associated ecosystem services relative to the outcomes of unregulated markets. There are trade-offs associated with habitat conservation just as there are with habitat conversion, and there will be both winners and losers from such decisions. Those asked to forgo private returns in order to ensure increased social benefits will tend to challenge the implementation of such regulation. Quantifying the welfare implications of public policies aimed at ensuring the continued provision of ecosystem services requires an understanding of how ecosystem function is affected by human activity, how these effects alter the provision of services from these ecosystems, and how this change in provision affects social welfare. p0040

Overview of Ecosystem Services s0015

The Millennium Ecosystem Assessment (MEA, 2005) introduces four different categories of ecosystem service. The p0045

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different characteristics across service categories impact efforts to value the individual services within each category. The first category, provisioning services, includes the services that are most familiar to society, such as agricultural products, seafood, and timber, among others. Provisioning services are ecosystem services that are directly consumed by humans and are often examples of renewable resources, a class of resource that has been well-studied by resource economists for nearly 70 years. These services are generally traded in traditional markets, and their enjoyment by society requires concerted effort by some members of society (e.g., the time, capital, and labor of farmers to harvest each year's crop). Even with markets for these provisioning ecosystem services, there are still externalities associated with their harvest, and the management of these provisioning services can significantly impact the quantity of service provision as well as its value to society. The value of these services comes from their consumptive use.

p0050 Regulating services impact human well-being through their regulation of natural processes. Examples of regulating services include the sequestration and storage of carbon by vegetation that helps to regulate climate, the mitigation of surface flows associated with storm events by vegetation that helps to regulate flooding extent, and the retention of nutrients and other pollutants by vegetative cover on the landscape that helps to regulate the quality of downstream water bodies. Regulatory services are typically not associated with markets, so government intervention is essential to ensure that there is an adequate provision of these services on the landscape. These services are typically provided without direct costly activity by humans. The value of these services comes from their use, though these services are quasi-public goods in that they are simultaneously enjoyed by groups of beneficiaries (i.e., they are nonrival and nonexcludable to segments of the population).

p0055 Cultural services cover a broad array of services related to both the direct and indirect social benefits of functioning natural systems. This umbrella of services runs from the enjoyment of outdoor recreation to the spiritual calming and restoration of either access to or knowledge of areas of scenic beauty and cultural importance. Aesthetic benefits such as the enjoyment of scenic coastal views, as well as the educational value of functioning natural systems, are included in the cultural ecosystem services category as well. Recreational opportunities and aesthetic benefits are unique among the cultural services in that occasionally markets can be used to value these services, whereas the cultural, educational, and spiritual services are typically not associated with markets. The value of these services exists due to interaction with nature, directly (e.g., the satisfaction from catching or eating salmon) or indirectly (e.g., the benefits of having water available to irrigate crops that are eventually grown to feed humans) or through use, as well as the knowledge of or satisfaction from the existence of nature, which environmental economists refer to as "nonuse" value. Furthermore, there are both consumptive use values, as in the case of eating freshly caught fish, and nonconsumptive use values, as in the case of time spent canoeing the tributaries of Chesapeake Bay.

p0060 The final category of ecosystem services defined by the MA
AU2 is the supporting services. These services represent natural processes that are directly responsible for the composition of each ecosystem though perhaps only indirectly related to the ecosystem services provided by that system. Examples of these processes include primary production, nutrient cycling, and soil formation. There are no markets for these services, and they are not typically valued directly; instead, they are acknowledged as contributing to the other categories of services that provide more easily quantifiable value to society. In economic terms, these services can be thought of as inputs to the production of the other categories of ecosystem services that are directly valued by society.

Ecosystem services are the outputs that result from a p0065
combination of different inputs. Cell phones, and many other products that we consume, are produced using a combination of raw materials, labor, and capital through a specific technology. Similarly, ecosystem services are produced by a combination of ecosystem components, both biotic and abiotic, through the function of that ecosystem. An ecological production function specifies the output of ecosystem services that are provided by an ecosystem given its condition and processes. These functions will vary across space due to site- and ecosystem-specific relationships.

Once an ecological production function is specified, re- p0070
searchers can quantify the impact of landscape change on the level of ecosystem-service outputs. In the past two centuries, human alteration of ecosystems on a large scale, such as the conversion of extant habitat to single-crop agriculture, or monoculture, led to an increase in some provisioning services (e.g., food production) at the expense of many regulating, cultural, and supporting services (MEA, 2005; Vitousek *et al.*, 1997). In the example of timber harvest in the Pacific Northwest, the easily definable and tangible value of Douglas firs for their timber led to massive consumption of this ecosystem service and a simultaneous loss of most other services associated with temperate coastal forests.

The production function through which biophysical pro- p0075
cesses in an ecosystem are converted into ecosystem services is impacted by several ecosystem characteristics. The plant and animal species that live within an ecosystem are important features of the system. Although the dominant vegetation type associated with an ecosystem has been shown to impact the quantity of ecosystem services produced by the system, the relationship between biodiversity and ecosystem services is less clear.

Ecosystem Services and Biodiversity s0020

The traditional motivation for conservation has been the p0080
protection of wildlife, especially the charismatic species, that live in the areas of interest for conservation. Generally, this approach sets tangible benefits of intensive land management against the fate of different species chosen to represent the health of the ecosystem of interest. In many instances, as in the case of the northern spotted owl, the value of the representative species to society is not easily defined, making it difficult to compare to the forgone profits associated with habitat conservation.

Although there is a consensus among natural scientists that p0085
human action has altered the species composition of many ecosystems through species invasions and extinctions, there

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are still uncertainties regarding the impacts of varying species composition and diversity on ecosystem function (Hooper *et al.*, 2005). Experimental work conducted in the grassland prairies of Minnesota suggest that species diversity increases the productivity of a system as measured by biomass (Tilman *et al.*, 1997). However, it is not well understood if such results will extend to impacts of altered diversity for non–primary producer species.

p0090 The introduction of the term "ecosystem services" and the focus on the benefits to society of functioning ecosystems was partially motivated by the challenge of convincingly conveying the importance to humanity of ensuring the continued existence of various animal and plant species. Although the value of the northern spotted owl might not be clear to the average policy maker or landowner, that same policy maker or landowner might be familiar with the importance of clean water to society. By connecting the forests that are home to the owl to the idea of water filtration by the trees in the forest, the societal trade-offs between logging and forest conservation may become more salient to people affected by the choice between forest conservation and conversion.

p0095 Maintaining biodiversity is not typically considered an ecosystem service. Although there is some expectation that a focus on ecosystem services will ensure the continued existence of different species, the shift in focus to ecosystem services from species conservation clearly aims to highlight the value of functioning ecosystems to humanity. Understanding the different approaches that can be applied to value nature is useful in determining which approach might be most appropriate for a given policy context or land-use decision.

s0025 Definition of Value

p0100 In discussing the value of nature, there are two alternative philosophical approaches that can be used to frame the issue. The anthropocentric approach claims that natural things and functioning ecosystems are of value only to the extent that they provide satisfaction to humans. The biocentric approach asserts that the satisfaction of humans as well as that of other species should be considered in determining the value of extant habitat and nature. Goulder and Kennedy (2011) provide a more-comprehensive discussion of the concepts that are briefly introduced here.

p0105 Although the anthropocentric approach assigns value based solely on benefits that accrue to humans, this does not imply that it offers a defense for the total exploitation of nature. This approach asserts that we should assign value and therefore protect nature and other species only because humans gain satisfaction or well-being from doing so. As such, if people feel that the protection of nature or other nonhuman species is truly beneficial to human satisfaction or well-being, then the anthropocentric approach will place significant value on nature and these other life forms.

p0110 The total value that is calculated under the anthropocentric approach represents the sum of values from a suite of different benefits that accrue to humans from nature. Broadly, the total value is the sum of both use and nonuse values. As previously mentioned, use values can be categorized as direct or indirect use values. Finally, nonuse values, which involve no direct or indirect interaction between humans and the benefits from nature, can provide significant satisfaction to members of society.

Unlike the anthropocentric approach, the biocentric approach gives weight directly to the well-being of all species. As a result, the biocentric approach allows for the possibility that other species and the habitats in which they exist can be of value even if the value does not directly or indirectly accrue to humans. This component of value, which is unrelated to humans, is often referred to as "intrinsic value." p0115

The impetus for calculating the value of ecosystem services is to help inform resource users and policy makers in evaluating potential resource uses and policy mechanisms. These decisions are frequently evaluated through benefit–cost analysis, which ranks alternatives based on their net returns to society, identifying the net gain to society of choosing one policy alternative over another. p0120

The benefit–cost technique involves summing all of the gains associated with a given policy option and then subtracting all of the losses of that same option to establish the net gain of each option before identifying the policy option with the greatest net benefit. Part of the controversy surrounding the ESA in the US is that the act specifically forbids the use of economic considerations to determine which species are eligible for protection. As a result, all species – from the red wolf and the North American cougar to the American burying beetle – are equally eligible to have their habitat protected by the act. This biocentric approach to land-use regulation, which unanimously passed the Senate in 1973, has become quite contentious as the value of conservation is measured in terms of the benefits afforded to the listed species, whereas the benefits of habitat conversion are measured using the anthropocentric approach and are therefore more easily relatable to landowners. By preventing application of benefit–cost analysis, the ESA has often been criticized as placing an overly onerous burden on private landowners (Brown and Shogren, 1998). Part of the reason for this criticism may be due to the fact that the connection between the survival of the less-charismatic species protected under the ESA and the benefits of their survival to humans is tenuously understood at best. p0125

The concept of ecosystem services is quite useful in highlighting the anthropocentric value of nature. By valuing each of the services provided, it is possible to quantify the anthropocentric value of a piece of habitat. The remaining sections of this chapter will focus on the anthropocentric approach to the valuation of ecosystem services. Having defined the approach to valuation that we will discuss in this chapter, we next consider the importance of assigning value to nature. p0130

Assigning Value to Nature s0030

When an objective is attained in the least-cost means, efficiency is a key concept and sought-after outcome in the discipline of economics. Under certain conditions, independent actors in competitive markets can achieve efficient social outcomes in the absence of government intervention. However, when these conditions do not hold, as is generally the p0135

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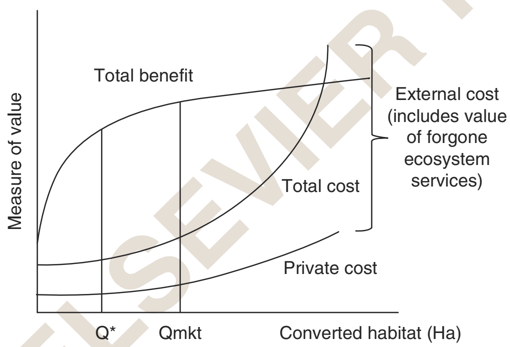
case with regard to natural resources, government action is necessary to achieve efficiency. Generally, when the cost effectiveness or efficiency of a policy choice is being evaluated, the benefit–cost methodology is used to calculate what resources had to be used to achieve the given choice and what the benefit, or value, of that choice is to society. **Figure 1** illustrates the inefficiency that arises in the absence of government regulation when the production of a good, here converted habitat, has higher social costs than private costs. This negative production externality is a classic example of conditions under which government regulation can increase the efficiency of market outcomes. It is possible to measure the benefits and costs of a choice in different units. However, identifying the net benefits of an action is more straightforward if the benefits and costs of the action are measured in the same units.

p0140 Since before the passage of the ESA in 1973, there has been discomfort associated with the idea of placing an economic value on nature. Some of this concern has been rooted in the belief that by discussing nature in dollar terms, the value of conserving key habitat or protecting certain species would actually prove to be less than the value to society of converting this habitat into intensive agriculture production or another intensively managed land-use system. One other potential cause for the unwillingness to use financial terms to measure the importance of nature is related to the distinction between anthropocentric and biocentric values. By thinking of the importance of nature in economic terms, we are implicitly ignoring its biocentric value, thereby placing the welfare of humans ahead of that of all other living organisms. At the same time, efforts to define habitat value in the context of species diversity and viability have failed to resonate with broad elements of society.



f0010 AU13 **Figure 1** The external costs of habitat conversion. In the absence of regulation, Qmkt units of habitat will be converted because this amount of conversion maximizes net private benefits (total benefits minus private costs). Qmkt is more than the socially optimal amount of conversion because the costs of habitat conversion that accrue to other members of society, including the loss of the benefits associated with the various ecosystem services provided by the habitat, are not included in the maximization of private net benefits. By valuing these ecosystem services, we are able to identify the optimal amount of habitat conversion (total benefits minus total costs) and design policies to achieve this level of conversion.

The key goal of valuing nature is to ensure that resource-use decisions are being made in ways that result in the greatest returns to society. The shift to a focus on ecosystem services reflects an effort to emphasize the anthropocentric value of nature. p0145

Ecosystem services are unlike most other market goods in that multiple services can be simultaneously produced by the same piece of habitat (e.g., a forest parcel provides carbon sequestration and storage, nutrient and sediment retention, and storm-peak mitigation). Because we are using the value of different ecosystem services to quantify the value of conserving extant habitat, we must take care to accurately value all services provided by a given patch of habitat. When policy makers and resource users choose to focus on the value of a single service, unintended consequences that induce additional costs on society can occur (e.g., Jackson *et al.*, 2005). p0150

It is possible to estimate the value of ecosystem services in ways that more faithfully represent true social preferences than the approach of simply summing biophysical units, which implicitly assumes that each service is of equal per-unit value to society, a condition that may not hold in reality. The outcomes of these techniques are also consistent with the benefit–cost approaches that are used to determine the land- and resource-use decisions that provide the greatest benefits to society. p0155

Quantifying the Value of Ecosystem Services s0035

This section presents some of the economic theories and methods used to measure the welfare changes associated with changes in the provision of various ecosystem services. This effort has been undertaken in several different contexts previously (Goulder and Kennedy, 1997, 2011; Salzman, 1997; Heal, 2000; de Groot *et al.*, 2002; Boyd and Banzhaf, 2007). Bockstael and Freeman (2005) provide a very thoughtful and comprehensive discussion of assigning value to nonmarket goods in the broader context of environmental externalities, and the forthcoming discussion closely follows Sections 3 and 4 of their chapter in Volume 2 of *The Handbook of Environmental Economics*. p0160 AU3

We present a general framework to measure the welfare implications associated with changes in the provision of various ecosystem services. The discussion here focuses on the direct welfare impacts of changes in ecosystem-service provision or prices. Understanding the full welfare impact of these changes requires an understanding of their impact on production of firms in different industries, which can be estimated using dynamic general equilibrium models. p0165

The ecosystem services provided by a chunk of habitat are a function of the geologic, biophysical, and spatial characteristics of that piece of habitat. The function describing the production of ecosystem services from a piece of habitat will differ for each service of interest. Let $ES_{jx} = f_j(A_x)$ represent the quantity of ecosystem service j (e.g., nutrient retention by vegetation or storm-peak mitigation) produced by a piece of habitat x, with attributes given by A_x. We introduce the index x in recognition of the fact that the production of a given ecosystem service on a piece of landscape or seascape will vary spatially. There is a significant challenge in the practice of p0170 linking biophysical outputs with the inputs required by valuation efforts (e.g., hydrological models might estimate the tons of phosphorous retained by forests, but additional effort is required to relate that metric to the metric of lake clarity, which impacts lake swimming and the value of nutrient retention in the context of recreation).

p0175 Let H_x represent the measure of human activity that impacts the provision of ecosystem services on the xth unit of habitat. H_x might include increased water quality due to more-stringent regulation of effluent, human disruption of salmon nurseries, or changes in the area of forests due to increased zoning for residential development. So, we now have $ES_{jx} = f_j(A_x,H)$ as the expression that describes how a piece of habitat's characteristics and human activity on that piece of habitat combine to impact the production of the different ecosystem services provided by habitat on a given piece of landscape or seascape. The total production of ecosystem service j in the study area of interest is given by ES_j, where $ES_j = \Sigma_X ES_{jx}$. Certain ecosystem services, such as the production of agriculture, fish, or timber for harvest or storm-peak mitigation by forests, will directly impact human welfare, whereas others, such as the availability of water for crop irrigation or the presence of insect pollinators near agricultural land, will matter to humans because they enter as inputs to a production process, which we will describe as $Z(ES_j)$.

p0180 In the case of logging operations in the US Pacific Northwest, H might describe the conversion of coniferous forest to bare soil due to clear-cut logging of old-growth Douglas firs. This activity will have different impacts on the various ecosystem services provided by the previously forested land. With regard to the service of timber production, the harvest of the firs represents a realization of this service and a direct increase in welfare. Regarding the service of storm-peak mitigation, converting the forest to bare soil represents a reduction in the provision of this service, which will accordingly correspond to a direct decrease in welfare. Removing the firs from a portion of the landscape may increase the water yield and therefore the water available for downstream irrigation, which will indirectly increase welfare.

p0185 Space is especially important in the valuation of ecosystem services. First, the location of service-providing habitat in the landscape, not just the habitat type, can impact provision. Generally, services are provided by ecosystems at a location that is some distance away from the segment of the human population that benefits from this service (e.g., forests in upstream portions of watersheds help to reduce the volume and timing of surface flows associated with storm events that reaches downstream populated areas). Next, different services provide value at different spatial scales (e.g., carbon sequestration provides benefits to people around the globe, whereas filtration of surface water used for drinking downstream is only valuable to the population within the same watershed) making it challenging to estimate the full value of a given piece of functioning ecosystem with a single analysis at a given scale. Hein *et al.* (2006) provide further commentary on this challenge.

p0190 The links that exists between ecosystem function, the provision of ecosystem services that are of use to humans, the effects of human activity on the provision of these services, and the welfare impacts of service provision can be represented with a simple model, which does not imply that identifying any one of these links is a simple matter. Let W represent the level of economic welfare. Then the model that describes the direct and indirect utility provided by a given ecosystem service, indexed by ES_j, can be expressed as:

$$ES_j = \Sigma_X ES_{jx} = \Sigma_X f_j(A_x, H_x) \quad [1]$$

$$Z(ES_j) \quad [2]$$

$$W = W(ES_j,\ Z(ES_j)) \quad [3]$$

We are able to track the welfare impacts of proposed regulation or changes in land use by predicting how these regulatory and behavioral changes will impact the production of the focal ecosystem service and then using eqns [1]–[3] to calculate the resulting welfare change in monetary terms. The response of firms and individuals to regulation is by no means a certain outcome, and the prediction of these responses is a difficult goal that lies outside of the scope of this chapter. p0195

Before proceeding with the exposition of estimating the value of a single service, we briefly return to the fact that habitat provides multiple ecosystem services simultaneously. The value of a given patch of habitat is given by the sum of the value of the suite of services provided by that patch, or $V_x = \Sigma_J W(ES_j,\ Z(ES_j))$. To accurately estimate the value of nature, we must accurately estimate the value of each of the provided services. p0200

The model presented in eqns [1]–[3] represents a simplified view of the problem that deemphasizes several challenges. Although we already briefly mentioned the issue of space, tracking the differential impacts of location on the provision of ecosystem services as well as appropriately incorporating the differential impacts of human activity on important characteristics of parcels across the landscape is a nontrivial task. That said, key spatial characteristics should be incorporated in the model. The temporal dimension also provides motivation to approach estimation of welfare impacts from ecosystem service provision with care. The issue of time also warrants careful consideration, particularly because certain ecosystem services represent stocks (e.g., the salmon available for harvest), whereas others represent flows (e.g., the sediment retained by a forest). Furthermore, if considering welfare effects of long-term changes in service provision, it is important to remember that the ecosystem production function may vary across time due to climate change, and the production function that takes ecosystem services as inputs may also vary through time as technology changes, so that calculations made ignoring such changes will provide inaccurate estimates of welfare impacts. p0205

In the following simple model of individual utility, we ignore uncertainty, allowing us to pinpoint how changes in inputs to the utility function alter utility. Let us first consider the case in which an individual's utility is a function only of private goods purchased, where the individual attempts to maximize her utility by choosing quantities of these goods to consume given an exogenous set of product prices and a fixed amount of personal income, denoted by M. The constrained p0210 utility optimization faced by the consumer is given by

$$\max U = U(X) \text{ subject to } P'X \le M \qquad [4]$$

where X is a vector of n goods and services and P is a corresponding price vector. The solution to this problem results in a set of n Marshallian demand functions given by

$$x_i = x_i(P,M), \quad i = 1, \ldots, n \qquad [5]$$

where eqn [5] represents the consumption of a given good that allows the individual to achieve her highest level of utility given her income and the prices of all goods. Substituting eqn [5] into eqn [4] results in an indirect utility function, representing utility as a function of prices and income based on the consumption decisions made by the individual when facing these prices with income level M

$$U = V(P,M) \qquad [6]$$

p0215 Ecosystem services can be introduced in three different ways to a consumer's utility function. First, for services such as production of salmon or air quality in Yosemite Valley, ES_j could enter the utility function in eqn [4] directly. Other services such as vegetative pollutant retention that maintains downstream water quality for consumption might enter the utility function as an input to the production of a household produced good – in this case, the health status of the individual as given by $Z(ES_j)$. Regardless of whether the given ecosystem service directly impacts utility or only has an effect on utility through the production of Z, ES_j would appear as an argument of the indirect utility function described in eqn [6].

p0220 The third mechanism through which ecosystem services might impact an individual's utility is by affecting the production process of one of the private goods that the individual consumes. In this case, the welfare effects of a change in service provision would manifest themselves through changes in the price of the privately produced goods or inputs to their production, which could alter one or more elements of P or could alter M or both. As an example, it might be the case that the harvest of fir trees for their timber could result in a reduction in the capacity of the landscape to prevent sediment from being carried into reservoirs during rainfall events. This result means that the sedimentation of the reservoir could occur at a faster rate than the operator of the hydropower station might have planned. As such, there could be an increase in the cost of power production, a resulting increase in the price of electricity, or possibly a reduction in rents to the hydropower owner and the income of plant employees. Under different conditions, the change in income alone could be used to measure the welfare impact, whereas other conditions would call for the inclusion of opportunity costs in the calculation of the welfare effects (See Freeman, 2003 for more details of this issue).

p0225 We have isolated the mechanisms through which ecosystem services impact individual utility. The change in utility resulting from a change in ecosystem-service provision could theoretically then be used to quantify the value of these services to the individual. Unfortunately, utility change is neither measurable for individuals nor additive across individuals, so we cannot use utility itself as a measure of welfare change. Instead, we can use the amount of money that must be offered or taken from an individual in conjunction with a change in the provision of ecosystem services to ensure that she maintains a constant utility level as our measure of the welfare impact of changes in ecosystem-service provision.

p0230 If we are interested in a small or marginal change in ES_j, we can identify the resulting marginal welfare change by differentiating the indirect utility function with respect to ES_j and M to identify the change in M necessary to compensate for the change in ES_j:

$$-\frac{dM}{dES_j} = \frac{\partial V / \partial ES_j}{\partial V / \partial M} \qquad [7]$$

p0235 The expression in eqn [7] will be positive if ecosystem-service provision increases and negative if provision decreases. If the changes in ecosystem-service provision and the resulting welfare impacts are relatively large or nonmarginal, then the concepts of compensating and equivalent variation are used to measure the welfare effects of these changes. Compensating variation represents the amount of money that must be taken away from (or given to) an individual to make her just as well off after the change in ecosystem-service provision as she was before the change. We can implicitly define compensating variation using the indirect utility function as

$$V(P^1, ES_j^1, M^1 - CV) = V(P^0, ES_j^0, M^0) \qquad [8]$$

where superscript 0 represents initial levels and superscript 1 denotes subsequent levels of the parameters, respectively. Presented in this way, the compensating variation has the same sign as the welfare change. For example, if the only change is an increase in ecosystem-service provision, meaning that $ES_j^1 > ES_j^{\circ}$, while $M^1 = M^{\circ}$ and $P^1 = P^{\circ}$, then the individual will clearly have to give up some income to be indifferent between the initial and subsequent parameter values, so that $CV > 0$.

p0240 Although compensating variation uses the utility level of the initial condition as the base case, equivalent variation uses the utility level of the subsequent condition as the base case. The equivalent variation is defined as the amount of money that must be given to (or taken from) an individual in lieu of a change in the quantity of ecosystem-service provision to make her just as well off as she would have been with the change in provision. We can implicitly define equivalent variation using the indirect utility function as

$$V(P^1, ES_j^1, M^1) = V(P^0, ES_j^0, M^0 + EV) \qquad [9]$$

p0245 Once again, we see that equivalent variation, defined in this way, has the same sign as the welfare change.

p0250 Having identified the three pathways through which changes in the provision of ecosystem services might impact welfare and introduced two measures to quantify the welfare impacts of such changes, we can now explore how compensating and equivalent variation can be used to quantify these welfare impacts. Thus far we have implicitly expressed CV and EV in terms of the indirect utility function, which expresses an individual's utility as a function of prices and income based on her consumption decisions made in an attempt to maximize utility with her fixed amount of income. We can now

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explicitly define CV and EV in terms of an individual's expenditure function.

p0255 The expenditure function is obtained by identifying the consumption decisions that would be made by an individual who would like to achieve a threshold level of utility while minimizing the cost of her consumption choices. The expenditure function is derived by solving the following constrained optimization problem:

$$\min P'X \quad \text{s.t. } U(X, ES_j) \geq U^0 \qquad [10]$$

where P represents the vector of product prices, X represents the vector of consumption units, and U° represents the threshold level of utility that the individual is attempting to achieve. It should be noted that the objective in expression [10] represents the dual to the utility maximization problem presented in expression [4].

p0260 By substituting the cost-minimizing demand for X into the objective function in eqn [10], we can identify the minimum amount of money necessary to achieve the targeted level of utility, given market prices and ecosystem-service provision,

$$e = e(P, ES_j, U^0) \qquad [11]$$

p0265 We are now able to explicitly describe compensating and equivalent variation of a change in prices or ecosystem-service provision. The compensating and equivalent variations for a price change are given by

$$CV = e(P^0, ES_j^1, U^0) - e(P^1, ES_j^0, U^0) \qquad [12]$$

and

$$EV = e(P^0, ES_j^0, U^1) - e(P^1, ES_j^0, U^1) \qquad [13]$$

whereas those for a change in the provision of the focal ecosystem service are given by

$$CV = e(P^0, ES_j^1, U^0) - e(P^0, ES_j^0, U^0) \qquad [14]$$

and

$$EV = e(P^0, ES_j^0, U^1) - e(P^0, ES_j^1, U^1) \qquad [15]$$

where

$$U^i = V(P^i, ES_j^i, M) \quad i = 0, 1 \qquad [16]$$

p0270 The majority of the benefits that accrue to humans as a result of functioning ecosystems are goods that are not traded on traditional markets. As a result, most of these services will impact welfare through changes in the quantity of provision as opposed to impacts on the production of market goods by firms that will have price effects. That said, agriculture, fisheries, and timber are important components of the global economy, and changes in the provision of these ecosystem services will impact welfare not only through changes in the quantity of the service itself but also through changes in the market prices for these goods.

p0275 Thus far, we have focused on estimating the impacts of changes in the price or quantity of a particular ecosystem on an individual's welfare. In the context of benefit–cost analysis, we would like to understand which resource-use options provide the greatest benefits to society. Doing so requires a method of aggregating the estimates of individual welfare impacts over the relevant portion of society. Moving from individual to social welfare outcomes could be accomplished by summing up the welfare measures across relevant individuals who might be differentially affected due to variation in preferences or because the welfare changes themselves vary. Still, if the change results in net welfare gains to some and net welfare losses to others, when should such a change be deemed beneficial to society? One approach involves summing the CVs across all affected individuals, with the policy change deemed beneficial if this sum is positive (Kaldor, 1939) (remember that CV represents the compensation necessary for those made worse off by the policy to accept it as well as the willingness to pay of those who benefit from the policy to ensure it occurs). This approach recommends such policy changes that make it possible for those who benefit from the change to compensate those who suffer from the change. In practice, those transfers do not occur, so this method does not truly address the potential equity issues of policy evaluation, particularly when it is possible for the benefits to accrue unevenly across income levels in society. The inability to clearly resolve distributional concerns regarding policy changes is a key reason that benefit–cost analysis can be insufficient to decide policy matters.

In addition to the equity issues associated with aggregating estimates of individual welfare changes to a measure of social welfare impacts, ecosystem services face aggregation challenges due to spatial variation in welfare impacts. As previously mentioned, the welfare impacts of different ecosystem services will accrue over different spatial scales. For this reason, care must be taken in identifying the appropriate group of individuals affected by changes in the price or quantity of ecosystem-service provision. Bateman *et al.* (2006) provide a thoughtful discussion of how estimates of individual welfare impact might be obtained to minimize potential biases in the resulting estimates of social welfare impacts. We now turn to a discussion of how observable information can be used to estimate CV and EV, the theoretically accurate measures of welfare in the context of ecosystem services. p0280

Welfare Measures with Marshallian Demand Functions s0040

As a point of origin for this portion of the chapter, we must review the distinction between two popular methods for estimating demand. The ordinary, uncompensated, or Marshallian demand function represents the bundles of goods that a consumer would choose to purchase under each price and income combination, assuming she is able to perfectly solve her utility-maximization problem, as specified in eqn [4]. The Hicksian or compensated measure of demand is derived in a way to isolate the substitution effects of changes in prices from the associated income effects of such changes. p0285

Briefly, a change in the price of a good that is in an individual's optimal consumption bundle (i.e., the good is a component of vector X in expression [10]) has two effects on an individual's consumption choices. First, the change in the price of the good will impact the individual's consumption of p0290

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that good because the price change will make the good relatively cheaper (for a price reduction) or relatively more expensive (for a price increase) than the other goods in the individual's consumption bundle. This effect of the price change is known as the "substitution effect," because the individual will substitute toward the good whose price has changed from the other goods (for a price reduction) or away from the good whose price has changed toward the other goods (for a price increase). The change in the price of the good will also impact the individual's overall consumption bundle because the price change will either make the consumer more wealthy (for a price reduction) or less wealthy (for a price increase). This effect of the price change is known as the income effect, because the change in the price of the good impacts the income available to be spent on the consumption of goods in the consumption bundle, which will alter total consumption. Hicksian demand is derived in such a way to uniquely identify the substitution effect of a price change by preventing or compensating for any simultaneous income effect.

p0295 If we could observe this compensated demand curve, then the calculation of *CV* or *EV* would be quite straightforward as previously described. In reality, when a change in the price of a good does not take place, be it an ecosystem service or not, it is not possible to isolate the substitution effects of this change from the income effects. As a result, we cannot generally derive Hicksian demand curves from observed behavior.

p0300 When dealing with uncompensated demand functions, which are derived from observed behavior, we are unable to isolate the substitution effects of a change in price from its income effects (Figure 2). As such, we are unable to directly derive accurate estimates of *CV* and *EV* from Marshallian demand functions.

p0305 The measure of welfare associated with Marshallian demand is known as consumer surplus, *CS*. Consumer surplus is defined as the area beneath the demand curve and above the market-clearing price from the origin to the market-clearing quantity of consumption for the good in question. Consumer surplus can be affected by both changes in the price of a good as well as changes in the quantity or quality of the good provided. Ecosystem services for which markets exist, such as provisioning services, will be able to impact welfare through price changes, whereas services for which there are no markets will have effects on welfare through changes in quality and quantity of the service provided.

p0310 The consumer surplus associated with a price change is given by the area beneath the demand curve between the initial and subsequent prices. In other words,

$$CS = -\int_{p_1^0}^{p_1^1} x_1(p_1,\hat{P},ES,M)dp_1 \quad [17]$$

where x_1 represents the good whose price is changing, $\hat{P}$ represents the vector of prices for all other goods, p_1^0 represents the initial price of the good of interest, p_1^1 represents the price of this good after the price change, and the other variables are as previously defined.

p0315 The definition presented in eqn [15] represents the change in consumer surplus associated with a price change in the good of interest. This calculation is common for market

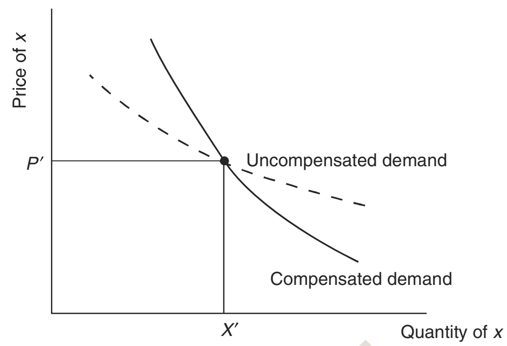

Figure 2 Compensated and uncompensated demand curves. The compensated demand curve illustrates the relationship between the price of a good and the quantity purchased, holding constant other prices and the individual's utility. The uncompensated demand curve illustrates the relationship between the price of a good and the quantity purchased, assuming that preferences, other prices, and income are held constant. The two curves intersect at point (x',p') because the individual's income at that point is just sufficient to achieve the utility level that is held constant on the compensated demand curve. The compensated demand curve is less responsive to price changes than the uncompensated demand curve, because the income effect, which is controlled for in the compensated demand curve, for normal goods is in the same direction as the substitution effect (i.e., a lower price leads to an increase in quantity purchased both because the good is relatively cheaper than other goods (substitution effect) and because the individual has more wealth to spend at the lower price (income effect)). f0015

goods. Therefore, the calculation in eqn [15] will be of use for provisioning services that undergo a change in market price. However, as we have explained above, the remaining categories of ecosystem services – regulating, cultural, and supporting services – are typically nonmarket goods. For these types of goods, the change of interest is related to the quantity or quality of provision (or both). In the absence of a market, the consumer surplus is defined as the area beneath the demand curve from the origin up to the observed level of consumption. In other words, AU4

$$CS = -\int_0^{ES_1^1} ES_1(P,\widehat{ES},M)dES_1 \quad [18]$$

where *P* represents the vector of prices for all market goods consumed, including provisioning ecosystem services, $\widehat{ES}$ represents the levels of all other ecosystem services consumed, and *M* represents income. The change in consumer surplus from a change in the quantity of ecosystem-service provision is found by differencing the consumer surplus associated with the original and shifted Marshallian demand curves.

It is clear that the observable (*CS*) and accurate (*CV*, *EV*) measures will differ under many conditions due to the presence of an income effect in observed conditions. Willig (1976) determined the precise differences between the measures, which are driven by the income elasticity of demand for the good in question and the magnitude of consumer surplus as a fraction of total income or expenditures. He concludes that p0320

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the differences between the welfare measures are relatively small and basically trivial for most realistic conditions. AU5 Randall and Stoll (1980) conduct similar analysis for changes in the quantity of the nonmarket good of interest and also determine that consumer surplus is a suitable approximation for *CV* and *EV*, though these findings may not be as robust as those of Willig (Hanemann, 1991). Still, these findings are supportive of the use of consumer surplus, which can be empirically derived, as a welfare measure. It should be noted that subsequent efforts have demonstrated practical means of estimating *CV* and *EV* directly from observable data (Hausman, 1981; Irvine and Sims, 1998).

s0045 Estimating Social Value

p0325 As previously described, it is relatively straightforward to derive estimates of the social value of changes in the price or quantity of a good for which a market exists. For many goods, including several ecosystem services, markets do not exist. As a result, the methods previously described, which depend on knowledge of the consumer's demand function for the good of interest, can only be applied using novel methods to identify the demand functions for these goods of interest. The next two sections briefly introduce the methodologies of several different approaches to this problem, which can be broadly grouped into two categories. The first category of approaches is referred to as ''revealed preference'' because these methods utilize observed behavior to estimate demand for nonmarket goods. The next category is referred to as ''stated preference'' because these approaches utilize information gleaned from individuals through their responses to surveys, questionnaires, and interviews. Each broad category of approaches to assigning value to nonmarket goods has its benefits and costs, which we will discuss in the next two sections, beginning with revealed-preference methods.

s0050 Revealed-Preference Methods

p0330 These methods to value nonmarket goods use observed behavior as well as information from other markets to estimate the demand for a particular nonmarket good. These approaches are referred to as ''revealed-preference methods'' because an individual's behavior in existing markets is used to reveal her preference for the nonmarket good being studied. There are two principal revealed-preference methods that are relevant to the topic of ecosystem services: the travel cost method for visits to a recreation site, and hedonic valuation, which uses the property value of a home to estimate the value of changes in ecosystem-service provision. Before introducing these two well-known approaches, we first consider an approach to value ecosystem services that are substitutes for market goods.

p0335 The specific revealed-preference method that is most appropriate for use in the valuation of a nonmarket ecosystem service depends on the relationship that exists between the ecosystem service of interest and other goods. In 1974, Karl-Göran Mäler laid the foundation for subsequent efforts to understand how preference information about a public good could be derived from the relationship between the public good and a substitute, market good. The correspondence between the estimated and actual welfare impacts of changes in the amount of ecosystem service provision depend on the substitutability of the ecosystem service and the market good.

Several ecosystem services – such as nutrient and sediment retention, storm-peak mitigation, and possibly air filtration – p0340 are perfect substitutes for goods that appear in an individual's utility function. In this case, where the ecosystem service and the market good are equally well suited to provide a valuable amenity to the individual, it is possible to identify the compensating variation due to a change in the amount of ecosystem-service provision using only information about the price of the substitute market good and the relationship between the market good and the ecosystem service in the production of the valuable amenity.

For example, consider an individual who maximizes utility, p0345 $U(X,Z,ES)$, subject to a budget constraint, $M - P^{\prime}X - p_z Z = 0$, where *ES* is the ecosystem service of interest, *Z* is the market-good substitute for *ES*, and *X* is a composite of all other goods. It is possible to recast this problem as one in which the desired good or service provided by *Z* or *ES*, *S*, directly enters the utility function, so that the previous expression becomes $U(X,S(Z,ES))$. As an example, we can think of *ES* as the nutrient retention provided by forests and *Z* as the water filtration provided by a water-treatment plant, where *S* is the quality of water available for consumption downstream of the forest.

In the case of perfect substitutes, under certain conditions p0350 it is possible to identify the compensating variation of a change in the provision of the focal ecosystem service, *ES*. Let us imagine that the individual currently produces *S* by purchasing some amount of *Z* and by enjoying the benefits of the current amount of ecosystem-service provision, ES°. If the amount of ecosystem-service provision were to change (from ES° to ES^1, with $ES^1 < ES^{\circ}$), and the reduction in the production of *S* due to the reduction in service provision could be perfectly offset by an increased purchase of *Z*, then the compensating variation associated with this change in *ES* is given by the cost of the increased purchase of *Z* necessary to return the individual to her original consumption of *S*. Similarly, if $ES^1 > ES^{\circ}$, and some amount of *Z* is still purchased, then the compensating variation associated with this increase in *ES* is given by the reduction in cost associated with the production of the initial amount of *S*.

It is important to note that these results only hold if the p0355 individual is using a combination of both *ES* and *Z* to produce *S* before and after the change in *ES*. If this is true, and the individual is at an interior solution of her constrained utility-maximization problem, then we do not need information about her preferences to estimate the welfare impacts of a change in the focal ecosystem service. So, in the case of perfect substitutes between an ecosystem service and a market good, when the individual is at an interior solution before and after the change in *ES*, then the amount of money necessary to return the individual to her initial level of *S* is the same amount of money necessary to return her to her initial level of utility. If the ecosystem service of interest is an imperfect substitute for a market good, then the above result does not hold, though it does serve as a bound on the resulting welfare impact. Bartik (1988) explores the results for imperfect substitutes, and the key points are thoughtfully explained in Section 7.2.2 of Bockstael and Freeman (2005).

p0360 The finding that the amount of money required to return an individual to her initial consumption of a good that is equally well provided by an ecosystem service at no cost or a market good does not mean that we can use actual expenditures on the market-good substitute as a direct measure of the value of the ecosystem service. The reason for this point is that the previous finding holds when we are able to isolate the substitution effect of a change in the quantity of ecosystem service provided from the income effect of this change in service provision (i.e., in the context of Hicksian demand). In real-world situations, individuals are unable to isolate the income and substitution effects in this way, meaning that the actual expenditure on the perfect substitute for the ecosystem service following a change in the quantity of ecosystem service available may change even more than expected due to the opportunity to adjust consumption of other goods in the utility function. Bockstael and McConnell (2007) and Bartik (1988) provide further explanations about the relationship between actual expenditures and the actual welfare change as a result of a change in an environmental amenity.

p0365 Several notable nonmarket ecosystem services (e.g., nutrient and sediment retention related to water quality, sediment retention above reservoirs, carbon sequestration and storage, storm-peak mitigation) seem to have perfect substitutes among market goods that might allow for valuation estimates based on changes in expenditures on these market goods. Other nonmarket ecosystem services (e.g., recreation, aesthetic or cultural benefits, and filtration of air pollutants by vegetation) can be thought of as complements and not substitutes to specific market goods. It is possible to estimate the value of changes in the quantities of these ecosystem services by envisioning them as attributes of heterogeneous goods in order to isolate how changes in the provision of these services impacts the willingness to pay for the complementary good. Two of the best-known revealed-preference valuation approaches, the travel cost method and hedonic price studies of the housing market, are examples of this approach.

p0370 The hedonic travel cost approach (Brown and Mendelsohn, 1983) differs from the travel cost procedure (Hotelling, 1949; Clawson, 1959) in that it assigns value to characteristics of destinations as opposed to the different destinations themselves. In this approach, ecosystem services can be thought of as a measure of the quality of a location that could be a destination for recreation. In this context, individuals gain utility from the consumption of a composite market good, the amount of recreation opportunities enjoyed, and the quality of that recreation experience. In this case, there is not a market price for recreation, but the cost of producing the recreation experience can be used as a measure for the price of recreation. This price can be quantified using the costs of transportation and the individual's time, which is estimated using a function of the wage rate. If the transportation and time costs are constant, then the marginal cost of producing the recreation experience can be thought of as the price of the recreation experience. By observing the visitation to sites with different characteristics, as well as the cost of arriving at those sites based on the individual's point of origin, it is possible to estimate the value of changes in the quality of the sites, as measured by changes in provision of ecosystem services. This approach has been used to consider the impact of water quality on recreation (e.g., Phaneuf *et al.* (2008)).

A similar approach can be used to estimate the value of ecosystem services using observed variation in housing prices. p0375
In this approach, we assume that the individual's utility is a function of a composite good, as well as the various attributes associated with the individual's choice of housing. The price of any house will be determined by the quantities of the different attributes associated with the given house (e.g., square footage, number of bedrooms, air quality at the site, water quality at a nearby lake, pond, or coast). The hedonic price function maps housing attributes, including the relevant ecosystem service, into market prices for houses. The derivative of this function with respect to any attribute can be interpreted as the marginal implicit price of that attribute. There are some complications with using this approach to determine the welfare impacts of changes in ecosystem service provision at different sites due to the fact that the level of service provision is a choice variable in this approach (see Rosen, 1974; Bartik, 1987; Epple, 1987 for detailed discussion of the causes of this outcome and Bockstael and Freeman (2005) for a thoughtful summary of this issue).

The hedonic property value models have been successfully applied to estimate the value of several different ecosystem p0380
services. Leggett and Bockstael (2000) use the hedonic pricing AU6
method to determine the impact of water clarity, which is related to nutrient and sediment retention provided by extant habitat around the property, on house prices around Chesapeake Bay. Bin *et al.* (2009), consider the value to society of riparian-zone buffers, through their impacts on water quality, using the hedonic pricing method.

With revealed-preference methods, analysis of actual be- p0385
havior is used to identify the value of the nonmarket good through its relationship with other goods or services that have observed prices. The hedonic pricing method involves deconstructing the price of a market good and attributing portions of the total value to certain good characteristics (i.e., square footage and number of bedrooms for a house) to identify the value of a particular nonmarket amenity. The travel cost method can be used to identify the social value of clear water through changes in visitation rates to a river or lake based on cost of travel and the clarity of the water.

For several ecosystem services, observed behavior within p0390
markets for related goods can be used to identify the value of these services by understanding how changes in the provision of these services is related to the demand for the related market goods. These revealed-preference approaches require the availability of detailed socioeconomic data on a fine scale (i.e., visitor or parcel-level resolution). One shortcoming of the revealed-preference techniques is that they fail to account for the nonuse value of different nonmarket goods, meaning that they may only provide lower bound estimates of the value of nature, capturing only the values stemming from use of the services provided. Stated-preference methods of nonmarket valuation can be used to identify the full value of such ecosystem services, including nonuse values.

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s0055 **Stated-Preference Methods**

p0395 Stated-preference methodologies rely on the stated behavior of individuals in a hypothetical setting to identify the value placed on the nonmarket good of interest. Although there are several techniques based on stated preferences, such as conjoint analysis, choice experiments, and contingent valuation, the contingent valuation method is the most commonly applied in the context of ecosystem services (see Farber and Griner (2000) and Powe *et al.* (2005) for examples of the application of conjoint analysis and choice experiments, respectively). In the contingent valuation approach (Mitchell and Carson, 1989; Bateman and Willis, 1999), the researcher uses a survey to elicit information from the respondent about the value that she attaches to a given nonmarket good using her stated willingness to pay (WTP) to experience an increase in the focal good or her stated willingness to accept (WTA) to tolerate a reduction in the focal good.

p0400 We can return to the previous definitions of compensating and equivalent variation to illustrate how WTP and WTA are related to these established measures of value. As noted, let the individual's indirect utility, $V()$, be a function of the prices of market goods consumed, P, the amount of ecosystem services consumed, ES, and the individual's income level, M. Consider the situation in which the amount of ecosystem services consumed changes, while the prices of consumed market goods and income are held constant; then the compensating variation, CV, is given by

$$V(P,ES^1,M-CV)=V(P,ES^0,M) \qquad [19]$$

and the equivalent variation, EV, is given by

$$V(P,ES^1,M)=V(P,ES^0,M+EV) \qquad [20]$$

p0405 If $ES^1>ES^\circ$ – namely, the change in ecosystem services is viewed as a desirable outcome and an improvement in the amount of service provision – then $CV>0$ and $EV>0$. In this case, CV measures the individual's maximum WTP to ensure that the change occurs, and EV represents the individual's minimum WTA to forgo the change. If the change in ecosystem-service provision is viewed as unfavorable, then $CV<0$ and $EV<0$, with CV measuring the individual's WTA to tolerate the welfare-reducing change, whereas EV measures the individual's WTP to avoid the change.

p0410 The contingent valuation approach involves providing individuals with hypothetical situations in which there is a change in the level of ecosystem services provided (e.g., there is a potential project to restore a wetland that will increase nutrient pollutant retention so that the quality of downstream water bodies will be improved) and then eliciting from those individuals estimates of their WTP or WTA to estimate their perceived value of the focal ecosystem service. This example illustrates the importance of providing very specific information about the change of interest in the survey, particularly in the context of ecosystem services, whose joint provision may potentially result in multiple ecosystem services being impacted within a given hypothetical scenario. In the parenthetical example of restoring a wetland, such action would contribute additional storm-peak mitigation, increased opportunity for bird-watching and other recreational activities, and sediment retention in addition to the retention of nutrient pollutants focused on by the survey, making it difficult to identify the value of the nutrient retention if the survey were not thoughtfully designed. Diamond and Hausman (1994) present some challenges that must be overcome in interpreting responses to contingent valuation surveys as credible estimates of WTP and WTA, whereas Hanemann (1994) provides an overview of how survey design and study methodology can address these challenges.

Carson and Hanemann (2005) provide a clear and thorough discussion of the steps that must be taken to move from p0415
the responses elicited through a contingent valuation study to estimates of WTP or WTA for the hypothetical change in the nonmarket good of interest. Briefly, the process entails conceiving of the survey responses as a random variable, which might be the outcome of individuals trying to maximize utility functions that contain a random component, from the perspective of the researcher. Next, a link must be made between the distribution of WTP or WTA that will result from this introduction of randomness and the distribution of responses to the survey. As Carson and Hanemann (2005) note, this linkage depends on the survey format, particularly regarding its use of either open-ended or closed-ended, single-bound discrete-choice formats. In the former case, for a survey of WTP for an increase in the provision of a specific ecosystem service, the respondent would be asked, "How much are you willing to pay for the change from ES° to ES^1 (where $ES^1>ES^\circ$)?" In the latter case, for the same survey the respondent would be asked, "Would you vote to support the change from ES° to ES^1 if it would cost you \$*A*?" With the open-ended format, the response directly reveals the respondent's value of CV, whereas the closed-ended format response provides an interval in which the respondent's value of CV must lie. To appropriately estimate the relevant measure of value, the researcher must acknowledge the impact of survey design and other assumptions on the relationship between survey response and the distribution of the relevant measure of value. Again, Carson and Hanemann (2005) provide a thoughtful description of these issues.

If thoughtfully designed, contingent valuation surveys can p0420
be used to estimate the full value of changes in ecosystem-service provision. However, the challenges of providing adequate information to ensure that the respondents are assigning value to the specific service of interest are not trivial, and significant thought must go into the methodological development of such studies. Finally, the hypothetical nature of such estimates – meaning that the respondents are not actually being asked to pay the amount of money that they indicate as their WTP in the survey – can be used to question the validity of valuation estimates derived using this approach.

As with the revealed-preference methods of estimating the p0425
value of ecosystem-service provision, there are obstacles that must be avoided in applying the contingent valuation methodology. That said, this method has been applied by frequently cited studies to estimate the welfare effects of changes in ecosystem-service provision. Desvousges *et al.* (1987) use
this approach to determine the impact of enhanced water AU7
quality on recreational experience on a span of river in Pennsylvania. Loomis *et al.* (2000) use contingent valuation to AU8
estimate the overall economic impacts of restoration along a

stretch of the South Platte River in Colorado, which would affect the provision of several different ecosystem services simultaneously (wastewater dilution, water purification, erosion control, recreation opportunities) as well as habitat for fish and wildlife.

s0060 Conclusion

p0430 As we are increasingly faced with the choice between habitat conversion and conservation, the importance of achieving efficient resource use increases as well. To understand the full benefits and costs of habitat conversion and conservation decisions, we must be able to quantify the value of conserved habitat. This chapter has reviewed several of the existing methods available for such a task. That said, identifying the value of different resource-use outcomes does not necessarily guarantee that the most desirable outcome will be achieved, or even that there will be agreement about the most desirable outcome. Even as our understanding of ecosystem function and its value to society increases, the issues of equity and political feasibility offer challenges to the successful implementation of policies aimed at achieving efficient resource use.

AU9 *See also*: Economic value of biodiversity, measurements of (00263). Priority Setting for Biodiversity and Ecosystem Services (00414). Economics of the Regulating Services (00183). The Value of Biodiversity (00372). Evaluating the Effectiveness of Conservation Policy (00337). Economics of Biodiversity (00360)

s0070 Appendix

s0075 Relevant courses

- p0445 graduate course in environmental science and management;
- p0450 advanced undergraduate or introductory graduate course in environmental and resource economics;
- p0455 graduate course in ecosystem services.

AU10 Uncited References

Bockstael and McConnell (1981); De Groot and Wilson (Boumans); Englin and Cameron (1996); Hanley *et al.*, (2003); Maler (1974).

References

bib1 Bartik TJ (1987) The estimation of demand parameters in hedonic price models. *Journal of Political Economy* 95: 81–88.
bib2 Bartik TJ (1988) Evaluating the benefits of nonmarginal reductions in pollution using information on defensive expenditures. *Journal of Environmental Economics and Management* 15: 111–127.
bib3 Bateman IJ and Willis KG (1999) *Valuing Environmental Preferences: Theory and Practice of the Contingent Valuation Method in the US, EU, and Developing Countries*. New York: Oxford University Press.
Bateman I, Day BH, Georgiou S, and Lake I (2006). The Aggregation of Environmental Benefit Values: Welfare Measures, Distance Decay, and Total WTP. Lincoln University Discussion Paper 114. bib4
Bin O, Landry CE, and Meyer GF (2009) Riparian buffers and hedonic prices: A quasi-experimental analysis of residential property values in the Neuse River Basin. *American Journal of Agricultural Economics* 91(4): 1067–1079. bib5
Bockstael, NE and Freeman AM (2005). Welfare theory and valuation. In: Maler K-G and Vincent JR (eds.) *Handbook on Environmental Economics*, (North–Holland, Amsterdam) 2: 517–570. bib6
Bockstael NE and McConnell K (1981) Theory and use of household production functions for wildlife recreation. *Journal of Environmental Economics and Management* 8: 199–214. bib7
Bockstael NE and McConnell K (2007) *Environmental Valuation with Revealed Preference: A Theoretical Guide to Empirical Models*. Berlin: Springer. bib8
Boyd J and Banzhaf S (2007) What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics* 63: 616–626. bib9
Brown G and Mendelsohn R (1983) The Hedonic travel cost method. *Review of Economics and Statistics* 66(3): 427–433. bib10
Brown G and Shogren J (1998) Economics of the endangered species act. *Journal of Economic Perspectives* 12(3): 3–20. bib11
Carson R, Hanemann W.M. (2005). Contingent valuation. Handbook on Environmental Economics, (eds) Maler K-G and Vincent JR, North–Holland, Amsterdam 2: 821–936. bib12
Clawson M (1959) *Methods of Measuring Demand for the Value of Outdoor Recreation*. Resources for the Future Reprint No. 10. bib13
De Groot, R.S., M.A. Wilson, R.M.J. Boumans. A Typology for the Classification, Description, and Valuation of Ecosystem Functions, Goods, and Services. *Ecological Economics* 41: 393–408. bib14 AU11
Desvousges WH, Smith VK, and Fischer A (1987) Option price estimates for water quality improvements: A contingent valuation study for the Monongahela River. *Journal of Environmental Economics and Management* 14(3): 248–267. bib15
Diamond PA and Hausman JA (1994) Contingent valuation: Is some number better than no number? *Journal of Economic Perspectives* 8(4): 45–64. bib16
Englin J and Cameron TA (1996) Augmenting travel cost models with contingent behavior data. *Environmental and Resource Economics* 7(2): 133–147. bib17
Epple D (1987) Hedonic prices and implicit markets: Estimating demand and supply functions for differentiated products. *Journal of Political Economy* 87: 59–80. bib18
Farber S and Griner B (2000) Using conjoint analysis to value ecosystem change. *Environmental Science and Technology* 34(8): 1407–1412. bib19
Freeman AM (2003) *The Measurement of Environmental and Resource Values: Theory and Methods*, 2nd ed Washington DC: Resources for the Future, Inc. bib20
Goulder LH and Kennedy D (1997) Valuing ecosystem services: philosophical bases and empirical methods. In: Daily G (ed.) *Nature's Services*, pp. 23–48. Washington, DC: Island Press. bib21
Goulder LH and Kennedy D (2011) Interpreting and estimating the value of ecosystem services. In: Kareiva P, Tallis H, Ricketts TH, Daily GC, and Polasky S (eds.) *Natural Capital: Theory and Practice of Mapping Ecosystem Services*, pp. 15–34. New York: Oxford University Press. bib22
Hanemann WM (1991) Willingness to pay and willingness to accept: How much can they differ? *American Economic Review* 81: 635–647. bib23
Hanemann WM (1994) Valuing the environment through contingent valuation. *Journal of Economic Perspectives* 8(4): 19–43. bib24
Hanley N, Bell D, and Alvarez-Farizo B (2003) Valuing the benefits of coastal water quality improvements using contingent and real behavior. *Environmental and Resource Economics* 24(3): 273–285. bib25
Hausman JA (1981) Exact consumers' surplus and deadweight loss. *American Economic Review* 71: 662–676. bib26
Heal GM (2000) *Nature and the Marketplace: Capturing the Value of Ecosystem Services*. Washington DC: Island Press. bib27
Hein L, van Koppen K, de Groot RS, and van Ierland EC (2006) Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics* 57: 209–228. bib28
Hotelling H (1949) *Letter quoted by R.E. Prewitt in Economic Study of the Monetary Evaluation of Recreation in National Parks*. Washington, DC: United States Department of Interior. bib29
Hooper DU, Chapin III FS, Ewel JJ *et al.* (2005) Effects of Biodiversity on Ecosystem Functioning: A Consensus of Current Knowledge. *Ecological Monographs* 75(1): 3–35. bib30
Irvine IJ and Sims WA (1998) Measuring consumer surplus with unknown Hicksian demands. *American Economic Review* 88: 314–322. bib31
Jackson RB, Jobbagy EG, Avissar R *et al.* (2005) Trading water for carbon with biological carbon sequestration. *Science* 310(5756): 1944–1947. bib32

bib33 Kaldor N (1939) Welfare propositions of economics and interpersonal comparisons of utility. *Economic Journal* 49: 549–552.

bib34 Loomis J, Kent P, Strange L, Fausch K, and Covich A (2000) Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. *Ecological Economics* 22: 103–117.

bib35 Millennium Ecosystem Assessment (2005) *Ecosystems and Human Wellbeing: Synthesis*. Washington, D.C: Island Press.

bib36 Maler KG (1974) *Environmental Economics: A Theoretical Inquiry*. Baltimore, MD: Johns Hopkins University Press for Resources for the Future.

bib37 Mitchell RC and Carson RT (1989) *Using Surveys to Value Public Goods: The Contingent Valuation Method*. Washington, DC: Resources for the Future.

bib38 Phaneuf DJ, Smith VK, Palmquist RB, and Pope JC (2008) Integrating property value and local recreation models to value ecosystem services in urban watersheds. *Land Economics* 84(3): 361–381.

Powe NAGD, Garrod, and McMahon PL (2005) Mixing methods within stated-preference environmental valuation: choice experiments and post-questionnaire qualitative analysis. *Ecological Economics* 52(4): 513–526. bib39

Rosen S (1974) Hedonic prices and implicit markets: product differentiation in perfect competition. *Journal of Political Economy* 82: 34–55. bib40

Salzman J (1997) Valuing ecosystem services. *Ecology Law Quarterly* 24: 887–904. bib41

Satchell M (June 25, 1990) The endangered logger: Big business and little bird threaten a northwest way of life. *U.S. News & World Report* 108(25): 27–29. bib42

Tilman D, Knops J, Wedin D, Reich P, Ritchie M, and Siemann E (1997) The influence of functional diversity and composition on ecosystem processes. *Science* 277: 1300–1302. bib43

Vitousek PM, Mooney HA, Lubchenco J, and Melillo JM (1997) Human domination of earth's ecosystems. *Science* 25: 494–499. bib44

Willig RD (1976) Consumer's surplus without apology. *American Economic Review* 66: 589–597. bib45