Chapter 1
Introduction

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MOTIVATION

Given the economic importance of wood products in the U.S. South, the value of southern forests as timberlands is well known and acknowledged in State policy decisions. However, timber represents only part of the value of forests, and forestry leaders are increasingly interested in quantifying the full value of the South's forests, i.e., the value of all final ecosystem services produced by forests, including cultural (non-tangible) benefits, regulation of environmental quality, and provision of services (timber and non-timber goods). Recent efforts to quantify forest ecosystem services (FES) at the State level have considered different sub-sets of these services and employed different methodologies (Escobido and Timilsina 2012, Moore and others 2011, Paul 2011, H. Simpson and others 2013), which have limited the credibility of the results, the utility of cross-state comparisons, and the ability to report regional values. To address these issues, this guide describes best practices for quantifying four categories of FES (cultural services, regulation of water quantity and quality, regulation of air quality, and provisioning of non-timber goods) and a framework for estimating the total value of gains or losses due to changes in FES. While these four categories of services have been identified as the most important to stakeholders in the forestry sector in the Southern States, they are not comprehensive, e.g. pollination services are excluded here but discussed elsewhere (Iovanna 2017). In this introductory chapter, we explain the increasing interest in ecosystem services, discuss the motivations for valuation of FES in particular, and place this work in the context of economic accounting.

The primary intended audience for this report is State forestry officials charged with requesting, selecting, guiding, and evaluating the results of FES assessments in their states. We assume prior knowledge only of introductory micro-economics or forest economics. Thus, this report is not intended as a comprehensive guide to actually carrying out an assessment, but rather to obtaining an assessment that is methodologically sound and policy relevant. For readers who are interested in expanding their understanding of approaches used to assess and value forest ecosystem services, we suggest consulting a recent state of the science review provided by the Northern Research Station, U.S. Forest Service (Binder and others 2017).

ANTECEDENTS

Interest in the economic value of changes to natural ecosystems has a long history, beginning in the 1960s (e.g., Clawson 1959, Krutilla 1967) and blossoming in the 1980s and '90s (Banzhaff 2010, Liu and others 2010). The 21st century has brought exponential growth in scientific publications on ecosystem or ecological services (Fisher and others 2009). One catalyst for this growth was a controversial article in the journal *Nature* by Costanza and others (1997), which has been cited over 15,000 times according to Google Scholar. Using benefit transfer techniques (often improperly [Plummer 2009]), Costanza and others (1997) estimated the world's ecosystem services to be worth $33 trillion, $15 trillion more than Gross World Product in 1997. A 1998 special issue of *Ecological Economics* contained eight stinging commentaries on Costanza and others (1997), while a 1998 column in *Nature* (vol. 395, page 430) called the article a "box office success … panned by the critics" and "a political document … of no use for policy analysis or implementation." Costanza and others (2014) conceded that the article was "clearly an awareness-raising exercise with no specific policy or decision in mind," and it certainly did raise awareness both of the value of ecosystem services and of the potential pitfalls in attempting to estimate total values.

In fact, the use of ecosystem service values in policy and management decisionmaking has been limited (Adamowicz 2004, Liu and others 2010, Laurans and others 2013, Rogers 2015). Laurans and others (2013: 241) concluded that the value of ecosystem services typically "receives no more than a cursory reference in the form of an expected, proposed or desired use," while Liu and others (2010: 73) state that "the contribution of ecosystem service valuation to ecosystem management has not been as large as hoped nor as clear as imagined." Recent Federal policy initiatives, however, have generated new interest in using estimated values of ecosystem services as inputs to policy and management decisions (Richardson and others 2015). For example:

- In 2011, a report by the President's Council of Advisors on Science and Technology (PCAST 2011) recommended:
    - establishing a Quadrennial Ecosystems Services Trends (QuEST) Assessment and
    - requiring Federal agencies to include valuation of impacts on ecosystem services in planning and management decisions.
- The U.S. Forest Service 2012 Planning Rule requires evaluation of ecosystem services associated with alternatives for managing the National Forests (USFS 2015).
- In 2013, the White House released "Principles and Requirements for Federal Investments in Water Resources" (CEQ 2013), requiring Federal agencies to use an ecosystem services approach to evaluate Federal investments in water resources.
- In 2015, the Council on Environmental Quality issued a memorandum directing all Executive Departments and Agencies to document how they would incorporate ecosystem services in their activities (CEQ 2015).

Most of these Federal guidelines call for agencies to consider how policy, management, and investment decisions affect flows of ecosystem services, quantified in terms of the value of those changes.

There is also increasing interest in mainstreaming ecosystem service valuation into accounts, or "green accounting." Progress has been made both internationally, e.g., by the G8 (TEEB 2015), the European Union (Brower and others 2013), and multilateral organizations (WAVES 2015), as well as at the State level, e.g., by the Ecosystems Services Working Group (ESWG) in Maryland (USDA 2015) and as reflected in adoption of the Genuine Progress Indicator by 20 States (Ceroni 2014). These efforts typically estimate total values of ecosystem services based on existing valuation literature.

PREVIOUS ASSESSMENTS IN THE U.S. SOUTH

Four Southern States have recently completed assessments of ecosystem services and FES in particular. The scope and findings varied from State to State, as summarized in table 1.1 and described in more detail below.

Following a scoping study by the Virginia Department of Forestry in 2006, the Piedmont Environmental Council funded a Yale University study to estimate the value of all ecosystems in Virginia. Annual ecosystem service benefits from Virginia's forests were estimated to be $15.3 billion ($880/acre/year), as reported in table 2 of Paul (2011). Choosing a narrower scope, the Florida Forest Service commissioned the University of Florida to quantify the most important values generated by forest lands enrolled in the Florida Forest Stewardship Program. The present value of the ecosystem services from the 437,800 enrolled acres was estimated to be $2.07 billion ($5,030 per acre or $151/acre/year at the assumed 3-percent discount rate) (Escobedo and Timilsina 2012). Funded by the Georgia Forestry Association, the University of Georgia assessed the value of all private forest lands in Georgia, resulting in an estimated annual value of $37.7 billion ($1,709/acre/year) (Moore and others 2011). The most recent effort, commissioned, funded, and implemented (with collaborators) by the Texas A&M Forest Service, found Texas' forest ecosystem services to be worth $92.9 billion/year ($1,489/acre/year) (Simpson and others 2013). The wide range in the estimated annual value of ecosystem services generated by an average acre of forest land (from $151/acre/year in Florida to $1,709/acre/year in Georgia) reflects both methodological differences and differences in the value of forests across the four States.

Table 1.1—Previous assessments of forest ecosystem services in Florida, Georgia, Virginia, and Texas

	Florida (Escobedo and Timilsina 2012)	**Georgia** (Moore and others 2011)	**Virginia** (Paul 2011)	**Texas** (Simpson and others 2013)
Value estimate	$2.07 billion ($151/acre/year)	$37.7 billion ($1,709/acre/year)	$15.3 billion ($880/acre/year)	$92.9 billion/year ($1,489/acre/year)
Scope	FSP lands	Private forests	All forests	All forests
Services valued	Water, carbon, timber, habitat	Water, climate, habitat, pollination	Water, carbon, forest products, habitat, recreation	Watershed regulation, climate, biodiversity, cultural values

FSP = Forest Stewardship Program.

One reason for the wide range in values is the different scopes of the studies. For example, the Florida study focused on the value of "the components of forests that are directly enjoyed, consumed, or used to produce specific, measurable human benefits," while the Georgia study used the more general concept of "ecosystem services as the things nature provides that are of direct benefit to humans." The authors of each State study made different choices about which services to include; for example, only Florida and Virginia included timber, and only Georgia and Virginia included pollination services. Most critically for the total value estimates, only Texas and Georgia included estimates of the non-use value of forests (e.g., aesthetic and cultural benefits). However, all studies estimated the value of forests for protecting water quality, regulating water flow, regulating climate change via carbon sequestration, and providing wildlife habitat or biodiversity. Water (including both quality and quantity dimensions) is a key component of the total value in all States: 66 percent in Florida, 54 percent in Georgia, at least a third in Virginia (varying by forest type), and 14 percent in Texas. This is consistent with findings from the stakeholder workshop described below, in which participants identified water as the most important ecosystem service to include in valuation studies.

The four studies varied in their methods. Although all used benefit transfer (or "value transfer") (Richardson and others 2015), the Virginia study only transferred values from published revealed preference studies, while the other studies drew on a much broader literature. All of the studies transferred "unit values" for some services, multiplying the value (or average value) per acre reported in the literature by the number of acres of a given forest type. They varied in how far they were willing to extrapolate values from the literature to different forest types and different locations. For the Florida study, the researchers estimated meta-regressions to obtain values of water and habitat adjusted to conditions in Florida. The Florida study also used the spatial modeling tool InVEST (Integrated Valuation of Environmental Services and Tradeoffs) for water, nutrients, and timber. In Georgia and Texas, original stated preference surveys were conducted to estimate non-use values.

The studies also reflect different approaches to disaggregating forests in order to calculate values. In Georgia, researchers divided private forests into categories based on forest type, riparian status, rare species abundance, scenic visibility, public land buffer, development class, and geographic region. They then transferred values per acre of each ecosystem service from the literature for each category of forest. The other State studies differentiated per acre values differently for each ecosystem service, e.g., using FIA (Forest Inventory and Analysis) forest types for carbon, watersheds or proximity to water for watershed services, and broad regions for other services. In some cases, researchers assumed that the supply of ecosystem services varies across regions, whereas in other cases, the demand was also assumed to vary. For example, the Florida and Texas studies estimated watershed and cultural values by multiplying household willingness-to-pay (WTP) by the number of households living in each region.

MOTIVATIONS FOR QUANTIFYING THE VALUE OF FES IN THE U.S. SOUTH

Often referred to as the "wood basket" of the world, the U.S. South produces over 18 percent of the world's pulpwood and 7 percent of industrial roundwood, generating more than $230 billion in traditional economic output and $48 billion in wages for almost 1.1 million people (SGSF 2013). Southern forests also provide regulatory and cultural ecosystem services, including air and water purification, climate regulation, wildlife habitat, and recreational opportunities. Rapid population growth throughout the South is driving land use changes that put forests at risk, while simultaneously increasing the number of people in the region who value FES. The Forest Service, U.S. Department of Agriculture, forecasts that 23 million acres of forest land will be converted to other uses by 2060 (Wear and Greis 2013). This conundrum of simultaneously increasing threats and values makes it essential to quantify changes in FES in order to better manage change in the forest sector.

To identify the specific motivations and goals for valuation of FES in the Southern States, we reviewed the reports summarized in the previous section and convened a meeting in February 2014 with 38 stakeholders from Federal (3 participants) and State (15) government, NGOs (12), private industry (4), and academia (4) in 10 Southern States. Most (90 percent) participants had more than 10 years of experience in natural resources fields.

The stakeholders all agreed that one key purpose for valuing FES is to increase awareness of the importance of southern forests and the consequences of forest loss. Some hoped that reporting a single (large) dollar value for all FES in a State would catch the attention of the public and policymakers, thus replicating the global influence of the Costanza and others (1997) study at the State level. As noted above, there are concerns about the theoretical validity of this approach and its utility to decisionmakers. In the following section, we therefore review the theoretical basis and mechanics of constructing economic accounts. This leads us to suggest that this objective can best be met by quantifying each FES in physical units, such as percent of drinking water that flows through forests or number of recreation user days in forests, while using valuation to understand changes in FES.

Other goals expressed by stakeholders require understanding how values vary across space and time in order to manage change, specifically by:

1. Improving policy, land use planning, and decisionmaking by quantifying the value of forests relative to other land uses and identifying which forests are most important for which ecosystem services;

2. Catalyzing and supporting the creation of ecosystem service markets by estimating the values of those services; and

3. Reducing the inherent bias of valuing forests (and setting policy) only for commercial forest products rather than by assessing the value of all benefits from all forests.

Of course, each stakeholder group has its own particular concerns. State forestry agencies need to evaluate forest conservation programs. For example, the USDA Forest Stewardship Program (FSP) provides funding to States to help landowners plan and sustainably manage millions of acres of forest land for timber, wildlife habitat, watershed protection, recreation, and other ecosystem services. One goal of a Florida State assessment of FES was to quantify the value of ecosystem services provided by properties enrolled in the FSP. State forestry agencies also must respond to the natural disasters that regularly affect southern forests, including hurricanes, floods, tornadoes, ice storms, drought, and wildfires. The resulting timber losses are well-documented, but methods are needed to quickly and accurately estimate losses of other FES, to help make the case for public assistance for recovery efforts in forests that are not actively managed for timber.

Although decisionmakers in State government have been the primary target audience for FES assessments, conservation organizations and private landowners also find them important. For example, conservation organizations can use the results to direct resources toward properties with high ecosystem service values, while private landowners can use the results to report how their land management affects FES and to guide their transactions in ecosystem service markets (cf., Kareiva and others 2015). Thus, most stakeholder goals require understanding the value of changes in FES resulting from marginal losses or gains of particular types of forest in particular regions.

ECONOMIC ACCOUNTS

Given that all stakeholders expressed interest in an accounting of the total value of FES in their States, we review here how standard economic accounts are constructed and interpreted, as well as the challenges of expanding these accounts to include FES. An accounting total is generally considered to be a "bottom line" measure that summarizes overall performance in a single monetary figure such as gross national product or income, which represents what economists call "utility," or, more broadly, "welfare." This figure is obtained by: 1) assembling data on quantities of "goods and services"; 2) assembling data on the value society attaches to these goods and services, as measured by "prices"; and 3) multiplying the quantity by the price for every good and service and summing over all goods and services.

Assuming that the quantities and values of all final goods and services have been identified and summed, the next question is how to interpret the results. Economic accounts are typically more useful as measures of changes from one year to the next than of any absolute level of well-being. For example, if the national product increased by $300 billion from one year to another, one might conclude that the country is collectively $300 billion (about $1,000 per person) richer than the year before. On the other hand, the national income of the United States is about $17 trillion per year. There is no reasonable basis for saying that we are, collectively, $17 trillion, or about $53,000 per person, better off than we would be if we produced and consumed literally nothing. Would the average American accept $53,000 to do without literally everything for a year? Likewise, we might identify increases or decreases in the acres of different forest types in a State and multiply these by per-hectare values of FES. However, even with good estimates of the per-hectare values, we could not use this procedure to calculate a figure that accurately reflects the consequences of the complete elimination of all forests in the State, i.e., the total value of all of those forests.

Thus, we focus on changes in accounting totals, considering what they reveal about changes in well-being. Economists assume that people make decisions in order to maximize their utility,[1] or the net benefits (welfare) they receive as a consequence of their consumption choices. As shown mathematically in Appendix 1.1, the change in an individual's welfare from one period to the next is just the change in the quantity of each good and service consumed by the individual, multiplied by its price, and summed over all goods and services. Thus, the change in the accounting total is the dollar value of the change in total welfare.

Next, we consider how to aggregate changes in individual welfare over the entire population. The simple answer is to add together the changes in aggregate consumption of each good weighted by its price. While this procedure is straightforward and often used, it has some fundamental problems. When we add up the changes in expenditures over all individuals, and call it a change in aggregate welfare, we are implicitly assuming that everybody has identical reactions to changes in their income (i.e., everyone has the same marginal utility of income). While unverifiable

[1] Or more accurately, people make decisions *as if* they were maximizing utility. According to a standard economic proof, if people prefer some alternatives over others in a consistent way, they behave as if their preferences were determined by a "utility function."

empirically (since utility cannot be observed or measured), it is reasonable to assume that a $1,000 increase in annual income would be much more important and valuable to someone with an annual income of $20,000 compared to someone with an annual income of $200,000. The only theoretical justification for adding up changes in individuals' expenditures to get some notion of the welfare of the population as a whole is the idea of "potential compensation." The "potential compensation" (or "Kaldor-Hicks") criterion holds that if the sum of accounting gains is positive, there is—at least in theory—a way to assure that everyone is made better off by redistributing the monetary gains (Johansson 1993). In practice, changes that increase the overall value of FES may have negative effects on the welfare of some groups even while they have positive effects on the welfare of other groups.

INCORPORATING FES INTO ACCOUNTS

While accounting appears to be a straightforward exercise, incorporating FES presents several complications. First, many goods and services that contribute to our well-being do not have prices that can be observed from transactions in markets. There are two likely reasons why we cannot observe prices for these ecosystem goods and services. One is entirely mundane, but always worth considering. We do not observe prices for things that are not worth much. This is a proposition that may seem at once counterintuitive and commonsensical. It may seem counterintuitive when applied to the goods and services nature provides, because goods and services such as fresh water and flood protection are essential to human life. However, common sense suggests that when small changes in the amounts of goods and services make no difference, they are not valuable. Things command high prices when a little more of them contribute substantially to our welfare, and this, in turn, happens when the things in question are in short supply relative to their demand. Fresh water is essential to life, but it is not very valuable when and where there is plenty of water available relative to the number of people who benefit from it.

The other possible explanation for the lack of observable prices is that the good or service in question is "public" in some or all aspects. A public good is one that is non-rival and non-exclusive. Non-rival means that when one person benefits from the good, it does not diminish the benefits for others. A good is non-exclusive when there is no feasible way to prevent others from benefiting from it. In this case, the value of an additional unit of the good is the sum of its value to all individuals who benefit from it. These characteristics of public goods undermine the functioning of private markets because the prices of any transactions in markets for public goods understate their value. There may not even be any transactions, if no one pays to provide something that confers a relatively small benefit to each of a relatively large number of people.

Non-market valuation techniques have been developed to estimate "prices" for goods and services that are valuable but not traded in markets. The following chapters discuss the most commonly used and appropriate techniques for different categories of FES. However, it is important to recognize that the prices determined through these techniques are highly context dependent. Real estate agents sometimes say that three things determine the price of a property: location, location, and location. Because a home is fixed on the landscape, much of its value is determined by its proximity to places of work, shopping venues, and attractive natural features. Likewise, the value of attractive natural features depends crucially on the number of people who can access them. Moreover, the values of ostensibly similar ecological features may vary tremendously depending on how much is available, now and in the future or under alternative policy scenarios. Market prices reflect this variation for most goods that are bought and sold in markets; the challenge is obtaining "prices" that reflect the local supply and demand for ecosystem services that are not traded in markets.

A second complication with accounting in general, and especially in accounting for ecosystem services, is that not all ecosystem goods and services are things we enjoy directly (sometimes called final goods and services or benefit relevant indicators) (Olander and others 2015). Some, called intermediate goods and services, are inputs required to produce final goods and services. Further, many of these inputs could be considered investments made today in order to produce final goods and services in the future. And furthermore, some of these capital investments may be for the purpose of averting or restoring damages.

The final challenge that we consider here is valuing investments—giving up some consumption now in order to enhance consumption possibilities later. Suppose that we define units so that, by giving up one "apple" now, we can acquire one unit of "capital." Let's suppose that "capital" can be used to enhance our future consumption of "bananas." So, what is the worth of the extra unit of capital we would get by foregoing consumption of an apple? It consists of the products of three things, which are first multiplied together, and then summed over the life of the capital investment:

- The utility derived from the additional banana consumption, times
- The extra banana production, afforded by the additional capital investment, times
- A discount factor that expresses the value of foregoing current consumption to increase consumption in the future.

If a consumer were to decide to eat an extra apple this year, we would multiply that apple by its price and add it to all the other consumption changes, weighted by their prices, in order to estimate the change in welfare. If the consumer forgoes eating an apple in order to grow more bananas, though, she is showing that she regards that investment (or input) to be at least as valuable for her overall welfare as immediate consumption of an apple. Hence, it is reasonable to add to the ledger of changes in welfare the net present value of investment.[2] Assuming that consumers and investors made this calculation in deciding how much to invest, we can simply record the dollar value of investment as a measure of its contribution to well-being.

The calculation of this value is more daunting when considering investments in the production of public goods. Investments and disinvestments in forests may not be made optimally when, for example, a landowner plants trees that store carbon or protect downstream water quality. In this case, we should still record the value of the investment, but we must now estimate values for the public goods of carbon storage and water quality. This requires understanding the "extent of the market," or the size of the population that benefits from these goods. Further, we must calculate these values over the life of the investment. This means, in particular, we must project the marginal value of the public good, the investment's contribution to the provision of that public good, and the discount factor to be employed, over the time horizon of the investment.

Finally, we note that many of the effects of (dis)investments in natural capital are eventually reflected in traditional economic accounts. For example, if clearing forests increases the probability of floods, the damage will eventually be reflected in lost assets or reduced agricultural yields. Thus, part of the motivation for green accounting is to attribute a portion of changes in gross domestic product (or other summary figures) to changes in natural capital. Another motivation is to project the effects of current (dis)investments in natural capital on future well-being. Finally, clearly some (dis)investments in natural capital affect well-being directly and thus are additional to standard economic accounts. To obtain a comprehensive measure of long-term economic performance, we would need to account for all of these future returns to investments.

STRUCTURE OF THE GTR

The following four chapters on cultural (chapter 2), regulating (chapters 3 and 4), and provisioning (chapter 5) services exemplify the different approaches and different levels of information found in the literature. Non-market valuation methods can be categorized as either stated preference, meaning that they are based on surveys that elicit people's values, or revealed preference, meaning that they infer values from prices in related markets. The chapter on cultural ecosystem services describes both stated and revealed preference methods that can be used to estimate the value of these services in particular contexts and for particular populations. The chapter on water services gives greater emphasis to revealed preference methods. The chapter on air quality emphasizes benefit transfer approaches embedded in accounting frameworks for urban forests and for climate change mitigation. The next chapter discusses provisioning of non-timber forest products (NTFPs). Once harvested, NTFPs are private (rather than public) goods, but there are still significant challenges in quantifying harvest and deriving the associated value of the forest provisioning service.

These chapters lay the groundwork for the concluding chapter to discuss aggregation of such highly variable information (across services, forests, and people) and potential pitfalls or red flags involved in doing this. While the four chapters on different categories of ecosystem services describe options for estimating the marginal values of those services, the final chapter considers how to aggregate those marginal values in order to track changes in value over time and project changes in value as a result of policy alternatives. This should be considered both when planning and when reviewing results of an assessment (e.g., when writing terms of reference or assessing deliverables). The concluding chapter argues that FES assessments should account for total flows of ecosystem services from forests (in physical units), but should quantify the marginal value (in dollar terms) of the most likely changes in forest cover. This approach will help steer FES assessments around the numerous possible pitfalls of green accounting.

LITERATURE CITED

Adamowicz, W.L. 2004. What's it worth? An examination of historical trends and future directions in environmental valuation. Australian Journal of Agricultural and Resource Economics. 48: 419-443.

Banzhaff, S. 2010. Consumer surplus with apology: a historical perspective on nonmarket valuation and recreation demand. Annual Rev. Res. Econ. 2: 183-207.

Binder, S.; Haight R.G.; Polasky S. [and others]. 2017. Assessment and valuation of forest ecosystem services: state of the science review. Gen. Tech. Rep. NRS-170. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 47 p.

Brower, R.; Brander, L.; Kuik, O. [and others]. 2013. A synthesis of approaches to assess and value ecosystem services in the EU in the context of TEEB. University of Amsterdam. http://ec.europa.eu/environment/nature/biodiversity/economics/pdf/EU%20Valuation.pdf. [Date accessed: October 6, 2015].

Carson, R.R.; Mitchell, M.; Hanemann, R. [and others]. 2003. Contingent valuation and lost passive use: damages from the Exxon Valdez oil spill. Environmental and Resource Economics. 25: 257–286.

CEQ. 2013. Principles, requirements, and guidelines for water and resources. Council of Environmental Quality. The White House. https://www.whitehouse.gov/sites/default/files/final_principles_and_requirements_march_2013.pdf. [Date accessed: October 6, 2015].

[2] The modifier "net" before value is important. It is certainly possible to make *dis*investments. One way to do this would be by failing to keep up with depreciation. Another is by liquefying capital assets, including natural capital such as forests.

CEQ. 2015. Incorporating ecosystem services into Federal decision-making. Council of Environmental Quality. The White House. https://www.whitehouse.gov/sites/default/files/omb/memoranda/2016/m-16-01.pdf. [Date accessed: December 3, 2015].

Ceroni, M. 2014. Beyond GDP: U.S. States have adopted genuine progress indicators. The Guardian. http://www.theguardian.com/sustainable-business/2014/sep/23/genuine-progress-indicator-gdp-gpi-vermont-maryland. [Date accessed: October 6, 2015].

Clawson, M. 1959. Methods of measuring the demand for and values of outdoor recreation. Washington, DC: Resources for the Future Inc., Reprint, 10. 36 p.

Costanza, R.M.; d'Arge, F.; Degroot, R.; [and others]. 1997. The value of the world's ecosystem services and natural capital. Nature. 387: 253-260.

Constanza, R.M.; Wilson, A.; Troy, S.; [and others]. 2006. The value of New Jersey's ecosystem services and natural capital. New Jersey Dept. of Environmental Protection. http://www.state.nj.us/dep/dsr/naturalcap/nat-cap-2.pdf. [Date accessed: October 9, 2015].

Escobedo, R.; Timilsina, N. 2012. Stewardship ecosystem services survey project. University of Florida. http://sfrc.ufl.edu/cfeor/docs/EcosystemServices.FloridaStewardshipReport.Jul2012.pdf. [Date accessed: October 6, 2015].

Escobedo, F.J.; Kroeger, T.; Wagner, J.E. 2011. Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. Environmental Pollution. 159 (8): 2078-2087.

Fisher, B.; Turner, R.K.; Morling, P. 2009. Defining and classifying ecosystem services for decision making. Ecological Economics. 68(3): 643-653.

Guerry, A.D.; Polasky, S.; Lubchenco, J. [and others]. 2015. Natural capital and ecosystem services informing decisions: from promise to practice. Washington D.C.: Proceedings of the National Academy of Sciences. 112(24): 7348-7355.

Iovanna, R.A.; Ando, S.; Swinton, D. [and others]. 2017. Chapter 1: Assessing pollinator habitat services to optimize conservation programs. Washington, DC: The Council on Food, Agricultural and Resource Economics (C-FARE) Report No. 0114-301b, http://www.cfare.org/publications/valuing-ecosystem-services-from-farms-and-forests. [Date accessed: July 12, 2017].

Kareiva, P.M.; McNally, B.; McCormick, W. [and others]. 2015. Improving global environmental management with standard corporate reporting. Washington, DC: Proceedings of the National Academy of Sciences. 112(24): 7375-7382.

Krutilla, J.V. 1967. Conservation reconsidered. The American Economic Review. 57: 777-786.

Lant, C.L.; Tobin, G.A. 1989. The economic value of riparian corridors in cornbelt floodplains: a research framework. Professional Geographer. 41(3): 337-349.

Laurans, Y.; Rankovic, A.; Billé, R. [and others]. 2013. Use of ecosystem services economic valuation for decision making: questioning a literature blindspot. Journal of Environmental Management. 119: 208-219.

Liu, S.; Costanza, R.; Farber, S.; Troy, A. 2010a. Valuing ecosystem services: theory, practice, and the need for transdisciplinary synthesis. Annals of the New York Academy of Sciences. 1185: 54-78.

Liu, S.; Costanza, R.; Troy, A. [and others]. 2010b. Valuing New Jersey's ecosystem services and natural capital: a spatially explicit benefit transfer approach. Environmental Management. 45: 1271-1285.

Moore, R.; Williams, T.; Rodriguez, E.; Hepinstall-Cymmerman, J. 2011. Quantifying the value of non-timber ecosystem services from Georgia's private forests. Georgia Forestry Foundation. http://www.warnell.uga.edu/news/wp-content/uploads/2011/02/Final-Report-1-24-11.pdf. [Date accessed: October 9, 2015].

Olander, L.; Johnston, R. J.; Tallis, H. [and others]. 2015. Best practices for integrating ecosystem services into Federal decision making. National Ecosystem Services Partnership, Duke University. https://nespguidebook.com/cms/wp-content/uploads/2015/07/es_best_practices_fullpdf_0.pdf. [Date accessed: July 12, 2017].

Paul, A. 2011. The economic benefits of natural goods and services. Report to the Piedmont Environmental Council. http://www.pecva.org/library/documents/Resources-Publications/Reports/Land-Conservation/2011-the-economic-benefit-of-natural-services-report.pdf. [Date accessed: October 6, 2015].

PCAST. 1998. Teaming with life: investing in science to understand and use America's living capital. President's Council of Advisors on Science and Technology (PCAST), Panel on Biodiversity and Ecosystems. https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-teamingwithlife.pdf. [Date access: July 12, 2017].

PCAST. 2011. Sustaining environmental capital: protecting society and the economy. President's Council of Advisors on Science and Technology (PCAST), Working Group on Environmental Capital. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast_sustaining_environmental_capital_report.pdf. [Date access: July 12, 2017].

Plummer, M. 2009. Assessing benefit transfer for the valuation of ecosystem services. Frontiers in Ecology and the Environment**.** **7**: 38-45. http://dx.doi.org/10.1890/080091.

Richardson, L.; Loomis, J.; Kroeger, T.; Casey, F. 2015. The role of benefit transfer in ecosystem service valuation. Ecological Economics. 115: 51-58.

Rogers, A.; Kragt, M.; Gibson, F. [and others]. 2015. Non-market valuation: usage and impacts in environmental policy and management in Australia. Australian Journal of Agricultural and Resource Economics. 59(1): 1-15.

SGSF. 2013. The economic importance of forestry in the South. The Southern Group of State Foresters. http://www.southernforests.org/resources/publications/Forest_Econ_Fact_Sheet_2013.pdf. [Date accessed: October 6, 2015].

Simpson, H.; Taylor, E.; Li, Y.; Barber, B. 2013. Texas statewide assessment of Forest Ecosystem Services. Texas A&M Forest Service. http://texasforestservice.tamu.edu/uploadedFiles/TFSMain/Data_and_Analysis/Contact_Us(3)/Ecosystem%20Services%20-%20TX%20Statewide%20Assessment.pdf. [Date accessed: October 9, 2015].

TEEB. 2015. The economics of ecosystems and biodiversity. http://www.teebweb.org/. [Date accessed: July 12, 2017].

USDA. 2015a. The Farm Bill. U.S. Department of Agriculture. http://www.usda.gov/wps/portal/usda/usdahome?navid=FARMBILL2008. [Date accessed: December 3, 2015].

USDA. 2015b. Spatial quantification and valuation of ecosystem services in Maryland. USDA Research, Education and Economics Information System. http://www.reeis.usda.gov/web/crisprojectpages/0231579-spatial-quantification-and-valuation-of-ecosystem-services-in-maryland.html. [Date accessed: October 6, 2015].

USDOI. 2015. History of Department of the Interior's Natural Resource Damage Assessment and Restoration Program. https://www.doi.gov/restoration/about/history. [Date accessed: October 2, 2015].

USFS. 2015. U.S. Forest Service 2012 planning rule. USDA Forest Service. http://www.fs.usda.gov/detail/planningrule/home/?cid=stelprdb5359471. [Date accessed: October 6, 2015].

WAVES. 2015. Wealth accounting and the valuation of ecosystem services. http://www.wavespartnership.org/en. [Date accessed: October 6, 2015].

Wear, D.N.; Greis, J.G. 2013. The Southern Forest Futures Project: technical report. Gen. Tech. Rep. SRS-GTR-178. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 542 p.

Appendix 1.1

To show that changes in accounting totals are indicative of changes in well-being, we consider how well-being can be expressed in terms of dollars-and-cents figures. First, consider an individual who buys apples and bananas and carrots and a host of other goods numerous enough to go through the alphabet many times over. Her utility, as a function of the number of apples, bananas, carrots, and so on, that she enjoys could be expressed as

$$U\left(x_A, x_B, \ldots, x_N\right), \qquad (1.1)$$

where N is now not the 14th letter of the alphabet, but rather, the very, very large number of different goods and services we enjoy. This expression can be decomposed to write changes in utility from one year to the next as follows:

$$dU = MU_A dA + MU_B dB + \ldots + MU_N dN. \qquad (1.2)$$[1]

In this expression, dU is the difference between the overall level of utility a consumer experienced this year compared to last year, i.e., her change in well-being. It can be decomposed into MU_A, the marginal utility she gets from consuming an extra apple, times dA, the number of apples she consumes this year over and above the number she consumed last year, plus the same calculation for bananas, and so on through all the things she consumes.

While we could measure changes in the quantities of things a person consumes between one year and the next, we cannot measure the extra utility she realizes from consuming a bit more of something (the *MU*'s). We can, though, do a simple trick and use a basic result from economic theory. The trick is to divide all the terms in the expression above by one of the marginal utilities—say, for convenience, the marginal utility of apples:

$$dU/MU_A = dA + MU_B/MU_A\, dB + \ldots + MU_N/MU_A\, dN. \qquad (1.3)$$

The fundamental result from theory is that the ratio of the marginal utilities of any two goods a consumer buys is equal to the ratio of the prices she pays for them; that is,

$$\frac{MU_B}{MU_A} = \frac{p_B}{p_A}, \qquad (1.4)$$

and so forth, for all other goods the consumer buys (recalling that we only have prices for goods that are bought and sold). The argument that this condition holds is a staple of basic economics textbooks and involves a proof by contradiction. If this condition did not hold, the consumer could buy more of the good that provides her with more marginal utility per dollar spent and less of that which provides less, and achieve higher overall welfare for the same monetary expenditure, contradicting the assumption that her choices are optimal.

So,

$$dU/MU_A = dA + p_B/p_A\, dB + \ldots + p_N/p_A\, dN \qquad (1.5)$$

or

$$p_A dU/MU_A = p_A dA + p_B dB + \ldots + p_N dN. \qquad (1.6)$$

[1] In mathematical jargon, expression is a *first-order approximation* to a change in utility. A second (or still higher)-order approximation might be more accurate, especially when the period-on-period changes in quantities are larger, as would likely be the case when the "periods" under consideration are longer. A more accurate approximation would involve the definition of many more terms, however, and would require empirical estimates of own- and cross-price elasticities of demand, which would be a daunting exercise.

Appendix 1.1 cont.

The right-hand side of expression 1.5 consists entirely of things we can observe: the prices of goods and changes in their quantities. To interpret the left-hand side, we need to apply a corollary to the result from consumer theory we just considered. Recall expression, which characterizes the conditions under which a consumer is maximizing her utility given the constraint that she cannot spend more money than her income allows. We can express it equivalently as

$$\frac{MU_A}{p_A} = \frac{MU_B}{p_B} = \frac{MU_C}{p_C} = \ldots = \frac{MU_N}{p_N}. \qquad (1.7)$$

The intuition for this condition is that if the consumer got more additional utility for the last dollar she spent on apples than she did for the last dollar she spent on bananas, she could reallocate her expenditures from bananas to apples and be better off overall. So, if her choices are optimal, she must get the same marginal utility per dollar spent on all goods. That means all the ratios in expression measure the same thing: the additional utility realized from an additional dollar of expenditure. The ratios are all equal to the marginal utility of income: the increase in welfare due to an additional dollar of income.

If we denote the marginal utility of income as MU_y, we now can write expression (1.6) as

$$dU/MU_y = p_A dA + p_B dB + \ldots + p_N dN\,. \qquad (1.8)$$

The left-hand side of this equation is now the dollar value of the change in utility, since units of utility (the dU) are divided by utility per dollar spent (MU_y).

To recap: we asked how we might represent a change in an individual's welfare from one period to the next. We started by decomposing it into changes in how much of each thing she consumes, multiplied by the price of each thing. We then rewrote this as the dollar value of the change in welfare, or change in utility, showing that it is the sum of the prices of goods multiplied by the changes in their quantities, which is just the change in the accounting total.