A transaction based approach to defining and measuring ecosystem services

WORKING DRAFT[1]

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1 Introduction

Over the past 4 years, since the publication of both the System of Environmental-Economic Accounting (SEEA) Central Framework and Experimental Ecosystem Accounting (SEEA EEA) there has been a significant amount of work focusing on measuring ecosystem services and the related issue of classification. In this paper we describe a transaction-based approach to defining ecosystem services for accounting purposes.

The popularisation of ecosystem services came with publication of the Millennium Ecosystem Assessment in 2005 (MA 2005) which popularised the classification of ecosystem services into four types: provisioning, regulating, supporting and cultural. Consistent with the MA approach and with other ecosystem service measurement approaches, accounting for ecosystem services in the SEEA EEA has started from consideration of the benefits obtained by people and society (including businesses) from ecosystems. Indeed, the MA 2005 explicitly defines ecosystem services as benefits gained by people and society from ecosystems.

The Common International Classification of Ecosystem Services (CICES) approach to the measurement and classification of ecosystem services has moved away from this equality between benefits and services to follow a general “cascade model” reflecting distinctions between ecosystem processes, ecosystem services and benefits – noting that the terms used to reflect these concepts can vary significantly (Potschin and Haines-Young 2011). In CICES cascade model, the most common focus is on final ecosystem services – i.e. where there is a direct link between the ecosystem and people.

At the same time, the CBD[2] defines an ecosystem approach as one based on the application of appropriate scientific methodologies focused on levels of biological organization, encompassing the essential structure, processes, functions and interactions among organisms and their environment. This approach recognizes that humans, with their cultural diversity, are an integral component of many ecosystems.

Both the CBD and the MA/cascade models provide useful starting points to develop a comprehensive set of ecosystem services. The CBD approach can be characterised as an ecological starting point and the MA as anthropocentric, defining ecosystem services as a set of services that provide benefits to humanity.

The challenge is that the description and definition of a set of ecosystem services using different starting points (benefits vs ecological) may be very different depending on the interpretation of boundaries between ecosystems and other elements of the environment. Even within benefit based approaches differences arise due to different interpretations of the boundary between human activity and ecosystems.

In summary, both ecological and benefit based approaches leave quite a number of issues unresolved from an accounting perspective. A particular concern is how to deal with intermediate or supporting services which commonly underpin the supply of final ecosystem services but also how to interpret the role of ecosystem assets in a comprehensive accounting framework. In this paper we

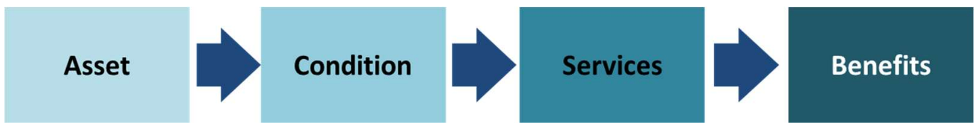
[2] MA 2005

seek to address the limitations of these approaches to defining, identifying and ultimately classifying ecosystem services.

2 The ecosystem accounting model

The approach described here continues to use the core ecosystem accounting model of the SEEA EEA as represented in the Figure 1 below. In it, ecosystem assets delineated in terms of spatial areas have an extent and condition and supply ecosystem services dependent on those factors ultimately contributing to the production of benefits.

Figure 1 Core ecosystem accounting model



A benefit based approach, as the name suggests, starts from the right hand side of Figure 1. While this appears to support the common aim of describing the connection between humans and ecosystems, commonly referenced in terms of final ecosystem services; there is no clear connection to the actual operation (function and processes) of the ecosystems themselves thus limiting the potential for the resulting information set to guide policy and land management interventions at the asset level.

By way of example, in providing information on the supply of different ecosystem services from a forest, say timber and carbon sequestration, we might focus solely on the quantity and value of those services. However, if we also wanted to understand the potential to trade-off between these services it is important to be able to make the connection between management choices, e.g. in terms of selection of trees to harvest, and the resulting change in ecosystem service flows. The link to estimating changes in service flows lies in understanding ecosystem processes. For accounting purposes, it is not necessary to fully record these processes but, at least at the definitional stage, we should understand the boundary between ecosystem processes and services as well as between services and benefits.

Given this ambition, we propose an approach to defining and identifying ecosystem services working from the left hand side of the core model (rather than the right hand side). We do so through application of accounting principles contained in the System of National Accounts (SNA) and the SEEA CF, particularly those relating to the definition of production.

3 Clarifying the units, transfers and transactions involved

To provide a basis for articulating an accounting approach starting from ecosystem assets we first define four types of environmental units: atmosphere, ecosystems, soil and groundwater (see Figure 2 below). These units reflect an adaptation and extension of the current SEEA Central Framework environmental assets. They are established to provide a richer framework to record the physical transfers occurring in the environment – primarily movements of water, carbon, nitrogen, and other elements.

Each environmental unit can be spatially delineated and SEEA Central Framework based recording can be used to account for physical transfers between the units. The water resources asset account points in this direction showing movements between different types of water sources (but excludes the atmosphere). However, the carbon stock account described in the SEEA EEA is perhaps the best example of a the units approach being envisaged for physical transfers here (See Appendix I). It shows movements of carbon between all of the different potential reservoirs (units).

By establishing environmental units that are located in the landscape and recording the various physical transfers, a bridge is established between the accounting approaches in the SEEA CF and the spatial accounting in the SEEA EEA. Indeed, the role of carbon and water accounts in supporting ecosystem accounting can be more clearly articulated.

In addition to these four types of environmental units, ecosystem accounting requires recognition of economic units (such as businesses and households) since these are also a part of the complete accounting picture. As humans engage with the landscape there will commonly be physical transfers to be recorded between economic units and between economic units and environmental units.

Having established a set of environmental and economic units that are relevant in recording all physical transfers, we then show how a set of transactions can be described as occurring between the units that is analogous to transactions in goods and services recorded in the SNA. These transactions reflect the exchange of ecosystem services.

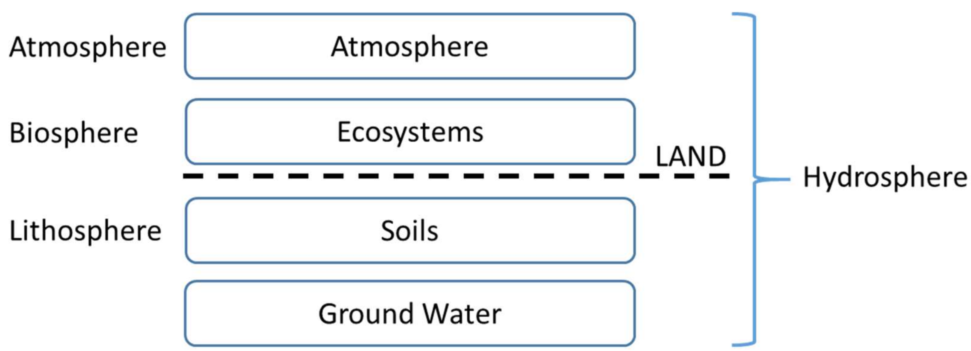


Figure 2 Environmental Units

In the SNA the starting point is a focus on production – i.e. where entities (economic units) combine capital and labour to produce goods and services undertaking production processes. We start with the same logic by considering that the various environmental units are analogous producing units that undertake different environmental processes (production). The outputs from those environmental processes are ecosystem services that are transacted with other units including both economic units (in which case they represent final ecosystem services) and other environmental units (in which case they are intermediate ecosystem services).

The key point here is that ecosystem services must be related to or emerge from a corresponding ecosystem process. Just as goods and services transacted and recorded in the SNA must be the result of production processes within economic units. It is not sufficient that there is a link to a benefit.

Since ecosystem services reflect transactions between units then for each ecosystem service produced by an environmental unit there must be a corresponding receiving or purchasing unit. Where the receiving unit is another environmental unit then the ecosystem service should be considered intermediate. Where the receiving unit is an economic unit then it will be a final ecosystem service. Thus, the same type of ecosystem service, e.g. water provisioning, can be either final or intermediate depending on the type of receiving unit. This is completely analogous to the treatment of products in the SNA. For example, the purchase of bread by a household will be treated as final consumption whereas the purchase of bread by a restaurant will be treated as intermediate. Trying to limit ecosystem services to only final services, necessarily implies limiting the view of ecosystems as producing units in an accounting context and thus limits the potential to see the application of a more complete national accounting treatment.

Forming this link to ecosystem (production) processes and treating ecosystem services as outputs of ecosystem units is inherent in the SEEA EEA accounting model but a clear description about how to define and classify ecosystem services has not been detailed. Although there is a definition of ecosystem services in the SEEA EEA as "contributions to benefits", it does not serve to sufficiently define and measure the services.

Overall, our view is that it is not possible to classify ecosystem services without first being very clear on the units involved, the boundaries between those units and the transactions that are taking place between the units. The following section provides detail on the units and the relationships between the units.

3.1 Biophysical environment and environmental units

Building of the core ecosystem accounting model in this section we start by describing the elements of the biophysical environment as a foundation to building a set of environmental units. The biophysical environment includes living things, such as plants and animals, and non-living things, such as rocks, soils and water. The biophysical environment shown in Figure 2 above is made up of four parts: the atmosphere, hydrosphere, lithosphere and biosphere. The atmosphere includes gases that are around the earth and everything that happens in them, such as heat from the sun, weather, smog and haze, climate and rain. The hydrosphere is the portion of the earth that is composed of water in all forms – running water, ice and water vapour. The lithosphere refers to the rocks and soils on the crust of the earth and how continents form and wear away. The biosphere is the zone of the earth and adjoining parts of the atmosphere in which plants and animals exist.

The biosphere contains areas of land, sea, and atmosphere in which organisms are able to live (REF). Each organism within the biosphere inhabits and interacts with the things that surround them. The biosphere is an irregularly shaped, relatively thin zone in which life is concentrated on or near the Earth's surface and throughout its waters. Both terrestrial and aquatic ecosystems function within the biosphere and the sum of all ecosystems is the biosphere. It is the unique interaction between the living and non-living elements that defines an ecosystem as a community functioning together as a unit.

The biosphere and the ecosystems it contains are the focus of ecosystem accounting. The aim is to understand the relationships between each of the environmental units and how they depend on and interact with one another.

The following sections describe each of the units in more detail.

3.2 Ecosystems

In the SEEA CF land use and cover are discussed and in the SEEA EEA ecosystems are described however it is not clear how the two are linked in accounting terms. It is not possible for accounting purposes to ignore the potential relationship between land and ecosystems particularly given the prominence of land in economic accounts.

From a biophysical environment point of view land is at the interface of the biosphere and the lithosphere (soils). However, it is more of an economic construct in order to measure the surface area of the earth on which we undertake economic activities. Land cover may be considered a step towards recognising the biosphere or ecosystems it contains.

Eigenraam et al 2015 argue there is a continuum between the SEEA CF concept of land and the SEEA EEA concept of ecosystems. This is useful because both can be measured in hectares and a concordance developed to link land and ecosystems via a spatial classifications process. In other words, the SEEA CF classification of land cover can be considered as a crude proxy for ecosystems classes.

The classical view of an ecosystem includes six components as shown in Table 1 below, which interact with one another and define an ecosystem unit (Odum & Odum, 1971; Odum & Barret 2005). Column one contains the high level ecosystem characteristics, column two the ecosystem components and finally the last column lists some of the high level functions of an ecosystem.

Table 1 EU characteristics and components

Ecosystem characteristics	***Ecosystem Components***	***Ecosystem Functions***
Biotic		
Producers	***(1) Autotrophs****: Plants (trees, shrubs, herbs, grasses), that convert the energy [from photosynthesis (the transfer of sunlight, water, and carbon dioxide into energy), or other sources such as hydrothermal vents] into food.*	Energetic Cycles – regulation Biogeochemical Cycles– regulation
Consumers	***(2) Heterotrophs****: e.g. animals, they depend upon producers (occasionally other consumers) for food.*	
Decomposers	***(3) Saprotrophs*** *: e.g. fungi and bacteria, they break down chemicals from producers and consumers (usually dead) into simpler form which can be reused*	Evolution – Information, development, behavior, integration, diversity
Abiotic	***(4) Inorganic Substances*** *(C, N, CO2, Water), air, water,*	
	(5) Environment: *substrate (bedrock), climate regime, hydrological regime*	
Other linking compounds	***(6) Organic Compounds*** *– proteins, humic substances (soil), fossil fuels*	

Within the list of ecosystem components is item 6, the organic compounds, which includes the soil which is strongly linked to item 5 the substrate (bedrock). The traditional depiction of the ecosystem includes the soil as a component. For our purposes we will consider the soil as a separate unit that provides a set of services to the ecosystem and the economic unit.

In order to characterise each ecosystem unit (EU) uniquely, a set of components needs to be described. A very common approach to describing an EU is to use the autotrophs, more commonly known as plant community associations. The taxonomy and physiognomy of autotrophs (component 1 above), or plant communities, (or vegetation cover) is what forms the main structural elements of terrestrial ecosystems, often organized in several floristic layers e.g. forest-trees, understory-shrubs, grasses and herbs, mosses and lichens.

Defining EUs using a vegetation communities approach is also relevant to estimating ecosystem services. Many ecosystem services are linked to biomass accumulation including carbon sequestration and storage, habitat for species, water and wind regulation. It is also quite common to use vegetation communities as an input to biophysical models. We will return to these ideas when classifying and describing the ecosystem services in Section 5 below.

3.2.1 Land

Land is not an environmental unit, however following the SEEA CF land is a unique environmental asset that delineates the space in which economic activities and environmental processes take place and within which environmental assets and economic assets are located. Therefore, land is an economic construct in which ecosystems and soils exist and function. It is important to note the when land is traded as part of an economic transaction, the right to use the soil and ecosystem are transferred with it. The land system embodies the relationship between human activities on land, socio-economic conditions, the natural environment and the systems of governance that manage these interactions (EEA 2016, Soil resource efficiency in urbanised areas).

Since land is central to many economic accounts it needs to be acknowledged when considering integrated environmental-economic reporting. It is commonly described in terms of land use/management and land cover which is sufficient to report economic activity and undertake environmental-economic accounting following the SEEA CF.

However, there needs to be a link to ecosystems is through land cover as a course proxy for describing an ecosystem. For instance, forest cover is a very general description of specific set of forest ecosystems which is the connection between the SEEA CF and SEEA EEA. The SEEA CF accounts for the total area of land whereas the SEEA EEA goes one step further to spatially locate the areas of land and define them as ecosystems.

The value inherent in land is based on the ability of the land to support different types of ecosystems. Basically the land value is a function of the soil it contains, climate and location. The owner of the land considers these aspects (and others, ie expected prices) when deciding on what ecosystem to employ for the production of ecosystem services. From an environmental units point of view it is important to measure and report how the units are interacting with one another and how the condition of the units' change with use. This is the core of ecosystem accounting with land being the key link to the SEEA CF and the economic owner of the land being the link to the SNA.

3.3 Soil

The EEA 2016 (soils paper) provides a comprehensive summary of the literature linking soil functions to ecosystem services (P. 9, Box 1.1). Key findings include:

- CICES no longer recognises supporting services which results in the risk that soil-based services are under-identified and possibly under-valued. Indeed, many soil-based services are seen as supporting services, which underpin provisioning, regulating and cultural services.
- Dominati et al 2010 argue that for soil to be appropriately considered, they have developed a conceptual framework that explicitly links the stocks of natural capital (soil) and what they call the inherent properties — that is static (e.g. slope, texture) — and the manageable properties — that is dynamic (e.g. structure, porosity, bulk density) — of soil with the flow of provisioning, regulating and cultural services that in turn meet human needs or wants. They also recognise the positive feedback between soil stocks and soil formation and the negative feedback between soil stocks and soil degradation, affected by both natural and human drivers and processes. Thus,

they argue that it is essential to consider soil stocks and flows simultaneously in an integrated framework.

- Robinson et al 2013 argue soil has to be understood as a complex system made up of components that can be configured differently to simultaneously deliver a range of services at individually varying levels. What is really needed, they argue, is an appreciation of the effects of multiple changes in soil characteristics, as this affects the multi-functionality of soil in the land, and associated trade-offs and synergies. Examples here include the joint and simultaneous effects of soil compaction and erosion on run-off, nutrient cycling and carbon exchange.
- Soil security is described by Koch et al 2013 as being at the heart of addressing a number of inter-related global issues: food security, water security, climate change abatement, ecosystem service delivery, biodiversity protection and energy sustainability. In order to maintain the visibility of soil functions, Koch et al 2013 emphasise soil as a discrete component, yet a core building block of land. They propose a soil-centric approach to policy design that raises awareness of soil degradation and addresses the issue, thus contributing to sustainable development.

The above review results highlight the need to have soil as a unit in the EUM. Soil is an essential environmental unit because of the services it provides, which underpin ecosystem viability and in turn ecosystem services. Soil properties include aggregate stability, bulk density, water holding capacity, soil erodibility, soil thermal properties, soil colour, soil strength, compaction characteristics, friability, nutrient cycling, cation exchange capacity, soil acidity and buffering capacity, capacity to form ligands and complexes, salinity and the interaction of soil organic matter with soil biology (Department of the Environment 2014).

The link between ecosystems and soils is fundamental. Generally, for an ecosystem to function it requires soil and soil services including[3]:

1. Soils serve as media for growth of all kinds of plants.
2. Soils modify the atmosphere by emitting and absorbing gases (carbon dioxide, methane, water vapour, and the like).
3. Soils provide habitat for animals that live in the soil (such as groundhogs and mice) and organisms (such as bacteria and fungi), that account for most of the living things on Earth.
4. Soils absorb, hold, release, alter, and purify water in terrestrial systems.
5. Soils process plant residuals and recycle nutrients, including carbon and nitrogen, so that living things can use them over and over again.
6. Soils serve as engineering media for construction of foundations, roadbeds, dams and buildings, and preserve or destroy artefacts of human endeavours.
7. Soils act as a living filter to clean water before it moves into an aquifer.

It is possible for an ecosystem to function without soil but an artificial medium needs to be provided in order for the ecosystem to access nutrients. Generally, soils are difficult to move from one location to another and do not change their properties (water holding capacity, infiltration rate, etc.). However, with sufficient resources both can be achieved. It is quite common for those areas that have sandy soils with low water holding capacity to add clay to increase both water holding capacity and improve infiltration rates. As a result, plants (the ecosystem) have access to water via their root system for longer periods and can grow for longer periods of time.

[3] https://www.soils.org

If an ecosystem exists with a purely artificial medium it is still an ecosystem but the soil services are being provided by humanity. There are also many instances where ecosystems are located on soils that are not at all amenable to the ecosystem however with sufficient inputs – nutrients and water – it is possible for the ecosystem to function. For instance, irrigated pastures on sandy soils in high temperature locations will have high water and nutrient inputs.

If a soil is degraded, it limits the ability of an ecosystem to function to its full potential. Soil needs to be accounted for in terms of its extent (the area of specific soil types), condition and depth. It is also useful to know what exists below the soil, for instance geological bedrock and groundwater systems. If a saline groundwater system is not far below the soil it is possible through the alteration of ecosystems to cause the saline groundwater to rise and make contact with the soil. This impacts on the soils ability to function and also brings salt into contact with an ecosystems root system. There many areas around the world that have what are considered to be degraded soils due to rising groundwater tables that have caused the soils to scald (salt appear on the surface).

Overall, soils are an important environmental unit to account for its asset value in line with the SEEA CF and to measure and report on the services it is providing to other environmental units and economic units.

3.4 Groundwater

The link to groundwater may be less obvious and in some instances of lesser significance. However, many soils around the world are quite close to both saline and fresh groundwater resources, which threaten or support ecosystems, respectively. Water within a groundwater system is also a resource in its own right so any use of it may have implications for ecosystems and the services they provide. Thus integrating groundwater as an environmental unit is an important part of a complete accounting picture and completes the coverage of the hydrosphere.

Groundwater systems or aquifers are an important environmental unit because they hold water that can be used by an ecosystem and they connect many ecosystems to one another. Groundwater systems extend over very large areas and also vary considerably in depth. There are shallow (they may be in contact with the base of the soil or some metres below) local aquifers and deep aquifers that may be hundreds of metres below the surface.

Local groundwater systems receive a lot of water via the ecosystems that sit on top of them. For instance, a crop ecosystem that is in fallow for long periods will provide more water to an aquifer than a forest ecosystem. Basically each ecosystem will contribute a different volume of water to a groundwater system. It is also very common for deep rooted ecosystems to access the groundwater system during drier periods.

If the groundwater system contains fresh water it is also quite common for water to be pumped directly from it for consumptive purposes. There is a clear link between the decisions economic units make with respect to the ecosystems they put on top of a groundwater system and the total resource that is available for use from the groundwater system. These relationships may be positive, where an ecosystem is allowing for significant recharge to the groundwater system and another economic unit is pumping water for consumption. Alternatively, there are systems where an economic unit has introduced irrigation of the ecosystem which is creating very large recharge volumes but the groundwater system is saline. The rise in groundwater height then comes in contact with non-irrigated ecosystems and causes them to fail or die through salt deposition in the soil. This process also degrades the soil.

At a landscape scale it is very common to include a mix of ecosystems to manage recharge volumes and the overall height of the groundwater system.

3.5 Atmosphere

The atmosphere plays an important role as a sink and for processing gaseous waste products. The SEEA CF does not include the atmosphere explicitly as an accounting unit but does recognise there are emissions to the atmosphere.

The atmosphere as an important environmental unit however it is challenging to measure and report on the relationships between it and economic activity, ecosystem function and soil function. Clearly there are links between climate change and atmospheric behaviour. The atmosphere continues to receive and store water vapour however climate change means that water vapour is being released in different locations and with differing intensities.

There is also a large body of work emerging in the urban context looking at the relationship between local atmospheric conditions (temperature) and how it can be regulated using ecosystems – e.g. trees in parks and green areas.

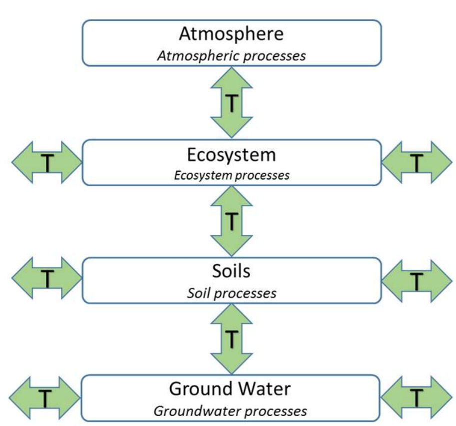
Although recognised as an important unit, the role of the atmosphere in relation to ecosystem services is beyond the scope of this paper.

3.6 Biophysical transfers between units

Biophysical transfers between units includes water, carbon, nutrients and biomass. A transfer may or may not result in change in economic benefits however they need to be measured and reported in order to have a complete accounting picture. Transfers are also important to understand and recognise because they emphasise the importance of the linkages between the SEEA CF and the SEEA EEA. The CF focuses on biophysical accounting and the EEA on ecosystems. The transfers between environmental units reinforces the idea that neither CF or EEA focused accounting can be undertaken without considering the fact they are intimately linked via physical transfers.

This section describes the biophysical transfers that are taking place between each of the environmental accounting units. Figure 3 below provides a schematic overview of all transfers. Many of these transfers are currently recorded as part of the SEEA CF including water, carbon and green-house gas emissions. The key difference in recording the transfers in the EUM is a recognition of the role the units play in balancing the transfers. This will be more apparent in the next section when we outline the services provided by each of the units.

Figure 3 Transfers between environmental units



In the SEEA CF the water asset account is conceptually closest to recording the transfers we describe as occurring between different environmental units. In effect, the volumes of water should be very similar but would be more complete when including water vapour stored in the atmosphere.

Water is the simplest to demonstrate how transfers occur between environmental units. Water is simple because it can exist in both gaseous and liquid form but when it is transformed there are no losses or gains. Whereas, for a nutrient such as nitrogen it becomes more complex because it exists in solid, liquid, gaseous forms and binds with other elements including oxygen to form other compounds.

However, all transfers (both additions and subtractions) between environmental units must net out to zero. In other words, when accounting for water transfers over a fixed period of time, all transfers need to be accounted for and combined with changes in storage and finally net to zero. It may be challenging to measure the volumes in the atmosphere however it is important to recognise it does store water that moves around the earth. Climate change is impacting on the location and frequency of rainfall so impacts on ecosystems and their ability to provide services. So even if measurement of water storage cannot be undertaken, the analysis of where precipitation will occur under climate change is nonetheless very important.

The discussion so far has focused on the vertical transfers that are occurring between the units. The same principles apply for lateral transfers between units and may be more important since this is the pathway in which externalities occur. For instance, there may be nutrient runoff from one location to another impacting on the ecosystem that is receiving the nutrients. The impact may or may not result in changes in economic benefits however that should not determine whether the transfers are measured and reported.

The following section will build on the transfers model and incorporate concepts from the SNA to show how transfers can be further described as transactions when they involve an economic unit and an environmental unit and how they can enter into an accounting model.

4 Ecosystem Transaction Model

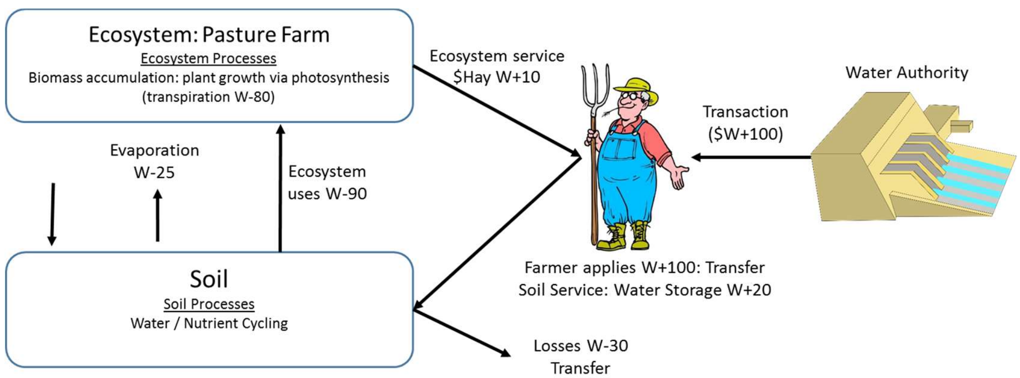
This section is presented in two parts, the first discusses transactions and transfers between economic actors and environmental units followed by the presentation of an ecosystem transaction model that will be used later to describe and report ecosystem services.

4.1 Environmental and economic transactions

The SNA will be used as the supporting construct to describe transactions that are occurring between all units (economic and environmental). According to the SNA 2008 economic flows reflect the creation, transformation, exchange, transfer or extinction of economic value; they involve **changes in the volume, composition**, or value of an institutional unit's assets and liabilities. A transaction is an economic flow that is an interaction between institutional units **by mutual agreement** or **an action within an institutional unit that it is analytically useful to treat like a transaction**, often because the unit is operating in two different capacities. The value of an asset or a liability may be affected by economic flows that do not satisfy the requirements of a transaction. Such flows are described as "other flows". Other flows are changes in the value of assets and liabilities that do not result from transactions. Examples are losses due to natural disasters and the effect of price changes on the value of assets and liabilities.

Figure 4 below is used as an example to describe a set of economic flows, transfers and transactions between environmental and economic units. Following the SNA construct, economic flows are occurring between two economic units – in this case the water authority and the farmer – the farmer is buying water to use for irrigation. There are changes in volume and composition for the environmental units as a result. The soil is receiving 100 units of water that the farmer is applying in the form of irrigation. The soil is providing a service to the farmer by holding and storing water for use by his ecosystem. There is 20 units of water held in storage from the last season (t-1) and 15 units of water that is going to held for the next season (t+1). His ecosystem (a pasture) is providing ecosystem services in the form of hay. The ecosystem process is biomass accumulation. Fundamentally the farmer is using the ecosystem to produce biomass which he is then combining with other inputs (capital and labour) to make hay and sell to other economic actors.

Figure 4 Linking economic units with environmental units



By recording all transfers between all units it is possible to measure and report all water in the system. The equation below shows how all water transfers are accounted for in the soil.

Soil Water Balance Account:

= +100 irrigation +40 rainfall –90 ecosystem –30 losses +20 storage (t-1) –25 evaporation = +15 storage (t+1)

This information allows for full accounting between all units and clearly shows the role of each unit. The losses shown in the figure may be entering a nearby ecosystem through later transfers in the soil profile or they may be entering a groundwater system. Either way they need to be accounted for as transfers between the units to balance all additions and subtractions between units.

The SNA records all transactions that are occurring between the economic units, in the example above the water authority and the farmer. Following the SNA, some transfers of water are analytically useful to treat as transactions (water storage by the soil for the farmer) since they have economic values associated with them. There are also other transfers occurring that are described in the figure as 'losses from the soil'. However, if the losses are moving to another environmental unit, say a groundwater system, and other economic actors are using the then they are also analytically useful to record as transactions.

The SEEA CF is accounting for additional environmental units and flows, which in this example includes the soil and water. The SEEA CF provides the basis for recording all the transfers between environmental units noted in the equation above. The SEEA EEA accounts for the hay as a final ecosystem service.

The model we have described adds in the following transactions:

- The transaction in soil water storage services between the soil and the farmer.

- The transaction in water/nutrient cycling services between the soil and ecosystem

The advantage of this approach is that it accounts for all transactions that occur between all environmental and economic units. This approach provides a more formal link between the SNA and the SEEA CF because the value of a soil as an asset and how it is supporting the production of pasture is clearer. Further, the link between the SEEA CF and SEEA EEA is clearer because we can now account for the transactions that are occurring between the soil and the ecosystem thus providing a clearer depiction of soil services being provided to both the ecosystem and the economic unit. This also clarifies the distinction between SEEA CF and SEEA EEA because it highlights the role of the ecosystem and allows us to identify the ecosystem services.

The next section builds on the transactions that have been described and further uses the SNA construct to account for production that is being undertaken by the ecosystem and the soil. Finally, the transaction based model will be used to define and report both final and intermediate ecosystem services.

4.2 Transaction-based ecosystem services model

The services described in this section include the full suite of ecosystem services and soil services. Whether a service is final or intermediate depends on the units that are involved in the transaction. In some instances, a service may be both final and intermediate depending on the unit receiving the service.

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 (SEEA EEA). It is these processes that result in a number of ecosystem services being provided.

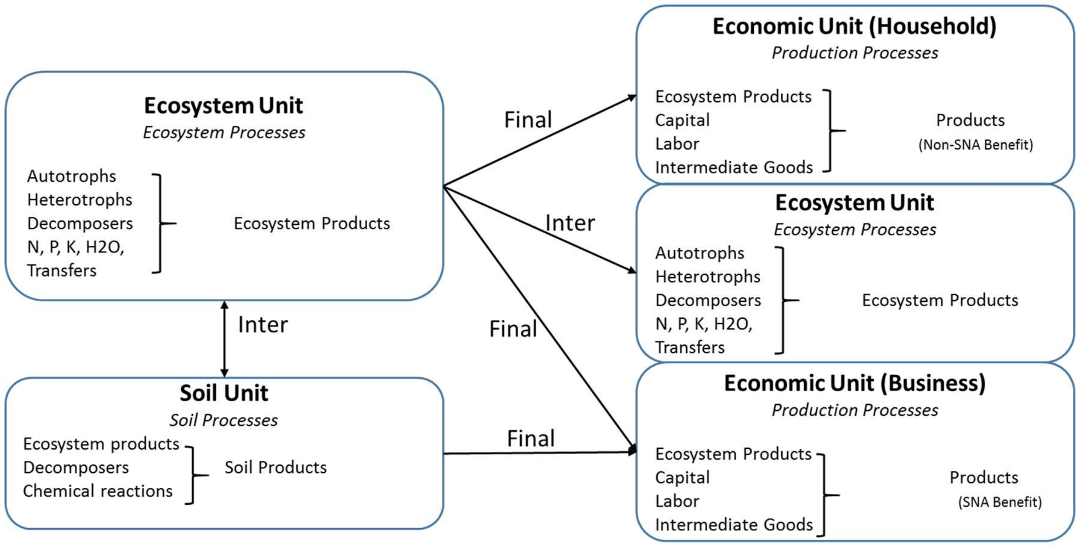
In general terms the processes transform energy, nutrients and water into biomass. This biomass can then be harvested as an ecosystem service, say logs or wheat. Other forms of ecosystem services include the stabilisation of soil through the existence of root structures and above ground biomass. More complex processes like water filtration also occur where say nutrient rich water enters an ecosystem and then leaves the ecosystem without nutrients. The ecosystem has captured and used the nutrients for growth combined with energy and light to produce biomass.

Ecosystem processes or transformation processes (water filtration) are similar to production as described in the SNA. The ecosystem is providing goods and services which are measured or described as ecosystem services.

Generally, in SNA and SEEA EEA accounting terms ecosystem processes are not measured and reported. It is the output of the ecosystem that is measured and recorded. However, in order to understand the relationship between the condition of an ecosystem and the supply of ecosystem services it is necessary to link condition to ecosystem processes.

It is ecosystem processes that are manipulated and managed by economic units to supply ecosystem services. Since ecosystem units have the potential to produce more than one ecosystem service simultaneously, it is also important to understand how different management approaches result in different mixes of ecosystem services.

Figure 5 Ecosystem (production) services model



The SNA 2008 states that a purely natural process without any human involvement or direction is not production in an economic sense. For example, the unmanaged growth of fish stocks in international waters is not production, whereas the activity of fish farming is production. However, for ecosystem accounting purposes where the focus in on natural processes, the SNA production boundary is too narrow. Ecosystem accounting aims to measure how natural processes are changing as a result of economic activity. In other words, we need to understand how ecosystem processes are changing as we use ecosystems to undertake economic activities.

Most ecosystems have some form of human involvement and direction. For instance, a pasture ecosystem is very actively managed, there are water and nutrient inputs, seeding and weeding and further the soil can be manipulated so the ecosystem can function and produce more. In forestry, nutrients added, weeds are removed and the trees are actively removed (thinned) in order to generate larger logs. There are few instances where the ecosystem does not have direct human involvement so all ecosystem processes are a form of production in the economic sense and need to be measured and reported.

For ecosystem accounting it is not relevant whether there is human involvement and or direction when deciding whether to record the transactions and transfers. In ecosystem accounting we treat

Case study application of the ecosystem production model

Using the elements described in Figure 5 above we describe a case study on valuing soil services. When the services of soil are considered to be explicitly part of the production process it is possible to value those services. For instance, if you were to remove soil from the ecosystem and replace it with a completely artificial medium. We know the cost of the medium and the costs associated with maintaining the medium to ensure it remains disease free and has the right density for plants to grow and water to be held for plant to access – processes that normally occur naturally within a soil. We also know how much it will cost to add fertilisers and recycle or dispose of residual plant material. Add up of these costs allows us to value the soil in economic terms.

Further, it is also possible to calculate the economic cost of degradation. If for instance, soil erosion occurs then the soil will have a lower water holding capacity. With lower seasonal water holding capacity a farmer will have to apply more irrigation water to compensate. The ongoing additional cost of water is the cost of degradation of the soil asset.

all ecosystems as producing units. Each ecosystem has a set of processes and is producing products and we are recording those transactions with other ecosystem or economic units.

In Figure 5 above there are 3 environmental units, an ecosystem and soil on the left and an ecosystem on the right. There are also 2 economic units, one is a business and the other is a household. The ecosystem unit is transacting with the soil unit. The soil is a medium for the ecosystem to grow, it holds water for growth and processes plant residuals and recycles nutrients. Recycled nutrients are a product that is produced as a result of soil services and used by the ecosystem. The ecosystem uses the nutrients and water combined with other processes to produce ecosystem products (services). The economic unit (business or household) take the ecosystem products and combines them with capital, labour and other intermediate goods to produce (economic) products that are measured and reported in the SNA. Alternatively, the products may go from one ecosystem to another. The products used by the economic units are final ecosystem services and the ecosystem products that are used by another ecosystem are intermediate ecosystem services.

A question may arise where we wish to differentiate between production and output. In general, all goods and services that are produced and used by the same economic unit (establishment) are excluded from the measure of output. However, there are exceptions. For example, output is recorded if the goods and services being produced are used for capital formation of the establishment. Similarly, output is recorded for products entering inventories even if eventually they are withdrawn from inventories for use as intermediate consumption in the same establishment in a later period.

It is important to apply the same differentiation to the environmental units that have human involvement or direction. Clearly the soil is an asset that is controlled by the economic unit so any changes in inventories that are held by the soil (say carbon, water and nutrients) will have a material impact on both current and future production. A farmer may employ a particular management regime the builds up a stock of nutrients or water in the soil which may be reflected in asset pricing and will have an impact on future production so needs to be measured and reported in an accounting model to be consistent with the SNA.

5 Transaction based classification of ecosystem services

In this section we show how using a transaction-based approach it is relatively straightforward to classify ecosystem services. Further the classification will be consistent with the SNA and use the ecosystem production model presented in Figure 5 above. For all ecosystem services there needs to be a transaction between either an ecosystem and an economic unit, or ecosystem to ecosystem. The services between an ecosystem unit and an economic unit are termed final ecosystem services in line with the SEEA EEA. And the transactions between two ecosystems are termed intermediate ecosystem services. There are cases where an ecosystem service may be both final and intermediate if there are two transactions – say ecosystem to ecosystem and ecosystem to economic unit.

In the following, ecosystem services are not classified as provisioning, regulating or cultural. Those groupings can be undertaken at later stage as they do not assist in identifying and classifying ecosystem services in a transaction based model.

Table 2 below contains a list of ecosystem services (products) in column three. Columns one and two describe the ecosystem and the ecosystem processes. The last 4 columns focus on the economic units and associated inputs, processes and benefits.

The types of ecosystem inputs are not listed and assumed to be much the same for each ecosystem and including light, energy, nutrients, water, etc. While they may vary in quantity across ecosystems, they are not a determinant of the types of ecosystem services supplied.

The first example in Table 2 is a pasture ecosystem. The ecosystem process (or production process undertaken by the ecosystem) is biomass accumulation. The product that results from biomass accumulation is grass. The economic unit – the farmer – uses economic inputs including fertiliser, labour and machinery to graze cows on the grass provided by the ecosystem. The farmer gains economic benefits by selling the cows. This is a relatively straightforward example. There are also transfers occurring. For instance, the farmer is transferring fertiliser from herself the economic unit to the environmental unit the ecosystem – the ecosystem sees the fertiliser as nutrients and uses them in its production process. The transaction however is between the ecosystem and the economic unit and the ecosystem service is grass.

The second example is based on a wheat ecosystem. It is similar to the pasture example except the ecosystem product in this case is a wheat plant. The economic unit, the farmer, then uses labour and machinery to harvest the wheat from the plant. The economic benefit is reflected in the wheat sold. In section 3.3 we noted the services provided by soil. In the case of a wheat farm the remainder of the plant will be decomposed and stored as nutrients and biomass in the soil for the next season. The soil is provided nutrient cycling and storage services to the ecosystem which in turn is benefiting the farmer. It is important to recognise 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, blue gums, etc.) and calculate the expected ecosystem services and price them according to the economic benefits they can provide.

Table 2 Transaction based classification of ecosystem services

	<<<<<< Transaction >>>>>						
Ecosystem Units	**Ecosystem Process (Production)**	**Ecosystem services (Products)**	**Economic Units**	**Economic inputs**	**Economic process**	**Economic product (benefits)**	**Final or Intermediate**
Pasture	Biomass accumulation	Grass	Farmer	Fertiliser, labour, machinery, etc.	Grazing	Cow	Final
Wheat	Biomass accumulation	Wheat plant	Farmer	Fertiliser, labour, machinery, etc.	Farming	Wheat	Final
Natural Forest	Biomass accumulation	Trees	Forester	Machinery and labour	Forestry	Logs	Final
	Biomass accumulation -structural	Habitat	Society	Pest removal	Government management of forest	Preservation of species	Final and Intermediate
		Water regulation	Society	Seedling trees	Government management of forest	Flood protection	Final and Intermediate
	Biomass storage	Carbon storage	Society	Seedling trees	Government management of forest	Carbon storage	Final and Intermediate

		Wind regulation	Individual	Seedling trees	Government management of forest	Wind damage protection	Final and Intermediate
Plantation forest	Biomass accumulation	Trees	Forester	Fertiliser, labour, machinery, etc.	Forestry	Logs	Final
Nursery – strawberry plants	Germination and biomass accumulation	Strawberry plants	Nursery owner	Fertiliser, labour, machinery, etc.	Farming	Strawberry seedlings	Final
Strawberry farm	Biomass accumulation	Strawberry plant with fruit	Farmer	Fertiliser, labour, machinery, etc.	Farming	Strawberries	Final
Wetland	Biomass accumulation	Water regulation	Society	Weed and pest control	Government management of wetland	Flood protection	Final and Intermediate
	Water holding or capture	Water storage	Farmer	Machinery (pump)	Irrigation farmer	Water	Final
	Nutrient capture and processing	Water filtration	Society	Weed and pest control	Government management of wetland	Clean water	Final and Intermediate
	Biomass storage	Carbon storage	Society	Seedling trees	Government management of wetland	Carbon storage	Final and Intermediate

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 (product) is in the form of trees. The forester uses machinery and labour the harvest the trees and receives economic benefits when they sell the logs. In this example we have attempted to differentiate the process of biomass accumulation to reflect changes in the structure of the trees. Structure is not 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.). It is important to note that this links with the description of an ecosystem provided in Section 3.2 above.

We have suggested an ecosystem is defined or described by the plant communities is contains. The taxonomy and physiognomy of autotrophs of plants may be classified as trees, shrubs, herbs (forbs and graminoids). The information collected on the age and size of trees in a native forest can be used to model or predict the habitat services an ecosystem can provide. Further this information can be used as an input to plant growth models to estimate water cycles including runoff, evaporation and transpiration (Eigenraam et al 2015). If the plant growth model is coupled with a soil process based model it is also possible to estimate soil water storage and infiltration to the groundwater system. Generally, the combination of plant and soil models is referred to as biophysical modelling. In effect the collection and data on plant communities if a form of condition measurement for the native forest and can be used to estimate a number of ecosystem services.

When collecting data of plant communities to infer condition it is also quite normal for data on pests to be collected, both flora and fauna. For instance, the presence of feral cats may have in impact on habitat services for some animals especially birds and ground dwelling marsupials. The presence of pests often indicates that a native ecosystem is degraded and needs active management. In the example we have provided the economic unit – the government – undertakes pest control in order to increase habitat services and preserve native species. The approach we have adopted for classifying ecosystem services allows for a clear connection to be made between the economic unit and changes in the ecosystem asset.

The other services coming from the native forest include water and wind regulation and carbon storage and sequestration. These benefits of these services may be either final or intermediate depending on the unit that is receiving the benefit. For instance, if a beef farmer is located nearby to the native forest they may receive benefits in the form of wind regulation. The farmer will place their stock near the forest during winter to keep them out of the wind and prevent their stock from losing weight. This is a very common practise amongst animal farmers and in many instances farmers will plant trees as wind breaks to maximise the production of animal biomass. The prevention of this loss if of direct economic benefit to the beef farmer and can be estimated if required.

A plantation forest has been included as a contrast to a native forest. The ecosystem process in the same and the economic benefits are the same. We have not listed the other ecosystem services that were listed for the native forest including habitat, water and wind regulation and carbon storage. However, it is clear these services can be provided, perhaps to a lesser extent in the case of habitat services since the trees are a monoculture rather than a mix of plant species. However, the same principles apply when modelling ecosystem services. A monoculture plant model combined with a soil process model can be used to estimate water regulating services from a plantation forest.

From an economic point of view the output of growing trees each year is an output from the ecosystem each year. Each year the forester values biomass accumulation in the form of trees and measures the value of the trees in terms of logs, as if they were cut down today. This change in tree inventory each year is the economic value the ecosystem is providing in the form of ecosystem services (products).

The next examples include a nursery that sells strawberry plant and a strawberry farmer. The nursery owner is getting ecosystem services in the form of strawberry plants. The ecosystem process includes germination and biomass accumulation. The nursery owner sells the strawberry plants to the strawberry farmer. The strawberry farmer provides fertiliser to the plant and then uses labour and machinery to harvest the strawberries from the plant. This is quite similar to the wheat example. However, in this case the strawberry farmer is preserved because the plant needs to reach a minimum age in order to provide fruit. There is an economic transaction between the nursery owner and the strawberry farmer. They each have specialised in the use of ecosystem services to gain economic benefits. The nursery owner has specialist skills in manipulating the ecosystem (plant breeding in this case strawberries) to produce strawberry plants. Whereas the strawberry farmer focuses on maximising the growth of the plant rather than plan breeding in order to maximise fruit production. The strawberry plant is a final ecosystem service for the nursery owner and the fruit (strawberries) from the plant is the final ecosystem service for the strawberry farmer.

The final example we have provided 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 the 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 top layer of mud that provides nutrient processing services to the wetland. The soil is still there to provide a 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 for later use 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.

6 Conclusion

In this paper we have shown there is an alternative to using a benefits based approach to defining and reporting ecosystem services. Firstly, we clarified the units that are involved by extending both the SEEA CF and the SEEA EEA and then using those units accounted for all transfers and transactions.

Secondly, by adopting the SNA construct on production and transactions it is possible to view the processes of both an ecosystem and a soil as production. Once viewed as producing units it is relatively straight forward to then identify the transactions taking place between the units still remaining within the SNA construct.

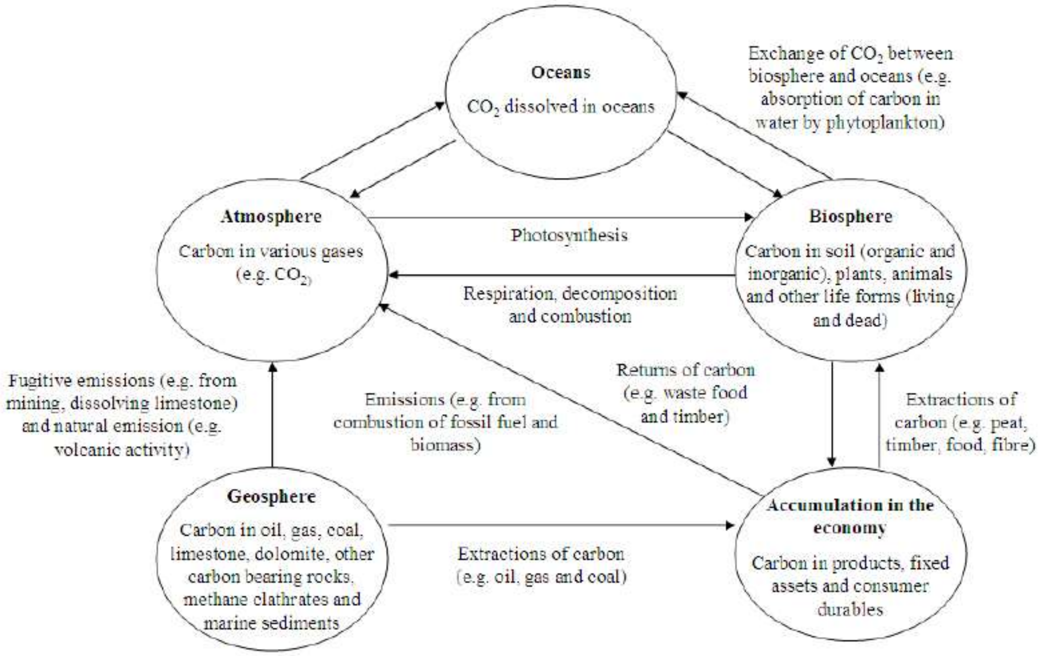
Finally, the goods and services produced by an ecosystem can then be clearly defined and reported as ecosystem services. The same principles can also be applied to soils to describe a set of soil services going to ecosystems and economic units.

The approach described here has the following advantages:

- greater clarity of transfers and transactions between units
- clarified the link between soil, land and ecosystems thus providing and better link between the SEEA CF and SEEA EEA.
- clarified the difference between and ecosystem services and benefits particularly for provisioning and regulation services with more work required for cultural services
- moved beyond the benefit constrained MA model and improved the clarity of units, services and benefits

7 Appendix I – SEEA EEA carbon cycle for accounting

Figure 4.1. The main elements of the carbon cycle



8 References

Department of the Environment (2014), Soil Organic Matter and Soil Function – Review of the literature and Underlying Data. Effects of soil organic matter on functional soil properties.

To be completed