Integrating Natural Capital into National Accounts: Three Decades of Promise and Challenge

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Introduction

Economists and ecologists have worked for over three decades to better define and measure sustainability—that is, achieving both sustained economic growth and ecosystem health. A key question is "Are a country's natural resources managed equitably and sustainably, both now and for the future?" Answering this question is increasingly urgent given the world's ecological crisis, accelerated by climate change (UNEP 2019) and demonstrated by the facts that a quarter of species face extinction, a quarter of all land has been degraded, and more frequent and severe extreme climate events have occurred. Humanity is nearing ecological tipping points, and over five billion people will lack clean drinking water by 2050 (Díaz et al. 2019).

Given these threats, applying natural capital concepts to inform decisions and better manage social welfare (Ambrey, Fleming, and Manning 2016) and the world's environment (Chaplin-Kramer et al. 2019) is urgently needed. Concepts and tools related to natural capital, natural capital accounting, ecosystem services, and ecosystem assets have been developed to respond to these interlinked economic and environmental concerns.

This article, which is part of a symposium on the Economics of Natural Capital,[1] describes how these concepts and tools have been applied at the national scale. We first provide a short history of natural capital and national accounts and then describe efforts to link natural capital to national measures of income and wealth. We then review the broad challenges faced and

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The authors would like to dedicate this article to the memory of Georgina Mace, who was pivotal to many global efforts to understand how biodiversity and natural capital support human well-being.

[1] The other symposium articles are Polasky and Daily (2021), which provides an introduction to the symposium; Barbier and Di Falco (2021), on agricultural land and living standards in developing countries; and Fisher, de Wit, and Ricketts (2021), on natural capital and human health.

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alternative options for incorporating natural capital into national-scale decision-making. The final section presents conclusions.

A Brief History of Natural Capital and National Accounts

This section introduces the concepts of natural capital, natural capital accounting, and ecosystem services and then provides a brief history of the System of National Accounts (SNA) and gross domestic product (GDP), the most common metrics of economic growth, and their shortcomings. We then describe approaches used for valuing natural capital and ecosystem services, which are fundamental to bringing them into the SNA and other forms of economic decision-making.

Natural Capital, Natural Capital Accounting, and Ecosystem Services

Natural capital is defined as "the naturally occurring living and non-living components of the Earth, together constituting the biophysical environment, which may provide benefits to humanity" (UN 2014a, 13). Natural capital accounting refers to reporting systematically on natural capital stocks and flows (UN 2014a). Ecosystem services are biophysical flows from natural capital stocks from which humans derive benefits, including provisioning, regulating, and cultural services (UN 2014b). Ecosystem assets refer to whole ecosystems providing these services; assets are a stock measure that cannot be divided into constituent parts (UK ONS and DEFRA 2017).

The concept of natural capital was first explicitly defined over a hundred years ago with the observation by Alvin Johnson that "men speak of investing capital in land, as of investing capital in buildings or machinery . . . We shall call the one artificial capital, the other natural capital" (Missemer 2018, 92). The term originally referred to the productive and consumptive value of renewable (e.g., timber, fisheries) and nonrenewable (e.g., oil, natural gas, coal, minerals) natural assets, but over time definitions of natural capital became broader. Ekins and colleagues (2003) defined four categories of natural capital—air, water, land, and living systems—and included nature's ability to absorb negative externalities such as pollution and siltation. Later definitions included broader aspects of nature's intrinsic value (Turner, Badura, and Ferrini 2019b).

While natural capital is a stock, ecosystem services are the biophysical flows from natural capital that benefit people (Mace 2019). The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005)[2] helped develop a typology for classifying ecosystem services. These classifications include regulating services (e.g., filtering pollution, coastal protection, pest regulation, pollination), material provisioning services (e.g., food, energy, materials), and nonmaterial services (e.g., aesthetics, experience, learning, physical and mental health, recreation; Polasky et al. 2019).

However, classifying and quantifying ecosystem services has been contentious as ecologists and economists try to disentangle the values of the ecosystem services delivered directly to people from the value of the underlying ecosystems themselves. As noted earlier, the concept of "ecosystem assets" refers to entire ecosystems that provide services that cannot be divided into

[2] The Millennium Ecosystem Assessment was a four-year global effort beginning in 2001 to assess the condition of the world's ecosystems, the services they provide, and the need for decision makers to better value and protect these ecosystems and their services.

constituent parts (UK ONS and DEFRA 2017). Discussions among ecologists and economists have focused on the overlaps between services and the challenges of assigning values to different users and uses, now and into the future (Hein et al. 2016). The issue of valuation is discussed in more detail below.

System of National Accounts

The SNA, developed in the 1930s, standardized in 1953, and periodically revised ever since, is a globally recognized accounting framework that measures a nation's economic activity. It measures output via market transactions between producers and consumers and arrives at a single measure of total output known as GDP. Economists have long criticized GDP, arguing that its emphasis on output and growth means that it fails to measure welfare and improvements in well-being (Hueting 1992). Here we briefly review key attempts to reframe GDP.

Nordhaus and Tobin (1972) developed the Measure of Economic Welfare, describing the costs associated with damages from environmental problems (e.g., pollution) and urbanization (e.g., congestion, low health standards, land scarcity). Other economists included additional concerns such as intergenerational equity and exhaustible resources (Solow 1974), which lower economic welfare. Daly and Cobb (1989) strengthened the environmental dimension by creating the Index of Sustainable Economic Welfare. This was the basis for the Genuine Progress Indicator (GPI), which tracks 26 economic, social, and environmental indicators (Anielski 2001; Lawn 2003). Meanwhile, Tinbergen, who helped develop the SNA, worked with Hueting (1992) to develop the Environmentally Sustainable National Income Indicator (Tinbergen and Hueting 1992), which was presented at the 1992 UN Conference on Environment and Development (the Rio Summit).[3]

The main criticisms of GDP at the time were that it failed to count environmental degradation and pollution as negative or investments in human capital as positive. In response, the UN revised the SNA in 1993, creating supplemental accounts for energy, water, and land (Harrison 2005). Unsatisfied with this, Hamilton (1994) built on Solow's (1974) work and piloted the genuine or adjusted net savings concept, aimed at improving how natural capital depletion and human capital gains were valued. For development economists especially, it was critical to value the way natural capital benefited future generations and how its depletion represented an economic loss, even if those benefits and losses were not valued in market transactions at the present time (Hamilton 1994).

In 1996, the UN Framework Convention on Climate Change asked countries to report on greenhouse gas emissions and carbon sequestration (Paustian, Ravindranath, and van Amstel 2006). This was the first time many countries had ever analyzed or reported on environmental stocks and flows. In 2007, a European Commission conference concluded that the SNA and GDP should remain unchanged but supplemented with environmental and social progress indicators (European Union 2007). This recommendation was supported by a high-level commission on the Measurement of Economic Performance and Social Progress (Stiglitz, Sen, and Fitoussi 2009).

[3] The 1992 Rio Earth Summit challenged the world to think and act differently, leading to dramatic growth in the literature, indicators, frameworks, methodologies and accounts seeking to integrate environmental concerns into economic development policies, programs, and investments.

The 2008 recession led G20 leaders to build on this recommendation and call for a "new, sustainable growth model" with new "measurement methods" (G20 2009). In 2010, German Chancellor Angela Merkel persuaded the International Monetary Fund, World Bank, and World Trade Organization to complement GDP through supplemental or "satellite" accounts rather than alter it (Daly and Posner 2011). However, development economists pushed back, arguing that having two sets of accounts (traditional national accounts with the GDP output measure and satellite environmental accounts) would not bridge the gap between environmental health and human welfare. For example, Arrow and colleagues (2012) argued that sustainability measures must be based on nondeclining generational well-being; improved wealth accounting; and appropriate shadow prices for renewable and nonrenewable resources, human capital, and health. Despite these and other efforts by some of the world's most prominent economists[4] to integrate sustainability measures into the SNA, their impact has remained largely academic.

Valuing Natural Capital and Ecosystem Services

Valuing natural capital and ecosystem services is essential if they are to be integrated into national accounts (Atkinson and Obst 2017; Weber 2018). This means finding a common measurement unit. National accounts are structured in monetary terms, and productive natural assets such as fossil fuels, minerals, agricultural land, and timber can be easily valued in monetary terms because standard principles of productive asset valuation can be used (Obst, Hein, and Edens 2016; Islam et al. 2019). However, values for other forms of natural capital and ecosystem services are not directly observed in markets. In these cases, to the extent possible, exchange values are used, that is, "valuing the quantity of ecosystem services at the market prices that would have prevailed if the services had been freely traded and exchanged" (UN 2014b, 108).

To better value ecosystem services, many techniques have been developed using exchange values, but techniques differ depending on the ecosystem service being valued, its location, and the scale of the benefits (Freeman, Herriges, and Kling 2014). Examples include pollination, which contributes to agricultural production; carbon sequestration, which is valued using the social cost of carbon dioxide emissions; and water filtration, which is valued for reducing water treatment costs. Global-scale data have been used to estimate total global ecosystem service value (Turner et al. 2012; Costanza et al. 2014), values of specific ecosystem types such as wetlands and coral reefs (Spalding et al. 2017; Davidson et al. 2019), specific services such as pollination (Potts, Imperatriz-Fonseca, and Ngo 2016), and alternative land uses such as agriculture versus forest (Carrasco et al. 2017). Using exchange values, one global estimate shows that the average economic value of global renewable assets (forestry, agricultural land, fish) slightly exceeds that of nonrenewable assets (oil, coal, gas, minerals; Islam et al. 2019).

Since some nonmarket ecosystem service values cannot be determined by approximating exchange values, a wide range of methods have emerged, from nonmonetary to monetary and from qualitative to quantitative (Turner, Badura, and Ferrini 2019b). Atkinson and Obst (2017) identify quantitative valuation techniques that can integrate multiple ecosystem services into a monetary framework, including:

[4] Tinbergen, Arrow, Sen, Stiglitz, Tobin, and Nordhaus are all Nobel laureates in economics.

1. Production, cost, and profit function techniques, used in valuing ecosystem services that provide an input to businesses, such as waste processing, raw materials (e.g., food, fiber), and water purification
2. Hedonic techniques, used to estimate the value of specific ecosystems that affect property markets, such as premium prices for waterfront homes.
3. Techniques using expenditure information, to estimate demand for specific ecosystem services, including defensive spending (such as sea wall construction) and travel costs (to measure recreation).
4. Stated preferences techniques, such as contingent valuation and choice experiments, to produce a demand curve for ecosystem services that provide public goods.

Ecosystem service values that rely on nonmarket techniques are considered inappropriate for national accounting purposes (given the SNA accounting standard cited above), and this limits the potential for integrating them fully (Chee 2004; King et al. 2021). More fundamentally, there are heated debates about including nature's value in economic decision-making at all (Lele et al. 2013; Hein et al. 2016; Costanza et al. 2017). Some argue that valuing nature is inappropriate because its value is effectively infinite (McCauley 2006) or because the complexity, uncertainty, and irreversibility of ecosystem degradation are not addressed by current valuation methods (Chee 2004; Victor 2020). There are also concerns that technological innovations will replace ecosystems, leading to greater environmental destruction (McCauley 2006; Mayer 2019). Yet many researchers have continued to work under the assumption that valuing nature is essential because decision makers ignore goods and services that lack monetized value (Miteva 2019). The next section presents examples of these efforts to value natural capital and ecosystem services.

Integrating Natural Capital with Measures of National Income and Wealth

Efforts to revise GDP by fully integrating nonmarket values of environmental degradation, health, and welfare have not succeeded. Nonetheless, there is important ongoing work to supplement the SNA with satellite accounts and to inform national-level economic decision-making with other indicators. This section explores several such approaches. We first discuss adjusted net savings, the first widely accepted adjustment to national accounts. We then examine the UN System of Environmental-Economic Accounting (SEEA), an approach first published in 2012 and subsequently expanded. Finally, we discuss comprehensive wealth measures and other national-scale approaches that use natural capital concepts to inform assessments of national economic and environmental sustainability.

Adjusted Net Savings

Starting in the 1970s, economists have argued that a country's net national income, which corrects for depreciating fixed capital, should also include net depletion of the country's natural resources (World Bank 2005). Adjusted net savings (ANS), also called genuine savings, makes these adjustments, corrects for changes in human capital from education, and incorporates damages from air pollution and carbon emissions (Bolt et al. 2002). By summing up total annual changes in a country's natural, human, and fixed capital, ANS indicates whether a country is saving for future generations. The advantage of ANS is that its units and terms are clearly understood by economists; a positive value suggests that the present value of social welfare is increasing. However, ANS calculations exclude important natural assets such as water, fisheries, land degradation, and ecosystems. In addition, ANS incorporates only one form of pollution and estimates changes in human capital based on public expenditure rather than learning outcomes (Lange, Wodon, and Carey 2018). Thus, ANS is an incomplete measure of changes in natural capital and an imprecise measure of changes in human capital (Daly and Posner 2011; Howarth and Kennedy 2016).

The World Bank has tracked ANS since 1970. From 1970 to 2014, OECD member countries had declining (yet mostly positive) ANS rates, while in 28 low-income countries, ANS rates declined and often became negative (Barbier 2019). These negative values are a red flag for economic sustainability, as they reveal that countries are inadequately reinvesting current income into any form of capital. Evidence of natural capital degradation is especially problematic for natural resource–dependent countries, and ANS highlights the importance of investing rents from resource depletion into future national savings (Hamilton 2000).

System of Environmental-Economic Accounting

The UN Statistical Commission introduced the SEEA to provide a consistent framework and definitions for measuring the contributions of ecosystems to economic activity. SEEA accounts are based on analyses of natural capital stocks and ecosystem service flows. After years of development, the SEEA Central Framework (SEEA-CF) was published in 2012 and the SEEA Experimental Ecosystem Accounts (SEEA-EEA) in 2014 (UN 2014a, 2014b).[5]

SEEA Central Framework

The SEEA-CF is an international standard for measuring the use of productive assets (i.e., water resources, energy resources, forests, fisheries, agricultural land). It also accounts for the flows of those assets back into the environment in the form of waste, air emissions, and water pollution (UN 2014a). A SEEA forestry account can, for example, track changes in forest assets over time by combining data on forest cover, biophysical modeling of forest ecosystem service flows, and quantities of goods produced through activities that exploit or destroy forests (e.g., Mkanta and Chimtembo 2002). Figure 1 presents a sample SEEA-CF template for physical asset accounts.

SEEA-CF accounts allow for consistent comparisons over time and across countries. To the extent that they are monetized, they can also become satellite accounts in the SNA.

SEEA-EEA framework

The SEEA-EEA framework was launched two years later (UN 2014b). While SEEA-CF accounts focus on the stocks and changes in productive assets such as minerals, timber, and land, the SEEA-EEA measures ecosystem assets and their associated goods and ecosystem service flows. As figure 2 shows, ecosystem physical accounts are divided into ecosystem extent, condition, and services, while ecosystem monetary accounts use the various techniques cited above to

[5] SEEA used alone includes both subcomponents SEEA-CF and SEEA-EEA.

Natural capital asset type		Natural capital accounting entries
Mineral & energy resources Land (inc. forest land) Soil resources Timber resources - cultivated Timber resources - natural Aquatic resources - cultivated Aquatic resources - natural Water resources	For each of these NC asset types ⇐ NC accounts compile data on these stocks and flows ⇒	Opening stock of resources Additions to stock of resources Growth in stock Discoveries of new stock Upwards reappraisals Reclassification Reduction in stock of resources Extractions Normal reduction in stock Catastrophic losses Downwards reappraisals Reclassification Closing stock of resources

Figure 1 Structure of the SEEA-CF physical asset accounts. Source: Modified from UN (2014a).

value both the supplies and uses of the services that flow from these ecosystems. Countries must have comprehensive ecological data, strong statistical expertise, and significant resources to create SEEA-EEA accounts (Hein et al. 2020).

The 2014 SEEA-EEA framework left unresolved many technical challenges related to ecosystem spatial extent, condition, services, and valuation and accounting. A UN-hosted revision process to address these concerns began in 2018 and will report back in 2021 (UN 2019).

SEAA applications

National governments, international organizations, businesses, and civil society organizations use both SEEA-CF and SEEA-EEA. Over 80 national governments have compiled or published at least one SEEA-CF account, and 24 countries have published SEEA-EEA analyses (Hein et al. 2020). SEEA accounts are typically developed by government statistical agencies and used by departments responsible for natural resources, specific geographical areas, or planning. Most national SEEA applications focus on water and forest resources accounts and, less frequently, minerals and energy (Ruijs et al. 2019). The European Environment Agency has developed land, water quality, and fish biomass accounts and pilot accounts for nutrient pressures, biodiversity, and freshwater conditions (European Environment Agency 2018). SEEA accounts have been used to inform reporting on the UN Sustainable Development Goals and the Post-2020 Biodiversity Framework (Miteva 2019; UNEP-WCMC and UNSD 2019).

Given the difficulties in conducting comprehensive environmental valuation, most SEEA applications contain physical but not monetary accounts (Turner, Badura, and Ferrini 2019a). One exception is efforts to link SEEA accounts with computable general equilibrium (CGE) models, although these promising efforts have been narrowly focused, with specific case studies

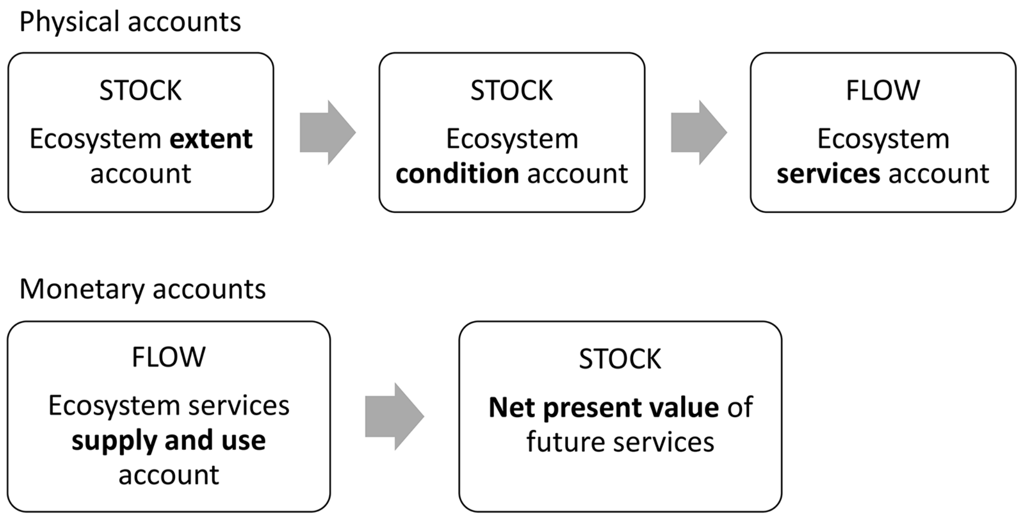

Figure 2 Ecosystem service accounts in physical and monetary terms. Source: Adapted from Bright, Connors, and Grice (2019).

including British Columbia (Ochuodho and Alavalapati 2016), the forestry sector (Banerjee et al. 2019), and Rwanda's land use sector (Banerjee et al. 2020).

The United Kingdom's Office for National Statistics has developed the most comprehensive application of SEEA accounts to date. In 2016, it published monetary estimates for three categories of ecosystem services[6] and estimated a total national net present value of ecosystem services of £958 billion (US$1.22 trillion; UK ONS 2019). Even supporters of this effort acknowledge that "the estimates look low—equivalent to around half a year's GDP"—but note that some ecosystem services were not included in these estimates, such as flood control, human health, and genetic material (Bright, Connors, and Grice 2019, 99). Nevertheless, this effort was deemed useful given that its main purpose was to provide order-of-magnitude estimates and a baseline for tracking trends over time (UK ONS and DEFRA 2017).

While the number of SEEA applications is growing, surveys have shown little evidence of policy impact at the national level (Fairbrass et al. 2020). This likely results from the difficulty of converting SEEA-EEA physical accounts into monetary values, which has limited both account development and their use in discussions of GDP, growth, and economic policy (Boerema et al. 2017; Hime, Sharman, and Cranston 2017). We will discuss these challenges further in the next section.

Comprehensive Wealth Measures

Another approach for incorporating natural capital into national accounts is comprehensive wealth, which was proposed by Arrow and colleagues (2012). They argued that measuring all forms of a country's total capital stock was better than measuring annual income, since capital stocks are required to generate income (a flow). A country's ability to generate sufficient income

[6]The three categories of ecosystem services are provisioning (agricultural biomass, fish capture, fossil fuels, minerals, timber, water abstraction, renewables generation), regulating (carbon sequestration, air pollutant removal, urban cooling, noise mitigation), and cultural (recreation, aesthetics).

for future generations therefore depends on maintaining or growing its total capital base. In addition to valuing productive natural capital, comprehensive wealth measures include such assets as nonagricultural land, nontimber forest products, and protected areas (Polasky, Tallis, and Reyers 2015). However, unlike ANS, which is an annual savings rate estimate that can be compared to the SNA, comprehensive wealth is a measure of total capital stock and does not directly relate to GDP or other SNA indicators.

Both the World Bank (Lange, Wodon, and Carey 2018) and the UN Environment Programme (Managi and Kumar 2018) have developed comprehensive wealth measures. These measures show that natural capital typically declines as a share of a nation's total wealth as it builds other forms of capital (see figure 3). This is because the process of development is largely defined by investing in human and fixed capital (e.g., infrastructure, construction, machinery) and increasing labor productivity. This process is often fueled by depleting a nation's nonrenewable resources and leaving renewable resources overexploited or even extinct. However, as figure 3 also shows, the per capita value of a country's natural capital typically increases even as its share of total capital declines, since its value to the economy and population increases.

Comprehensive wealth analyses lack the detail of SEEA and, as with ANS, do not align with a country's SNA indicators. But they serve as a reliable indicator of the sustainability of a given economy (Cohen et al. 2017). They provide useful information for a country deciding whether to deplete its capital stock to increase current economic activity and welfare or to save it for the future and, ultimately, the well-being of future generations (Barbier 2019). As Daly (2020) argues, if a country degrades its renewable natural capital below a certain point, ecosystem

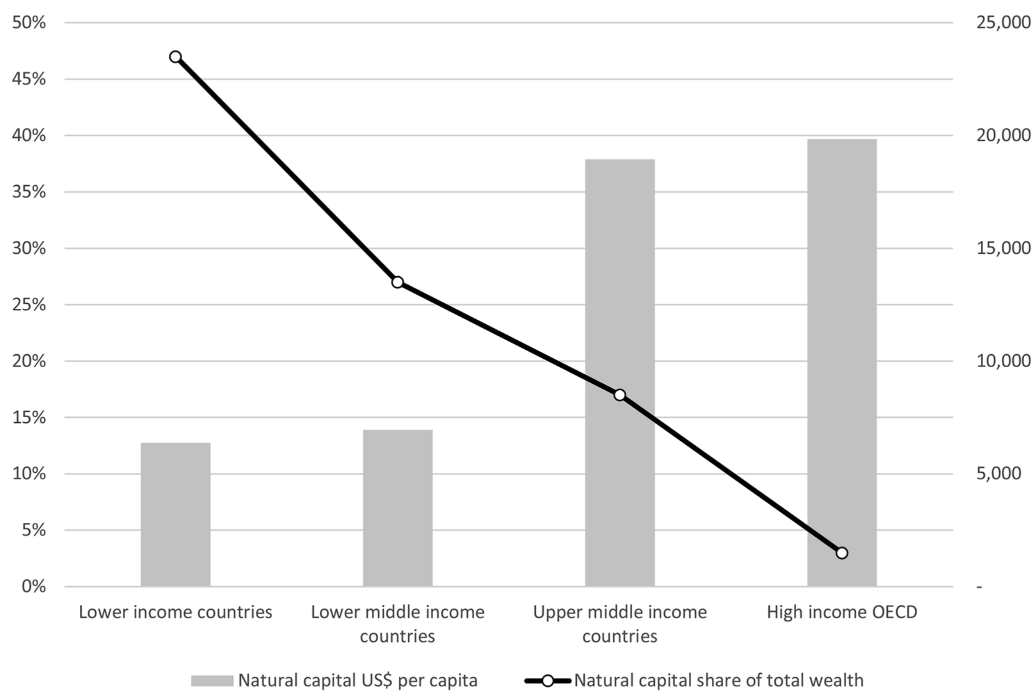

Figure 3 Natural capital: share of total wealth versus per capita value. Source: Lange, Wodon, and Carey (2018).

services are lost, and the country's population cannot sustain itself. Thus, comprehensive wealth measures highlight fundamental macrolevel choices that affect both current and future welfare and natural capital in a way that disaggregated natural capital estimates and accounts cannot (Hamilton and Hepburn 2017).

Other National-Level Assessments of Natural Capital

There are many other approaches to quantifying natural capital at a national scale, each with different methods, data requirements, units of measurement, strengths, and weaknesses. Table 1

Table 1 Other national-level assessments of natural capital

Initiatives	Description
Footprint and biocapacity (Global Footprint Network: http://www.footrpintnetwork.org)	How much of the biosphere's regenerative capacity do humans use (measured in hectares), and how is biocapacity distributed on Earth? Biocapacity is a limiting factor for the global economy; this shows how much you have, use, and trends. Provides a bottom-line answer to a central question: is there enough biocapacity to support the economy? Currently no direct link to financial figures.
Planetary boundaries (PBs; Stockholm Resilience Centre: http://www.stockholmresilience.org)	What are the limits of PBs, and for each one, how close is humanity to those limits? PBs make a scientific global case for multiple dimensions and the possibility of global overshoot. PBs are not easily applicable at the local scale. Each PB can be conveyed, building on independent scientific assessments. Some PBs are global (e.g., carbon dioxide) and others are local (e.g., water, nitrogen). Hard to understand trade-offs among PBs and apply at subplanetary scale.
Material flow analysis (Wuppertal Institute: http://www.wupperinst.org, http://www.materialflows.net	How much mass moves through an economy (kg/per capita/year)? Mass flow is a proxy for the overall amount of resource being used. Easy to grasp. Having good material statistics is key but interpreting or using results to guide policy is not obvious (e.g., 1 kg of gravel has different impact on nature and links to supply than 1 kg of wood).
Carbon footprint (IEA/IPCC: http://www.Ipcc.ch)	How much carbon dioxide from fossil fuel is released in a country (kg/year), including by activity? Much global attention to carbon accounting, yet carbon dioxide is only a subset of broader environmental and ecological issues.
Genuine Progress Indicator (GPI; https://en.wikipedia.org/wiki/Genuine_progress_indicator)	What is the net income of a country, including nonmarket benefits and excluding defensive expenditures? Can be used to adjust GDP but is not part of SNA. Uses monetary units, but only accepted by a few countries and US states. Selecting the 26 indicators to add or subtract from GDP to get GPI is complicated, and valuating each can be arbitrary. Better for macrolevel messaging than policy analysis.
The Economics of Ecosystems and Biodiversity (TEEB; UNEP: http://www.teebweb.org)	What is the economic value of ecosystem services, and how do ecological benefits compare to economic benefits? Powerful case stories applicable to business and policy contexts, but not comprehensive and mostly based on assessments of financial values.

Source: Adapted from Galli et al. (2016).

shows six such approaches. Some are indexes, such as the GPI; others are accounts, such as mass flow analysis and carbon footprint; and still others are modeled data, such as ecological footprint and The Economics of Ecosystems and Biodiversity (TEEB). Clearly, no single approach fully captures the complexity of a country's environmental and economic sustainability, given the diversity of theoretical assumptions, value judgements, and data availability. In fact, Evans, Underwood, and Seidl (2012) compared several of these approaches and found that comparative sustainability rankings across 20 countries varied greatly, implying that each approach may be answering a different question and thus needs to be interpreted carefully.

One notable approach to natural capital measurement is the Chinese gross ecosystem product (GEP; Ouyang et al. 2020). GEP is distinct from SEEA, but analogous to GDP: it uses market prices and modeled surrogate values to calculate the value of ecosystem services and aggregates them into a measure of ecosystem contributions to the economy. One fully monetized provincial GEP account has been completed for Qinghai province. It shows that aggregate ecosystem services values are trending upward, mainly as a result of the rising value of water provided by Qinghai's ecosystems to downstream provinces. This finding raises awareness of nature's value, allows monitoring over time, can be used for policy planning and evaluation, and helps determine financial compensation for ecosystem services provision (Ouyang et al. 2020).

Given the large number of national-level methods and indicators developed in recent years to assess sustainability, Fairbrass and colleagues (2020) have placed them in a framework designed to help national decision makers select the best approach for their needs, capacities, and resources. However, because this framework is new, additional work is required to test its utility.

Challenges of Incorporating Natural Capital into National Accounts

While numerous approaches have been developed to integrate concepts and methodologies related to natural capital and ecosystem services into national economic accounts, challenges remain. These include (1) understanding the complex links between a country's natural capital, ecosystems, and sustainability; (2) improving the quality of data, methods, technical capacity, and institutional coordination; and (3) strengthening the necessary political will.

Challenge 1: Natural Capital: Assessing Complexity, Threats, and Uncertainty

Natural capital concepts and applications are complex. Mace (2019, 61) and others have identified ecosystem complexity as a key challenge to accounting and valuation: "the asset–benefit relationships are complicated, multi-dimensional, multi-scale, and non-linear." For example, while a machine can be deconstructed into component parts, the same cannot be done for ecosystems. An ecosystem's mechanisms are hard to delineate. Most ecosystem services depend on a combination of assets, and most ecosystem assets contribute to many services. Furthermore, an ecosystem's value is greater than the sum of its parts (Maechler and Graz 2020), which hinders efforts to map assets to services. Further complexities arise when the use of a natural asset, such as timber, reduces the flow of other ecosystem services, such as soil retention, recreation, and carbon sequestration. As another example, when peatlands are drained, their agricultural value is improved, but this process generates disservices by emitting significant quantities of carbon dioxide (Obst, Hein, and Edens 2016).

The relationship between biodiversity and ecosystem services is also complicated. Biodiversity is the foundation of a healthy ecosystem, so its loss affects ecosystem assets and flows (Oliver 2015). Although biodiversity is captured implicitly in several components of the SEEA framework,[7] it is not considered an ecosystem service in and of itself (UN 2014b). This means that SEEA measures ecosystem assets and service flows that are generated by healthy ecosystems (see figure 1), but it may undervalue biodiversity's role in supporting resilience and maintaining ecosystem health and productivity (UNEP-WCMC 2015). Recognizing this problem, the SEEA-EEA revision process has established a dedicated subgroup on accounting for biodiversity, due to report back in 2021.

Identifying and assessing threats to natural capital and the uncertainty about how an ecosystem might respond is also difficult. Recent assessments indicate that threats to natural capital are increasing as both direct and indirect drivers of change are accelerating (Diaz et al. 2019; UNEP 2019). Such threats can be proximate (land clearing) or distant (climate change), and there is uncertainty about the speed, extent, and impact of these accelerating threats (Bowler et al. 2020). There is also uncertainty about how changes in natural capital affect ecosystem service flows. For example, Steffen and colleagues (2015) report considerable uncertainty about the specific thresholds of climate change, biosphere integrity, and freshwater use that would trigger abrupt changes in environmental processes. Trisos, Merow, and Pigot (2020) find that wildlife die-offs and ecosystem collapse will likely be abrupt as climate change causes temperature thresholds to be surpassed. In short, ecosystem degradation is often irreversible, leads to sudden collapse, and may trigger broader effects far beyond the degraded ecosystem itself (Lenton 2013). Yet these frightening and lasting impacts are not included in estimates of market- or exchange-based estimates of natural capital value because the risks of abrupt but uncertain changes are not included in valuation methods. This failure to capture ecosystem complexity, threats, and uncertainty undervalues the benefits of investing in natural capital.

Challenge 2: Closing Data, Methodological, Capacity, and Coordination Gaps

The extent and complexity of data requirements, valuation methodologies, institutional capacity, and institutional coordination have hindered the uptake of natural capital applications (Guerry et al. 2015; Boerema et al. 2017; Recuero Virto, Weber, and Jeantil 2018). Below we describe four of these challenges.

Data challenges

Information gaps related to a lack of data and data-sharing between agencies have limited the development of natural capital accounting and hence its role in economic decision-making (Milligan et al. 2014; Hime, Sharman, and Cranston 2017). A review of 28 natural capital-related data platforms highlighted their variability in relevance, accessibility, transparency, and flexibility (GGKP 2020). These findings suggest that there are challenges at multiple stages of

[7] These include land cover, timber, fish, ecosystem extent, ecosystem condition, and local species accounts.

natural capital accounting, from data collection to reporting, analysis, policy application, and use in decision-making. In particular, primary data are rarely collected for natural capital accounting, and it is difficult to use secondary data for the specialized purpose of natural capital assessments (Recuero Virto, Weber, and Jeantil 2018). Additional challenges relate to aligning the geographic boundaries of the data with the requisite analysis. The boundaries of biophysical modeling of natural capital and ecosystem services are typically determined by ecological boundaries, while economic decision-making is typically aligned with administrative boundaries.

Over time, further development of natural capital accounts may catalyze data collection and sharing, and recognition of data challenges may help prioritize data collection efforts (Bordt 2018). Recent efforts to address these challenges include computer-based modeling tools such as InVEST (Natural Capital Project), Co$ting Nature (Kings College London and United Nations [UN] Environment Programme-World Conservation Monitoring Centre), and ARtificial Intelligence for Environment and Sustainability (ARIES; Martínez-López et al. 2019). Other efforts include data platforms such as NatureMap (led by the International Institute for Applied Systems Analysis) and the UN Biodiversity Lab (led by the UN Development Programme). There are also efforts leading up to the 2020 UN Convention on Biological Diversity Conference of Parties to identify the world's most critical natural assets from the combined points of view of biodiversity, climate mitigation, and ecosystem service provision (Watson et al. 2018; Chaplin-Kramer et al. 2019).

Methodological challenges

A second gap that needs to be addressed concerns methodological issues related to natural capital valuation, which, as described earlier, have severely limited efforts to integrate physical accounts into economic decision-making. For example, the challenges of converting the many components of the SEEA-CF and SEEA-EEA frameworks into monetary terms limit their use in mainstream national accounting (Obst, Hein, and Edens 2016). Atkinson and Obst (2017) recommend future work aimed at (*a*) improving valuation methods for specific ecosystems services and their benefits; (*b*) developing methodologies for valuing ecosystem assets, such as the estimation of asset lives, the choice of discount rates, and integration with existing national accounts balance sheet values; and (*c*) promoting extended discussion between national accountants and environmental economists, to increase understanding of the nature of the differences in their approaches to valuation.

Limited government capacity

A third gap is the limited capacity of governments to develop and use information about natural capital (UNEP-WCMC and UNSD 2019). Surveys show that government representatives do not understand how to best implement natural capital applications or how to combine natural capital with existing national environmental statistics (Recuero Virto, Weber, and Jeantil 2018). To address this problem, both the World Bank and UN Statistical Office have long-running technical assistance programs promoting the SEEA approach and its use. Since SEEA is only one of many environmental and economic decision-making tools, policy makers can be overwhelmed by the diversity of approaches. An assessment by the European Environment Agency led the agency to combine SEEA accounting efforts with other analytical approaches such as life cycle analysis, ecosystem assessments, sectoral and economy-wide models, national accounts, and ideas about what environmental status is socially acceptable (EEA 2018). Ruijs and colleagues (2019) found that countries with relatively mature SEEA accounts have had time to develop complementary policy-focused methods and supporting institutional structures and so were better able to integrate a range of environment-related analyses into policy-making.

Lack of institutional coordination

A final gap is the lack of coordination across government agencies and ministries, which is especially important for SEEA approaches. Since SEEA approaches are standardized and implemented by national statistical offices, sectoral policy makers are infrequently engaged and may ignore them in decision-making (Feger et al. 2019). This absence of collaboration between policy makers and the SEEA statisticians has led to a lack of "pull" from policy makers for natural capital accounting information (Vardon, Burnett, and Dovers 2016). Avoiding this mismatch of SEEA supply and demand requires the engagement of finance and planning ministries before and during the development of accounts to ensure that they see natural capital accounting information as relevant to policy making (Recuero Virto, Weber, and Jeantil 2018).

Challenge 3: Lack of Political Will

The third major challenge to scaling up the use of natural capital–related concepts and approaches in economic policy-making is the lack of political support. While environmental economists and ecologists may recognize the need for action to protect critical resources and better understand linkages to GDP (Bright, Connors, and Grice 2019; Chaplin-Kramer et al. 2019; Ouyang et al. 2020), government leaders may not share this view, or they may prioritize other concerns. Yet high-level leadership is crucial to catalyzing and financing the integration of natural capital applications into government decision-making processes (Milligan et al. 2014; Ruckelshaus et al. 2020). One barrier is the perceived risk that natural capital accounting may highlight politically sensitive issues about the rate, value, and economic importance of unsustainable natural capital dependence and depletion (Vardon, Burnett, and Dovers 2016).

As Polasky and colleagues (2019, 5234) note, "The center of gravity in economics remains far removed from the challenge of sustainable development," and economists are much closer to decision-making power in ministries of finance, commerce, and planning than are ecologists. To build political support, Guerry and colleagues (2015) suggest more targeted efforts, such as securing water for cities, coastal development planning, fishery management, corporate supply chains, and infrastructure investment. Garnering high-level political support will require both bottom-up and top-down pressure on national leaders to manage the earth's resources better to benefit current and future generations.

Conclusion

This article has examined how natural capital concepts and applications can be incorporated into national economic policy-making. There are many approaches, ranging from SEEA to other indexes and modeled data tools such as ANS, comprehensive wealth measures, the GPI, and China's GEP. We find that these approaches are often fragmented and incomplete, in terms of both the types of natural capital and ecosystems they include (e.g., water, land, different ecosystem types) and the values they measure (e.g., market vs. nonmarket values). Integration with national economic accounts and analysis has been elusive, if not impossible, given the lack of common metrics and monetary values. SEEA accounts may be too complex, and the requirements for data and capacity too steep, to address many environmental-economic problems in the near term (Narita et al. 2018; Stage and Uwera 2018).

Still, the need for natural capital applications is urgent. Fenichel and Hashida (2019) argue that "economists and natural scientists need to continue to expand collaborative efforts to collect data since measuring economic programmes and valuing natural capital is an inherently interdisciplinary endeavour." Environmental decision-making, given today's growing ecological and climate crises and rapidly changing financing opportunities, needs more timely data and analytics. Other disciplines, such as biophysical modeling, and new data streams, such as social media and citizen science, can dramatically improve data on changes in ecosystem stocks and service flows. However, these newer techniques are still of limited use in economic applications (such as SEEA) that rely on government-collected data, such as environmental expenditures, production of environmental goods and services, and flows of environmental taxes and subsidies.

Ideas raised by Nobel prizewinners almost 40 years ago related to improving GDP to better reflect environmental and welfare concerns remain unrealized for conceptual, empirical, and political reasons. The question "Is it better to adjust or supplement GDP?" has been answered in favor of supplements, not adjustments. While the need to fundamentally rethink GDP is still important, the need to proceed with practical approaches to analyze today's environmental problems is more urgent. Alternatives for incorporating the value of natural capital into economic decision-making, such as those outlined above, are vitally important and more accessible to countries where data, capacity, and political will for formal natural capital accounting are lacking.

Helm (2019, 1) argues that "natural capital is a concept whose time has come" and challenges practitioners to ground "the objectives in positive freedom and the entitlements of future generations" (11). Ultimately, advancing reforms to GDP, and making natural capital approaches part of the economic mainstream, will be a political process—one that makes it more and more difficult for politicians, business leaders, and the media to hide behind GDP growth while ignoring deteriorating ecosystem health, declining living standards, decreased well-being, and unsustainable environmental impacts (Howarth and Kennedy 2016).

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