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Extending the production boundary of the System of National Accounts (SNA) to classify and account for ecosystem services

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ABSTRACT
There is a broad acceptance to depicting the relationship between ecosystems and human well-being using the concept of ecosystem services, emanating in large from the findings and research published in the Millennium Ecosystem Assessment in 2005. While the generic concept of ecosystem services provides an excellent platform for discussion, the ongoing lack of clarity surrounding the definition, classification and measurement of ecosystem services, is emerging as a barrier to more extensive collaboration across disciplines.

This paper applies the principles of national accounting to bring additional rigor and consistency to the discussion on ecosystem services. In this paper we revisit four fundamental aspects of the System of National Accounts (SNA) that underpin the measurement of the economy, namely, the definition of economic units; the definition of production; the recording of transactions and the recording assets. By considering each of these aspects in the context of the United Nations’ System of Environmental-Economic Accounting, the paper presents a framework to describe the relationship between ecosystems and human activity that can then be used to consistently define, classify, measure and account for ecosystem services.

Introduction

Over the past 10–15 years there has been a significant amount of work that has focused on defining, classifying and measuring ecosystem services. This work has been driven by the need to demonstrate the importance of the environment (natural capital or ecosystems) and the contribution it makes to social and economic wellbeing in the form of ecosystem services.

A broad acceptance of the relationship between ecosystem services and human well-being exists, emanating in large part from the research commenced by the Millennium Ecosystem Assessment (2005). To embed this relationship into financial and economic decision-making, a fundamental requirement is to measure and report this relationship using a fully integrated conceptual framework.

A number of approaches have been proposed, each encompassing the key components of ecosystems, ecosystem services and human well-being in different ways (Haines-Young and Potschin 2010). However, a recent study (Cruz-Garcia et al. 2017) highlighted that most approaches assume ecosystem services and well-being are interlinked without explicitly testing the strength of this hypothesis or providing a model for application across all ecosystem services. Further, their study concluded that trade-offs and synergies among different ecosystem services and the links to specific population groups were understudied.

Looking across these approaches there is still a lack of agreement on the boundaries a model should apply for measurement and reporting purposes including (i) spatial boundaries; (ii) the nature of the boundaries and connections to other systems (e.g. the economic system); and (iii) the fundamental boundaries and links between ecosystem services and human well-being. This lack of agreement has limited the potential for the collaboration and exchange of information and, most importantly, limited the wider uptake of ecosystem services thinking in policy and decision-making. Consequently, policy and decision makers can choose to ignore the concept of ecosystem services entirely since experts do not speak with a common language, or they are able to select a decision-making framework based on political drivers rather than necessarily good science and replicability.

However, the lack of clarity and consistency with respect to boundaries has not hampered the generation of independent approaches to the measurement and assessment of ecosystem services (Chaudhary et al. 2015; Hanna et al. 2018). Across the continuum of perspectives on ecosystem services, and indeed recognizing the many ways in which the ecosystem services concept can be applied (Pascual et al. 2017), there is strong agreement that the measurement of ecosystem services is important because it provides a means to describing the essential and multi-faceted relationship between human activity and the biophysical world in which we live.
The premise of this paper is that the discipline of accounting can provide a means to bring additional rigor and consistency to the measurement and reporting of ecosystem services, particularly in the context of integrating ecosystem services into discussions on finance and economics that are often at the heart of decision making. This paper builds on the work on ecosystem accounting that has been occurring under the banner of the United Nations’ System of Environmental-Economic Accounting (SEEA) (United Nations et al. 2014b).

The SEEA is a statistical accounting standard for integrating environmental and economic data that is built on the principles of national accounting as reflected in the United Nations’ System of National Accounts (SNA) (European Commission et al. 2009). The SEEA applies the same principles that are used for the standardized measurement of the economic system around the world, headlined in the measurement of Gross Domestic Product (GDP). Of course, the limitations of the SNA since its development around World War II are widely known and indeed the limitations of its ability to describe the linkages between economic and environmental systems was the motivation for the original development of the SEEA (Bartelmus 1989).

However, from the perspective of data organization and policy influence, the national accounts must be considered a success. There are large and regular government outlays allocated for the collection and processing of economic data to measure the structure and growth of economies, and policy makers work with a common understanding of, and information about, concepts such as corporate profits, investment, wages, production and consumption. The measurement boundaries for, and interactions between, institutions (economic units) are commonly understood and broadly adopted to ensure that polices and decisions can be critically analyzed.

The application of national accounting principles to ecosystems and ecosystem services measurement is not new. Examples include the literature on extensions to wealth accounting (Barbier 2013), the connection of ecosystem services to GDP (Boyd and Banzhaf 2007), and, most comprehensively, work to extend the United Nations System of Environmental-Economic Accounting (SEEA) to incorporate ecosystem assets and services (United Nations et al. 2014a; Obst, Hein, and Edens 2016; Edens and Hein 2013). Work continues to advance the SEEA ecosystem accounting framework through many initiatives around the world (United Nations Statistics Division 2018). In March 2018, a global process was commenced to standardize as many elements as possible of the initial SEEA Experimental Ecosystem Accounting (SEEA EEA) (United Nations et al. 2014b). This paper responds directly to various elements of the research agenda of the global process, which includes advancing the understanding and language on the precise boundary between ecosystems and economic units and improving consistency on the measurement and accounting for ecosystem services.

To describe a pathway forward, this paper revisits four fundamental aspects of the System of National Accounts (SNA) that underpin the measurement of the economy, namely, the definition of economic units; the definition of production; the recording of transactions and the recording of assets. By considering each of these aspects in the context of the SEEA’s ecosystem accounting framework, we present a conceptual framework that clarifies an appropriate production boundary for measurement of ecosystem assets and their services and supports full integration with economic data as presented in the SNA.

System of environmental-economic accounting (SEEA)

Work on the SEEA commenced in the early 1990s culminating in the adoption of the SEEA Central Framework as an international statistical standard in 2012 (United Nations et al. 2014a) and the SEEA Experimental Ecosystem Accounting (SEEA EEA) (United Nations et al. 2014b). The latter is the first description of a framework for the integration of ecosystem services and measures of ecosystem extent and condition with the national accounts. A more complete history of the development of the SEEA is presented in Obst and Vardon (2014).

The SEEA work on ecosystem accounting builds on developments in ecosystem services measurement over the past 10–15 years. This includes the work of Haines-Young (2010) which used a “cascade model” to distinguish between ecosystem services and the associated benefits following the work of the Millennium Ecosystem Assessment (2005). An important element of the work was the description and classification of ecosystem services into four broad groups including provisioning, supporting, regulating and cultural. Related work has looked at: clarifying the boundaries between final and intermediate services (Wallace 2007; Fisher, Turner, and Morling 2009; Boyd and Banzhaf 2007); determining appropriate classifications of

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1. See Annex 1 for examples of initiatives by agencies including the UK, Netherlands, Conservation International, EU Measuring and Assessment of Ecosystem Services (MAES), World Bank Wealth Accounting and Valuation of Ecosystem Services (WAVES) and the UN Statistics Division.

2. See https://seea.un.org/content/seea-experimental-ecosystem-accounting-revision.
ecosystem services (Brown, Bergstrom, and Loomis 2007; Costanza 2008; Haines-Young and Potschin 2010; Landers and Nahlik 2013); delineating spatial areas for the measurement and analysis of ecosystem services (Andersson et al. 2015); understanding the connection between the underlying biophysical structure and processes and the supply of a given ecosystem services through spatially explicit models (Morse-Jones et al. 2011); and distinguishing the notion of “process” (referred to the operation of the ecosystem) from that of “capacity” (pertaining to the supply of specific services) (La Notte et al. 2017).

The SEEA EEA has proved a successful platform for global exchange of theory and practice in measurement, highlighting the need to record both ecosystem services and ecosystem assets (reflecting the stock and flow elements of accounting). However, a key gap in current models is the way in which the measurement of ecosystem services should be aligned with the measurement of goods and services produced by economic units as recorded in the national accounts.

Building on discussions on ecosystem accounting over the past 5 years as well as related research, this paper describes a framework for the full integration of ecosystem services with the national accounts. The approach taken is to present the most relevant national accounting principles and then demonstrate the extent to which these principles have been applied in the most common forms of environmental accounting namely accounting for environmental flows such as water, energy and GHG emissions. A particular feature of that discussion is the articulation of an environmental units model that, in conjunction with the national accounting principles, permits the integration of ecosystem services to describe a comprehensive framework. The remainder of the document discusses the main conceptual barriers that are resolved through the use of the framework and provides some examples of the application of the framework.

**SNA accounting features**

There are four fundamental principles of national accounting that provide the basis for recording and determining consistent accounting treatments. They are: (i) the definition of institutional (economic) units; (ii) the definition of production; (iii) the recording of transactions; and (iv) the recording of assets. Each of these principles is explained briefly in this section and reflect the national accounting treatments described in the SNA (European Commission et al. 2009).

**SNA economic units**

The SNA is built on recording and aggregating information about individual units within the economy. In the SNA, these are strictly referred to as institutional units but are referred to here as economic units for ease of exposition. In the SNA, economic units are considered from two perspectives. One perspective reflects a unit’s legal, institutional and behavioral aspects. From this perspective economic units are classified, following SNA guidance, to one of five primary institutional sectors: non-financial corporations, financial corporations, general government, households (including unincorporated businesses) and non-profit institutions (European Commission et al. 2009). This perspective is most relevant when considering the ownership of assets, economic returns on assets and financial assets and liabilities.

The second perspective on economic units reflects the type of productive activity that a unit undertakes and leads to the grouping of units by industry type. Thus, at the highest level of industry aggregation, economic units can be grouped according to activities such as agriculture, manufacturing, retail trade and professional services. In the regular measurement of economic activity, reflected in measures of gross domestic product (GDP), it is the production perspective of economic units that is most commonly considered and reported.

At the heart of both perspectives is the concept of a single economic unit that is observable in the economy and distinguishable from other economic units. Each unit has a defined measurement boundary and forms the fundamental building blocks of economic measurement. In many countries, a register of economic units is maintained to ensure that economic surveys and administrative data collections have the most complete coverage possible.

With respect to accounting for ecosystems and ecosystem services and the application of national accounting principles, it is relevant to establish ecosystem units that are distinguishable from economic units and incorporate perspectives of production and institutional context. Most importantly it is necessary to establish the boundary between economic units, ecosystems and ecosystem services for measurement and reporting purposes.

**SNA production**

An economy is defined for measurement purposes by the set of economic units that are resident within a specified economic territory (European Commission et al. 2009). This is usually a country, but conceptually the principles can be applied at all spatial scales. Economic activity, as defined by GDP, is measured in relation to the productive activity of each of these economic units. In broad terms, the concept of production can be described as involving the production of goods and services by combining labor and capital that is sold to other economic units (European Commission et al. 2009). However, since there are
many different roles that economic units perform ranging from manufacturing, distribution and retail, to finance and government services, various treatments and conventions have been developed to ensure the definition of the production boundary is precise and measurable.\(^3\)

The key aspect of the definition of production in the SNA that is relevant to accounting for ecosystem services is that production reflects a process in which capital and labor are combined with intermediate inputs (i.e., other goods and services such as electricity and paper) to produce goods and services. Therefore, the SNA production boundary is defined not only in relation to the goods and services that are the result of the production process—the outputs—but also in relation to the nature of the production process that leads to the creation of those goods and services. For example, the output of meals is considered production in the SNA when made in a restaurant but is excluded from production when made at home. Knowing both the output (meals) and the nature and context of the production process (business versus household) is essential in understanding and applying the production boundary.

The application of these two aspects of production leads to the explicit exclusion from the SNA production boundary of outputs that are created as a result of purely natural processes (European Commission et al. 2009).

By way of example, the time of recording of the output of timber resources is different in those situations where the timber is harvested from natural or unmanaged forests and those where the growth of the timber resources is managed or cultivated, e.g. plantation forests. In the former, production is recorded at the time of harvesting the timber while in the latter production is recorded on a continuous basis as the timber grows.

Applying the concept of the SNA production process is a very useful starting point when considering ecosystem processes and how they may be treated in accounting terms. As well, full integration of ecosystem services with the national accounts requires alignment with the SNA production boundary, and the measurement and reporting of ecosystem services as inputs to the production process.

**SNA transactions**

The definition of economic units and the production boundary provides a framework for the measurement and recording of transactions. Transactions in goods and services are the most common focus for measurement since they comprise the elements for reporting on changes in economic activity.

The majority of transactions recorded in the national accounts are transactions undertaken in monetary terms—i.e. a good or service is exchanged for payment in monetary terms between two economic units. However, because the production boundary is not defined with respect to the use of money, there are situations in which it is necessary to record transactions where no monetary payment takes place. The case of subsistence agriculture is one example, where households produce and consume their own agricultural output. Here, the national accounts impute a transaction within the economic unit. Without recording this transaction both the actual production and consumption would be missed. Perhaps, the most significant example in many economies is the transaction in rent that is imputed for households that live in a dwelling they own. Again, there is a transaction that is imputed between the household economic unit as a producer and the household as a consumer.

Two key features emerge that are of particular relevance in accounting for ecosystem services. The first is that since the national accounts principles do not rely on the existence of a monetary payment, there is an opening to consider ways in which national accounts principles can be applied to account for ecosystem services, given that these services are not normally paid for in monetary terms. Secondly, building on the approaches that have been developed to account for non-monetary transactions in the SNA, the potential exists to impute transactions between ecosystems and economic units and hence build a broader, more integrated, system of accounting that encompasses both economic and ecosystem service flows.

**SNA assets**

The final SNA accounting principle introduced here concerns the recording of stocks and changes in stocks of economic assets. Economic assets come in a range of types including produced assets, inventories, natural resources (e.g. timber, fish, minerals), non-produced intangible assets (e.g. brands, patents, goodwill) and financial assets (European Commission et al. 2009). The stocks of these assets may change through investment, depreciation, or catastrophic loss among many other reasons.\(^4\)

The common feature of economic assets is that they are included in the accounts by virtue of providing the owner or manager of the asset, the economic

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\(^3\)Readers are referred to SNA 2008 Chapter 6 for a detailed description of the production boundary underpinning the measurement of GDP.

\(^4\)SNA 2008 Chapters 10 and 13 provide a thorough description of the scope, definitions and accounting treatments of stocks.
unit, an expectation of receiving benefits in the future (European Commission et al. 2009). Economic benefits are the economic returns received by the owner of the asset either through income generated from the asset (e.g. net income from production by using machinery, equipment, buildings and land; interest income from financial assets) or through the asset holding a re-sale value—where the expected sale price reflects a future economic benefit. The combination of ownership by economic units and the flow of future economic benefits describes the SNA asset boundary, i.e. the set of assets that are included in SNA-based measures of wealth.

With respect to ecosystems and ecosystem services, application of the current SNA boundaries will mean that the benefits arising from the flows of many ecosystem services are not included in SNA-based measures of wealth since they are not considered economic benefits. By way of example, a forest ecosystem will have value in the national accounts to the extent that the timber resources it holds provide economic benefits to economic units. However, the supply of air filtration services will not be included as an economic benefit since this activity is outside the scope of the definition of income from production. Hence, the total value of the forest will not incorporate the value of this ecosystem service in a standard national accounts treatment. In this situation, it is the definition of the production boundary that determines the scope of economic benefits and hence the measurement of wealth. This tight connection between the production boundary and the asset boundary is fundamental from a national accounting perspective but commonly unappreciated when considering the integration of ecosystem stocks and flows into the national accounting system.

Therefore, a framework that accounts for ecosystem services must also provide a logic for the extension of the asset boundary. Indeed, this goes beyond the measurement of wealth but also to the core accounting notions of investment and depreciation. Investment and depreciation are flows that relate to changes in assets. To the extent that some parts of the value of an ecosystem asset are excluded from the asset boundary, then measures of investment and depreciation (or degradation in the case of ecosystems) will be similarly affected. In short, to achieve a common goal of the early founders of the SEEA and produce degradation adjusted measures of GDP, the conceptual framework must accommodate both production boundary and asset boundary considerations.

The following two sections describe the application of these four key national accounting principles to accounting for ecosystem services and assets. Following the logic above, the initial focus is on defining relevant units for ecosystem accounting and then proceeding to discuss the application of the concepts of the production boundary, transactions and assets.

**Defining units for ecosystem accounting**

One of the key features of the SEEA Central Framework is accounting for physical flows between the economy and the environment as depicted in **Figure 1**. Here, the economy is defined by the set of outputs (i.e. goods and services) within the standard SNA production boundary. The additional flows recorded in the SEEA Central Framework are natural inputs and residuals. The physical flows of natural inputs and residuals are accounted for in physical supply and use tables and examples include accounts

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**Figure 1. Physical flows in the SEEA Central Framework, Source: UN et al 2014a, Figure 2.1.**
for flows of water, energy, greenhouse gas (GHG) emissions, solid waste, and elements such as nitrogen and phosphorous.

The SEEA Central Framework describes various accounts for recording flows between a standard set of economic units (as described in the previous section) and the environment, where the environment is effectively considered as a single unit, without spatial specificity or variation. This framing of the connection between the environment and the economy is sufficient for the purposes of the SEEA Central Framework since the broad aim is to start from the perspective of the economy as a distinct system and record the interactions between it and the environment. In physical terms, for any single type of flow (e.g. water, energy, GHG emissions), the SEEA Central Framework applies mass balance recording principles which also ensures a balance between supply and use as required for national accounting.

The definition of units for ecosystem accounting is presented in this paper as an extension to the SEEA Central Framework. In this paper, rather than treating the environment as a single unit that supplies and receives all environmental flows from the economy, the aim is to partition the environment into multiple, ecologically meaningful and mutually exclusive units. This partitioning is completed in two stages.

In the first stage the environment is separated into four primary layers. Figure 2 shows a stylized portrayal of these layers, namely the atmosphere, the biosphere, the regolith and aquifers. The atmosphere includes gases that are around the earth and processes including the transfer of heat from the sun, weather, smog and haze, climate and rain. The biosphere is the zone of the earth and adjoining parts of the atmosphere in which plants and animals exist. The regolith refers to the rocks and soils on the crust of the earth. Aquifers (confined and unconfined, saturated and unsaturated, isotropic and anisotropic) contain groundwater which flows through the spaces between grains of soil or rock, connects with rivers, streams, lakes and wetlands and feeds trees and vegetation.

In the second stage, each layer is divided up into units. For example, the atmosphere can be divided into airsheds, aquifers into artesian basins, and the regolith into areas based on soil types. The focus in this paper is on the biosphere as the basis for the delineation of mutually exclusive (in spatial terms) ecosystem units. Figure 3 gives a stylized portrayal of the different units.

Before discussing the delineation of ecosystem units in more detail, it is important to recognize that the same mass balance and accounting principles that underpin the physical supply and use tables of the SEEA Central Framework, can be applied to compile extended supply and use tables that record the physical flows between all the different environmental layers and units (both vertically and horizontally), and with economic units. Further, the recording of these physical flows can be combined with the recording of stocks of the specific substances or elements that are present in any unit at a point in time. This combination of recording stocks and flows for a given substance or element including between different environmental units is reflected in two SEEA accounts—the water resources asset account (United Nations et al. 2014a) and the carbon stock account (United Nations et al. 2014b).

As introduced above, the delineation of ecosystem units for use in ecosystem accounting, requires partitioning of the biosphere. In the same way that economic units can be delineated on the basis of their different production and ownership characteristics, ecosystem units are delineated, in a large part, on the basis of having different biophysical characteristics (e.g. vegetation cover, ecological structure) performing different environmental functions. It is assumed that within each ecosystem unit the ecological structure is relatively homogenous, and that the unit can be differentiated from its neighbors. Depending on the purpose, there may be interest in delineating ecosystem units using more than vegetation and incorporating additional information, for example, on the regolith (soils). In this model, this can be achieved through integrating environmental units for two layers, the biosphere and soils.

Ecosystem units can be delineated in greater or lesser detail, reflecting the application of a classification of ecosystem types. That is, each ecosystem unit is classified to a single ecosystem type such as a forest, wetland, grassland, etc. Since the broad aim in ecosystem accounting is to encompass all areas within a country, then by extension, the delineation of ecosystem assets extends well beyond what might be considered purely natural areas to incorporate agricultural and urban areas for example. Further, the principles of delineating units as spatial areas as described here can be applied to marine and coastal areas and inland waters. In principle, this approach
can be used to establish a global set of mutually exclusive ecosystem units for accounting purposes.

An SNA based approach to accounting for ecosystem services

Extending the SNA production boundary

The idea that ecosystem units might be considered producing units was discussed in SEEA EEA Chapter 6 as a possible means by which ecosystem units and ecosystem outputs might be integrated with the SNA accounts. In that chapter, and also in Edens and Hein (2013), the producing unit approach was discussed alongside an approach in which ecosystems are treated as assets owned or managed by an existing economic unit (e.g. farms managing agricultural ecosystems). However, neither the SEEA EEA nor Edens and Hein provided a complete solution as to how the production boundary could be extended in line with the SNA. In this section we apply the national accounting principles discussed above to describe the connection between ecosystem units and SNA production. Two features are key to making this connection:

- First, each ecosystem unit is considered a producing unit that supplies ecosystem services, analogous to the production perspective of economic units described earlier.
- Second, the supply of ecosystem services is understood to be the outcome of ecological processes that reflect the ecological structure and function of the ecosystem unit. These processes can be considered analogous to the production processes of economic units.

The extension to recognize ecosystem units as additional producing units (i.e. additional to the standard set of economic producing units) provides the basis for recording the output of ecosystem units as additional production. Thus, flows of ecosystem services can be recognized as additional outputs from a larger set of producing units and, most significantly, the production boundary of the SNA is extended. The effect of this treatment is to define an extended production boundary that considers natural and ecological processes as being included alongside measures of standard economic output.

The extensions described here recognize ecosystem units as separate producing units while remaining consistent with national accounting principles and can be justified on the following grounds.

(1) There are no limits in national accounting on the inclusion of additional units. The recording of transactions is unaffected, conceptually, by the number of units within scope of a set of accounts. It is true that where there are more units there are more transactions to be recorded, but the underlying accounting principles are unaffected. The inclusion of additional units is also consistent with common practice in corporate accounting where large firms identify cost or profit centers and thus record (internal) transactions with other parts of the business.

(2) It is aligned with the current treatment of owner-occupied housing in the SNA. For this activity, the houses/dwellings are effectively producing units that deliver services to economic units, i.e. households. These units do not utilize labor as an input and hence the supply of services completely reflects outputs attributable to the underlying asset. For ecosystem accounting, the soil and the ecosystem can be treated in the same way. They are both providing services to economic units, say a farmer.

(3) It allows for the recording of the supply of multiple ecosystem services from a single ecosystem asset to multiple units (i.e. to both economic and other ecosystems). This is quite different from standard accounting approaches to accounting for assets which effectively assumes that each asset provides a single service to a single user. Considering ecosystem assets as under the total management of a single existing economic unit thus

Figure 3. Stylised portrayal of ecosystem units.
requires a reworking of accounting entries to allow for multiple ecosystem outputs.

(4) Although not at all widespread, there are emerging situations in which ecosystem units are being recognized as distinct entities in law (Charpleix 2018; Zimmer 2017). This builds on initial thinking in legal circles on this point from Stone (1972). The recognition of ecosystems as distinct entities for accounting purposes is a natural corollary to recognizing an ecosystem as having legal rights. By extension, giving an ecosystem legal rights infers that it needs to be accounted for as a legal entity and as one which engages with other legal entities, including economic units.

**Recording transactions in ecosystem services**

According to the SNA 2008, economic flows encompass the creation, transformation, exchange, transfer or extinction of economic value; and reflect changes in the volume, composition, or value of an institutional (economic) unit’s assets and liabilities (European Commission et al. 2009). A transaction is a type of economic flow that is either an interaction between institutional (economic) units by mutual agreement or an action within an institutional (economic) unit that is analytically useful to treat like a transaction, often because the unit is operating in two different capacities. Examples of this second type of transaction include depreciation, subsistence agriculture and own account capital formation.

For ecosystem services, building on the extension of the production boundary just described, recording additional output, or supply, must imply recording additional consumption or use. Consistent with the treatment of all other production of goods and services, this requires the recording of transactions in ecosystem services between the supplying unit, in this case the ecosystem unit, and the receiving unit.

Where the receiving unit is another ecosystem or environmental unit then the ecosystem service should be considered intermediate. Where the receiving unit is an economic unit then the ecosystem service should be considered final. Therefore, the same type of ecosystem service, say water provisioning, can be either final or intermediate depending on the type of receiving unit. This is completely analogous to the treatment of goods and services in the SNA. For example, the purchase of bread by a household is treated as final consumption, whereas the purchase of bread by a restaurant is treated as intermediate. Trying to limit the conceptual framework for ecosystem accounting to only final ecosystem services, necessarily implies limiting the view of ecosystems as producing units and thus limits the potential to see the application of a more complete ecosystem accounting treatment and fully encompass the role of ecosystem units.

Recognizing ecosystem services as transactions between ecosystem units and economic units is significant since it permits the seamless application of all relevant accounting principles concerning production, consumption, income and assets. In this regard, the approach described here does not treat ecosystem services and related ecological functions as special or unique. Rather it abstracts from these ecological realities (while still ensuring their influence) and considers ecosystem units to be operating alongside the mix of different economic units. To be clear, there is little homogeneity in the context of economic units—units involved in agriculture, construction, manufacturing, retail, finance and entertainment all have distinct production processes. Incorporating ecosystem processes as simply another type of production process is thus not daunting and, it should be clear that in doing so, the potential for full integration of ecosystem services into standard accounting is real.

**Defining ecosystem assets**

To complete the application of accounting principles, it follows that since the production boundary has been extended and the level of output has been increased, then the measure of income that is recorded will be increased (reflecting “sales” of ecosystem services) and the set of flows within the scope of the concept of economic benefits is extended. With an extended set of economic benefits, the asset boundary of the SNA is broadened such that additional value can be attributed to ecosystem units, which are equal to the net present value of the future flow of ecosystem services. This additional value can be readily interpreted as a value of an ecosystem asset and added to the value of other assets already included in measures of wealth (as undertaken in wealth accounting studies e.g. (Lange, Wodon, and Carey 2018)).

Since the future flow of services can be attributed to each individual ecosystem unit then each ecosystem unit can also be considered an individual ecosystem asset. Recognizing ecosystem units as ecosystem assets supports the application of a range of other accounting concepts such as investment, depreciation and degradation and ensures that the incorporation of ecosystems and ecosystem services within the national accounting system is both seamless and comprehensive.

A concern may be raised that, in many cases, ecosystem services are inputs to the production of

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5This estimated value is not intended to reflect an all-encompassing or complete “value of the environment” that incorporates, for example, intrinsic and cultural values.
goods and services already within the standard SNA production boundary. Examples include the flow of ecosystem services into agricultural and other primary production. However, the treatment in this framework is to show a transaction in ecosystem services (for primary production it will commonly be reflected in biomass growth) from the newly established ecosystem unit (e.g. the agricultural land) to the relevant economic unit (e.g. farmer). Explicitly recognizing this transaction has the effect of increasing total output and total intermediate consumption by the same amount (i.e. the supply and use of ecosystem services). As a result, total value-added (the difference between output and intermediate consumption) remains unchanged but the contribution and value-added of the ecosystem asset is made explicit. Importantly, since the ecosystem asset being managed by the primary producer will also supply ecosystem services to other units (e.g. carbon sequestration), these additional outputs can be recorded in the system and the potential trade-offs between different management practices and sets of outputs can be accounted for and assessed.

The core ecosystem accounting framework (CEAF)

Using the building blocks of units, production, transactions and assets as described above it is now possible to describe a simple yet powerful core framework that underpins the application of ecosystem accounting. The core ecosystem accounting framework (CEAF) described here (see Figure 4 below) contains four key elements. Ecosystem assets are delineated in terms of spatial areas which have an extent (e.g. measured in hectares) and a condition (or quality), and each asset supplies ecosystem services which are, in turn, used in the production of benefits.

In many ways, the CEAF reflects other approaches that have sought to establish the connection between the use and supply of ecosystem services. Examples include the work of Banzhaf and Boyd (2012; 2007), the cascade model of Haines-Young and Potschin (2010) and, most recently, in the work of La Notte & Maes, (2017) in describing an “ecological” supply side perspective. The advance described in this paper is not in presenting the established logic of the connection between ecosystems and the benefits they deliver, but rather in grounding this logic for measurement and reporting purposes using the accounting principles of the SNA.

It is important to distinguish the core framework described here (and the other supply focused approaches to ecosystem services just noted), from use or demand focused models and definitions of ecosystem services. In particular, we note that in the Millennium Ecosystem Assessment, ecosystem services were defined as “the benefits that people obtain from ecosystems” (Millennium Ecosystem Assessment 2005). This approach to defining ecosystem services implicitly starts from a use perspective—i.e. the way in which people interact with the environment and draw benefit from it. Indeed, a human use perspective appears to remain the most prominent way of framing ecosystem services as reflected in the nature’s contributions to people framework (Pascual et al. 2017) being developed by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES).

Unfortunately, a use or benefit-based approach, i.e. starting from the right-hand side of Figure 4, tends to suffer from not making a sufficiently refined connection to the actual operation (function and processes) of the ecosystems themselves. This limits the potential for the resulting information set to guide policy and ecosystem management since, by necessity, these must involve intervention at the asset level, i.e. starting from the left-hand side of Figure 4.

Accounting for ecosystem transactions and physical flows

One of the challenges in understanding the accounting-based, transactions approach described above, is that there is commonly a misconception about the links to the recording of physical flows, such as energy, water or GHG emissions. Accounting for physical flows following mass balance principles is a key component of the SEEA Central Framework (United Nations et al. 2014a).

In a number of situations, the physical flows recorded will correspond to transactions in ecosystem services. For example, for provisioning services involving the extraction of timber or fish, the quantity of ecosystem service transacted will equal the gross physical flow of the material from the environment to the economy. However, for many ecosystem services the connection with the physical flow will not be direct and the general observation is that there is no requirement that transactions in ecosystem services satisfy a
mass balance principle of recording. For example, flood (regulation) control by mangroves in coastal areas does not have an equivalent physical flow that quantifies the service directly, even though the associated flows of water still satisfy mass balance principles.

Figure 5 below is used as an example to describe physical flows and transactions between environmental and economic units. Following a national accounts framing, a transaction occurs between two economic units—in this case the water authority and the farmer—when the farmer buys water for irrigation of pasture (an agricultural ecosystem). As an outcome of the transaction there are changes in the volume and composition of water resources for each environmental unit, which can be recorded as physical flows between units. The soil receives 100 units of water from the farmer via irrigation, and an additional 40 units of water from precipitation (rain) from the atmosphere. These changes are all added to the 20 units of water already stored in the soil resulting in 160 units of water in the soil. The farmer’s ecosystem (pasture) is undertaking the production process of biomass accumulation via photosynthesis using 90 units of water from the soil as an input of which 80 units are transpired (back to the atmosphere) during photosynthesis, with 10 units of water captured in the biomass (hay) that is harvested by the farmer. Finally, there are 25 units of water lost from the soil through evaporation (to the atmosphere) and 30 units moving into groundwater.

By recording all physical flows between all units, it is possible to measure and report all water in the system. Typically, soil water balance is calculated to account for i) the flows of water in and out of the soil profile and ii) the volume of water stored in the soil profile that is available to plants for growth (see Equation 1 below). The balance of all water flows in and out of the soil can be accounted for and nets to zero, with 15 units of water being stored in the soil for the next season (closing stock in Equation 1 below).

\[
\text{Soil Water Balance} = 20 \text{ opening stock} + 100 \text{ irrigation} + 40 \text{ rainfall} - 90 \text{ ecosystem} - 30 \text{ groundwater} - 25 \text{ evaporation} - 15 \text{ closing stock}
\]

The farmer then utilizes produced capital (tractors) and human capital (labor) to harvest the biomass which is then sold in the market (to other farmers) as hay. There has been a transaction in a biomass accumulation service between the ecosystem and the farmer. The farmer is utilizing ecosystem processes to produce biomass which he is then combining with other inputs (capital and labor) to make hay and sell to other economic actors.

In this example, it is important to recognise that not all physical flows of water described above, which themselves reflect ecosystem and hydrological processes, are recorded as transactions in ecosystem services. For example, the physical flow of water between the atmosphere and the ecosystem recorded as precipitation is not a transaction in ecosystem services.

Ecosystem services are an accounting construct designed to show the relationship between the supplying ecosystem asset and the using economic unit. Recording them is undertaken in parallel with the recording of ecosystem processes and physical flows, in the same way as transactions in motor vehicles (sales) is undertaken in parallel with recording the motor vehicle production process. It is the role of ecosystem accounting to translate biophysical information recorded in physical flow accounts into transactions in ecosystem services that can then be fully integrated into standard economic accounting.
Recording the production of ecosystem services

Building on the distinctions between recording physical flows and recording transactions in ecosystem services, this section discusses in more detail how the core ecosystem accounting framework can be applied to record the flow of ecosystem services that are produced as a result of ecosystem processes. Ecosystem processes include the capture of light, energy and carbon through photosynthesis, the transfer of carbon and energy through food webs, and the release of nutrients and carbon through decomposition (Odum and Barrett 2005). In general terms, these processes transform energy, nutrients and water into biomass. This production of biomass can be considered an ecosystem service and following the logic of economic production functions, this service (biomass production) can then be combined with capital and labor and ultimately harvested as an output, say logs or hay.

Other ecosystem services are also produced through these types of ecosystem processes, including the stabilization of soil and wind regulation through the existence of root structures and above ground biomass, respectively. More complex processes, like water purification, also occur where say water rich in nutrients enters an ecosystem and then leaves the ecosystem without nutrients.

To more fully understand the relationship between the condition of an ecosystem and the supply of ecosystem services it is necessary to understand the link between ecosystem condition and ecosystem processes. In practice, it is the ecosystem processes that are manipulated and managed by economic units (e.g. farmers) to influence the supply ecosystem services, and it is these management activities that affect the condition of the ecosystem. Since ecosystem assets have the potential to produce more than one ecosystem service simultaneously, it is important to understand how different management activities affect ecosystem processes and thus result in different combinations of ecosystem services. The core ecosystem accounting framework described here is designed to record information in a manner that informs the trade-offs in ecosystem management, many of which are commonly ignored.

Describing and classifying ecosystem services

In this section we show how using the transaction-based approach of the core ecosystem accounting model can be applied to structure and approach to the description and classification of ecosystem services. Given the basis of the accounting model, we have described, the classification will be aligned with the SNA. In the following, ecosystem services are not classified as provisioning, regulating or cultural. Such higher-level groupings can be undertaken at later stage if required but they do not assist in identifying and classifying ecosystem services in a transaction-based model.

Table 1 reflects a structured approach to describing ecosystem services based on the CEAF. For a selection of ecosystem types and ecosystem services, the table demonstrates how services can be described and subsequently classified. Columns one and two describe the ecosystem and the ecosystem processes, column three shows the ecosystem service and the last five columns focus on the connections to economic units and associated inputs, processes and benefits. Each row describes a specific service. There is no intention to be exhaustive in this table. Instead the focus is on demonstrating how the core ecosystem accounting framework can be applied consistently across many situations.

The first example in Table 1 is a pasture ecosystem. The ecosystem process (or production process undertaken by the ecosystem) is biomass accumulation. The output that results from biomass accumulation is grass. The economic unit—the farmer—uses economic inputs including fertilizer, labor and machinery to graze cows on the grass provided by the ecosystem. The farmer gains economic benefits by selling the cows. There has been a transaction between the farmer and the ecosystem in the form of grass. There are also physical flows occurring. For instance, the farmer is applying fertilizer to the ecosystem—the ecosystem sees the fertilizer as nutrients (N, P, K) and uses them in its production process.

The second example is based on a wheat ecosystem. It is similar to the pasture example except the ecosystem output in this case is a wheat plant, not wheat grain. Rather, the economic unit, the farmer, then uses labor and machinery to harvest the wheat grain from the plant. The economic benefit is reflected in the wheat grain sold. Above we noted the services provided by soil. In the case of a wheat farm the remainder of the wheat plant will be decomposed by the soil and stored as nutrients and biomass (carbon) in the soil for the next season. The soil is providing nutrient cycling and storage services to the ecosystem which in turn is benefiting the farmer. The CEAF can be used to explicitly recognize these soil services as they will vary based on the type and condition of soil and should also be reflected in the asset value of the soil (land price). An economic unit wishing to buy the land will assess the capacity of the soil to support alternative ecosystems (wheat, barley, maize, pasture, etc.) and calculate the expected ecosystem services and price them according to the economic benefits they can provide.

The natural forest ecosystem provides a larger suite of ecosystem services which have both economic...
and non-economic benefits. The ecosystem process is the same, biomass accumulation, and the ecosystem service is in the form of trees. The forester uses machinery and labor to harvest the trees and receives economic benefits when they sell the logs. In this example we have also attempted to differentiate the process of biomass accumulation to reflect changes in the structure of the trees. Structural attributes of the trees may not be apparent or important when the trees are young but as they age the structure is important because it provides habitat services for species (birds, possums, etc.).

The final example is that of a wetland. Biomass accumulation occurs as in other terrestrial systems but in the form of water plants and algae. The plants and algae are a food source for animals that live in the wetland including fish and ducks. The link to soil is more complex for a wetland because the soil profile generally contains a significant upper layer of mud that provides nutrient processing services to the wetland. The soil is still there to provide a growing medium for many of the larger water plants as well. The water filtration service may be final or intermediate depending on whether the water is used by an economic unit or an ecosystem unit, respectively.

The storage of water in the wetland for use later is also a final ecosystem system service because the water is being used by an economic unit for irrigation purposes. The economic unit (the farmer) uses machinery and fuel as additional inputs to pump the water out of the wetland to be used elsewhere for irrigation. There is a transaction between the wetland and the farmer, the water can be valued in economic terms based on the benefits it is providing.

These examples demonstrate how the core ecosystem accounting framework can be used to describe and classify ecosystem services using a transaction-based approach and are consistent with the SNA and can be fully integrated with SNA accounts.

### Table 1. Transaction based classification of ecosystem services.

| Ecosystem Unit | Economic process | Economic process | Economic process | Economic process | Economic process | Economic process |
|----------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Pasture        | Biomass accum      | Cow. buy. grain   | Fertilizer, labor, machinery, etc. | Grazing          | Final            |
| Wheat          | Biomass accum      | Farmer buy. grain | Fertilizer, labor, machinery, etc. | Farming          | Final            |
| Natural Forest | Biomass accum      | Forester          | Machinery, labor, etc. | Forestry         | Final            |
| Wetland        | Biomass accum      | Government manage | Seedling trees    | Wetland          | Final and Intermediate |
|                | Biomass accum      | Government manage | Seedling trees    | Wind damage protection | Final and Intermediate |
|                | Biomass accum      | Government manage | Seedling trees    | Flood protection | Final and Intermediate |
|                | Biomass accum      | Government manage | Seedling trees    | Water flow       | Final and Intermediate |
|                | Biomass accum      | Government manage | Seedling trees    | Water quality    | Final and Intermediate |
|                | Biomass accum      | Government manage | Seedling trees    | Carbon storage   | Final and Intermediate |
|                | Biomass accum      | Government manage | Seedling trees    | Wind damage protection | Final and Intermediate |
|                | Biomass accum      | Government manage | Seedling trees    | Flood protection | Final and Intermediate |
|                | Biomass accum      | Government manage | Seedling trees    | Water flow       | Final and Intermediate |
|                | Biomass accum      | Government manage | Seedling trees    | Water quality    | Final and Intermediate |
|                | Biomass accum      | Government manage | Seedling trees    | Carbon storage   | Final and Intermediate |

### Conclusion

In this paper, we have shown there is an alternative to using a benefits-based approach to defining and recording ecosystem services. First, we clarified the units that are involved by extending both the SEEA Central Framework and the SEEA EEA and then using those units to account for all transactions between ecosystems and economic units.

Second, by adopting the SNA construct on production and transactions it is possible to view ecosystem processes as analogous to economic production processes. Once ecosystem units are viewed as producing units we have shown it is relatively straightforward to then identify the transactions taking place between the units while continuing to apply national accounting principles.
Finally, the goods and services produced by an ecosystem can then be clearly defined and recorded as ecosystem services.

The approach described here has the following advantages. It provides:

- a clear distinction between recording physical flows and transactions between units
- a framework to link soil, land and ecosystems thus providing a better link between the SEEA CE and SEEA EEA
- an explanation of the difference between ecosystem services and benefits by starting from a supply side perspective

Ultimately, the treatment of ecosystems in the core ecosystem accounting framework is completely aligned with the national accounting philosophy of recording stocks and flows that are of analytical and policy relevance. There is no doubt that a reasonable proportion of flows of ecosystem services are captured in the current accounting entries of the SNA but in standard accounts these flows of ecosystem services are invisible. Ecosystem accounting allows these ecosystem services flows to be explicitly recorded.

More significantly, there are the well-established and significant problems of ignoring flows of ecosystem services that are not incorporated at all in standard accounts and there is also the general lack of recognition of the capital costs of degrading ecosystems and, in parallel, the improvements in capacity arising from good ecosystem management. Without an approach that makes information on these stocks and flows visible, the national accounts system is incomplete and insufficient for policy and analytical purposes. This paper solves a key aspect of creating a more complete picture of the relationship between ecosystems and human well-being.

Disclosure statement

No potential conflict of interest was reported by the authors.

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