Land and ecosystem services: measurement and accounting in practice

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Table of Contents

1 Introduction

1. Environmental-economic accounting aims to describe the interactions between the environment and the economy. In the past, there has been little or no 'accounting' for the environment when reporting economic performance (e.g. GDP). Environmental-economic accounting provides information linking the performance of the economy to the performance of the environment. Environmental-Economic Accounting is particularly useful for providing information to decision makers on the costs and benefits of trade-offs made between environmental and economic objectives.

2. The United Nations (UN) System of Environmental-Economic Accounts Central Framework (SEEA-CF) provides an accounting approach to environmental assets consistent with the System of National Accounts (SNA). In the SEEA-CF, environmental assets are treated as discrete components of the bio-physical environment with no account of how these components are defined or function together as an ecosystem.

3. An important extension of the SEEA-CF, and a key element of Environmental-Economic Accounting, is the SEEA Experimental Ecosystem Accounts (SEEA-EA) which considers ecosystems and the capacity they have to generate ecosystem services.

4. The SNA currently reports the allocation of land assets to the production of *most* provisioning, cultural and tourism services. The challenge for environmental-economic accounting is to report the generation of other ecosystem goods and services and link their generation to the management of ecosystem assets. Further environmental-economic accounting must provide a link between the goods and services reported in the SNA and other (non-SNA) ecosystem goods and services so that tradeoffs can be made with respect to both their use and generation.

5. The production of the SNA is possible because there are well-functioning markets for the goods and services. Well-functioning markets do not exist for regulating, maintenance and supporting services. However, the goods and services reported in the SNA rely on regulating, maintenance and supporting services as an input for their production.

6. In Victoria work has been underway over the past 10 years to extend traditional market principles to include regulating, maintenance and supporting services. In order for the markets to operate there has been a need to define how ecosystem services will change as a result of changes in land use and management. Environmental metrics have been developed that represent a change in the flow of ecosystem goods and services as a result of changes in land use and management. In Victoria landholders (the economic unit) receive periodic payments for changes in land use and management to increase the generation of ecosystem goods and services. Following a market transaction in Victoria it is possible to report changes in the condition and extent of ecosystem assets and the change in generation of ecosystem goods and services.

7. This paper will use the lessons learnt over the past 10 years in Victorian environmental markets to inform the design and application of both the SEEA-CF and the SEEA-EA. We will show that it is possible to develop an operational ecosystem accounting approach that is consistent with traditional accounting practices. To do this, we show that ecosystem assets can be dealt with in an accounting manner similar to economic units. By thinking of ecosystems like economic units, we can estimate ecosystem goods and services flowing through them and describe how it is possible to apply national accounting concepts like Gross Domestic Product (GDP) to produce a Gross Ecosystem Product (GEP) which is the net ecosystem goods and service flows between ecosystem assets. This approach also allows us to make trade-offs between ecosystem and economic objectives by associating ecosystem flows with either ecosystem or economic/societal utility.

8. The paper is organised as follows: Section 2 defines the terminologies used in the paper, and provides an overview of related works that serve as foundations for the proposed methodology. Section 3 details the proposed methodology. Section 4 provides illustrative examples of the proposed methodology in the Victorian context.

2 Conceptual Framework

9. It is our observation that many of the issues and debates that have been occurring to date perceive environmental accounting to be a *special case* of accounting. It is our view that the environment is different and challenging but many of the accounting principles already exist and it is an extension of those principles that is required, not the creation of new principles. The SEEA-CF provides principles and guidelines for the reporting and classification of assets that are consistent with the System of National Accounts. The SEEA-EA aims to extend those accounting principles to classify, measure and report ecosystem services. This section provides a critical examination of the aims and definitions that have been presented and or discussed in both the SEEA-CF and the SEEA-EA to develop a conceptual framework for application of environmental-economic accounting.

2.1 Environmental asset

10. The SEEA-CF classifies environmental assets as mineral and energy resources, land, soil, aquatic, other biological and water assets (SEEA-CF Table 5.2.1). They are naturally occurring living and non-living components of the Earth, together comprising the bio-physical environment that may provide benefits to humanity (SEEA-CF 5.8).

11. A key limitation of accounting for only environmental assets is that it does not reflect interactions between the components. The extraction of environmental assets may directly influence the volume of ecosystem services provided to society. For example, the removal of timber stocks from a forest will reduce water filtration and habitat ecosystem services. Reporting the supply, use, stock and flows of only environmental assets will not provide a complete picture of society's interaction with the environment.

2.2 Ecosystem Assets

12. In Figure 1 below, *ecosystem assets* are the structures, processes and functions formed by the complex interaction of biotic communities (e.g. plants, animals, micro-organisms) and the physical environment (which includes abiotic). The classification of a given area of land based on its structures, processes and functions defines it as an ecosystem asset. The total area of terrestrial based ecosystem assets must equal the total area of the environmental asset land.

13. For the purposes of defining an ecosystem asset we include all land defined in both the SNA and the SEEA-CF. Ecosystem assets may contain economic and environmental assets, some of which may already be accounted for in the SNA. Under this definition, unmodified forests, grazing land and housing estates would all be considered ecosystem assets. Ecosystem assets can be classified and reported on based on their capacity to produce ecosystem goods and services.

14. In this paper we assume that any given unit of land has the capacity to produce several ecosystem goods and services jointly. In economic terms this is commonly referred to as joint production. For instance, a forest provides habitat, wood and water filtration at a minimum. An ecosystem accounting framework needs to incorporate and explicitly recognise the joint production capacities and capabilities of all ecosystem assets.

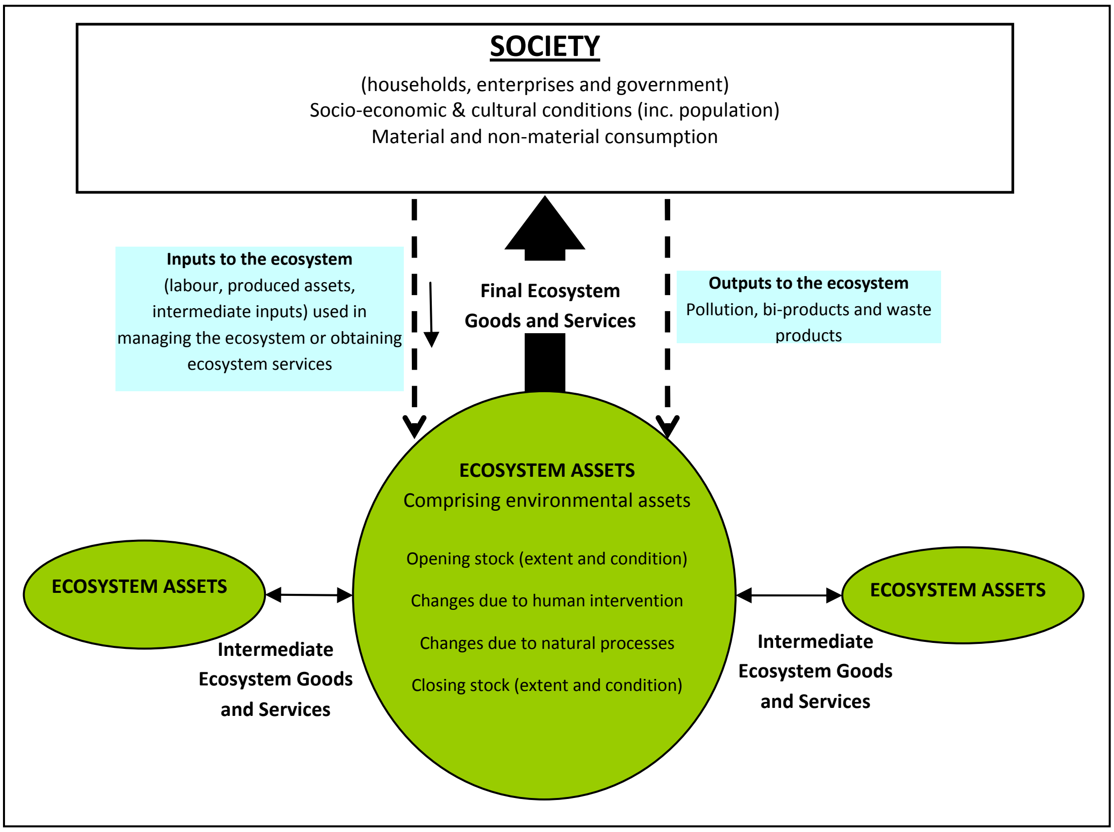


Figure 1: Overview of the flow of intermediate and final ecosystem services

2.3 Ecosystem capital

15. Ecosystem capital is a concept borrowed from finance and economics to recognise that an ecosystem asset is a store of future benefits in the form of ecosystem goods and services. Future ecosystem goods and services may be based on the capacity, condition, connectivity and extent of an ecosystem asset.

16. These concepts provide a familiar link with the concepts of depreciation and obsolesce as reported in the SNA and noted in the SEEA-CF. The capacity of an ecosystem asset may be depreciated due to the loss of soil via erosion processes through poor management. This form of deprecation recognises that the store of future services has declined, assuming the soil cannot be replaced and there are no substitute technical solutions.

17. Our approach accounts for all flows of ecosystem goods and services from all ecosystem assets. This enables us to collate information to address issues such as resilience and degradation. There may be opportunities to infer a '*value*' for ecosystem capital based on its future potential to provide goods and services. Inferring value based on a capitalised view of future goods and services will not be covered in this paper.

2.4 Ecosystem goods and services

18. A key challenge for ecosystem accounting is the use of language to describe ecosystem goods and services and what is being accounted for. Terms such as goods, services, ecosystem, function etc all have different meanings for specialist such as economists, accountants and ecologists, etc. In order to present our conceptual framework in this paper we have adopted a set of terms which may violate the definitions used by anyone or all specialists. We acknowledge that at some stage terms need to be agreed upon but in the first instance the elements of the framework need to be refined to meet the needs of accounting for links between the economy and ecosystems. We have drawn on the ideas of a number of authors to develop our conceptual model including De Groot et al. (2002), MA (2005), Boyd and Banzhaf (2007) Wallace (2007), Fisher et al. (2009), TEEB (2010) and Haines-Young and Potschin (2011). They all use the terms noted above but there is still considerable work needed to reconcile how each gives the term meaning and how it is applied.

19. In our view ecosystems are dynamic interrelated collections of living and non-living components organized into self-regulating units. Some degree of biodiversity exists in all ecosystems. An ecosystem can be viewed as a unit if boundaries are defined so it can be distinguished from its surroundings. The living and non-living components affect each other in ***complex exchanges*** of energy, nutrients and wastes. We associated these complex exchanges with the terms regulation, maintenance and supporting processes, systems or services (De Groot et al., 2002; MA, 2005; TEEB, 2010; Haines-Young and Potschin, 2011). It is these dynamic and complex exchanges, both fast and slow, which provide ecosystems with their distinct identities. We define the ***aggregate of all exchange processes*** within ecosystems as ***ecosystem function*** and estimate it via **capacity or condition** measures. We further define the products that are being exchanged both within and between ecosystems as ***ecosystem goods and services***.

20. Goods and services should be distinguished for accounting purposes. Goods are generally considered tangible; they can be touched, gripped, handled, looked at, smelled and tasted. They are not perishable – i.e. when rendered, they still exist. Goods are separatable and non-simultaneous; it is possible to consume the good at a different time and place to where it was rendered. Finally, goods are not variable – the recipient will not change their nature. On the other hand, services are intangible, perishable, non-separatable, simultaneous and variable (see Table 1 below).

Table 1: Goods and services

	Good	Service
Tangible • can be touched, gripped, handled, looked at, smelled, tasted	✓	×
Perishable • when the service has been completely rendered, it irreversibly vanishes as it has been consumed	×	✓
Separatable • consumption can be separated from delivery	✓	×
Simultaneous • rendering and consumption must occur during the same period of time	×	✓
Variable • regarded as heterogeneous or lacking homogeneity and are typically modified for each consumer or each new situation	×	✓

21. All ecosystems can both generate and consume ecosystem goods and services. Ecosystem accounting needs to be able to report both the generation and consumption of goods and services and link it to the economy where appropriate or necessary. Ecosystem goods and services flow within an ecosystem, between ecosystems and between ecosystems and the economy. Ecosystem goods and services used within the ecosystem are considered **'intra'** goods and services, ecosystem goods and services transferred between ecosystems are considered **'inter'** and ecosystem goods and services used directly by the economy are considered **'final'** (see Table 2 below).

Table 2: Use classifications of ECOSYSTEM GOODS AND SERVICES

Ecosystem functions generate	Within ecosystem 'Intra'	Between ecosystems 'Inter'	Ecosystem to economy 'Final'
Goods	1) A dead tree falling to the ground Nutrients	2) Water	3) Wood, water, minerals, cultivated natural resources
Service	4) A hollow log providing shelter Pollination	5) Pollination Bird carrying a seed between ecosystems	6) The tree remains in the forest for picnics Clean water to swim in

22. Intra ecosystem goods and services are all those exchanges that happen within an ecosystem (boxes 1 and 4 in Table 2). An example of an ***intra good*** would be nutrients in the soil used by plants to grow, or seeds eaten by birds that reside in the ecosystem. An example of an ***intra service*** would be a hollow log providing shelter to a mammal or pollination provided by bees

residing within the ecosystem. In our accounting approach the measure for intra ecosystem goods and services is estimated via a capacity or site condition indicator. This measure is asset-specific and does not take into consideration the contribution of the ecosystem in the broader landscape (inter goods and services).

23. ***Inter*** ecosystem goods and services are the flow of goods and services between ecosystems (boxes 2 and 5 in Table 2). An example of ***inter goods*** is water flowing down a catchment, or seeds that are consumed by a bird from another ecosystem. ***Inter services*** include pollination provided by bees across multiple ecosystems, or birds carrying seeds across ecosystems. The measure of inter ecosystem goods and services is a result of both ***ecosystem capacity*** and ***ecosystem significance***[1] in the landscape. Significant ecosystems are highly connected ecosystems within the landscape. The better the connections the greater the opportunity for an ecosystem to provide inter ecosystem goods and services.

24. The economy (society) utilises 'final' ecosystem goods and services (boxes 3 and 6 in Table 2). The economy can extract ***final goods*** like wood from a forest or water from a river to be used in economic activity. The economy can also add goods to the ecosystem, resulting in positive or negative consequences. For example, water from a dam can be provided to a wetland ecosystem to assist with its function. Alternatively the economy may provide residual goods in the form of dirty water to an ecosystem that has a deleterious impact on the receiving ecosystem.

25. ***Final services*** used by the economy are generally cultural or educational services. For example, the forest ecosystem provides a place to have a picnic; a river provides you a place to swim and wind regulation to shelter stock. There are also instances where the economy might offer services to the ecosystem. For example, the economy might relocate species between ecosystems to improve genetic diversity in both.

2.5 Accounting for the exchange of goods and services

26. For completeness, ecosystem accounting needs to measure and report all functions and work towards understanding the relationship between intrinsic ecosystem functions (intra) and human intervention. By consuming ecosystem **goods** *society* is making a trade-off between economic activity and ecosystem function. Our conceptual framework reports how the use of goods for economic activity impacts on ecosystem function and in turn how this changes flow of ecosystem goods and services.

27. Any depletion in the availability **goods** to an ecosystem will have an impact on an ecosystems ability function and provide ecosystem goods and services. The removal of a good from and ecosystem (say wood) will result in a change in the stock of that good and have an impact on the function of ecosystem. In contrast, consuming a service is passive and will not change the availability of the service. For example, honey is a good and pollination is a service provided by bees. Extracting the honey from the hive will immediately influence the capacity of the hive to produce honey. This

[1] See Appendix 1 for further discussion of ecosystem significance.

disruption will subsequently influence the pollination service provided by the bees. However, use of the pollination service will not have an immediate impact on the capacity of the hive to produce honey.

28. A schematic diagram of the flow of ***final*** ecosystem goods and services to the economy and ***inter*** ecosystem goods and services to other ecosystems is presented in Figure 2. Final ecosystem goods and services are used by society and enter in the economy and recorded as part of the economic activity. Inter ecosystem goods and services are used by other ecosystems. An ecosystem relies upon inter ecosystem goods and services for it to continue to functioning. It is possible for the condition of an ecosystem to decline (even if it starts out in perfect condition) if the ecosystem is not receiving adequate inter ecosystem goods and services from other ecosystems to function.

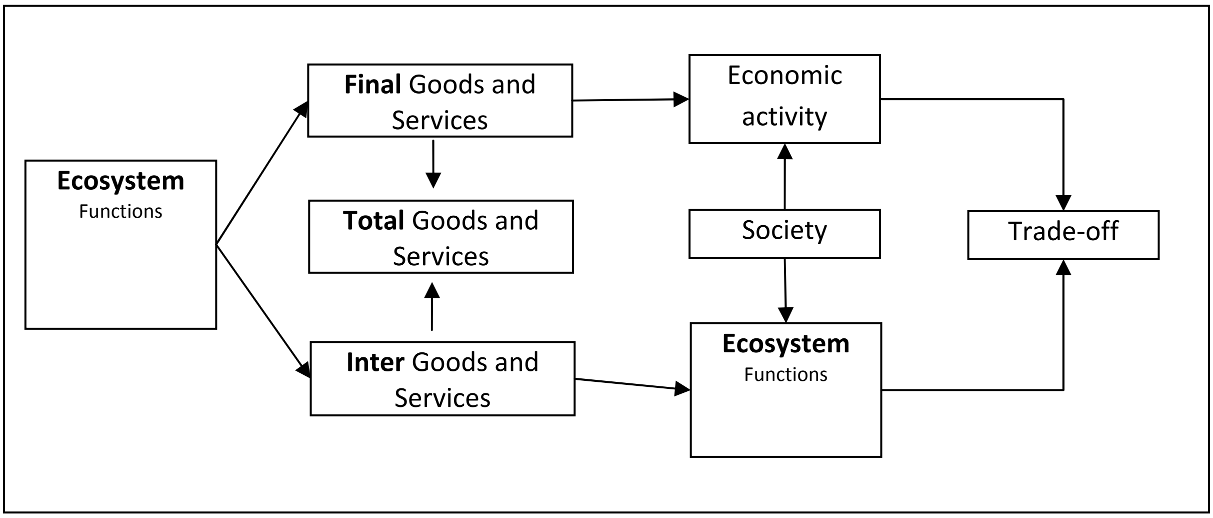


Figure 2: The tradeoff between final and inter ECOSYSTEM GOODS AND SERVICES

29. The general form and principles SEEA-CF accounts do not need to be adjusted for the purposes of ecosystem accounts as ecosystem goods behave like environmental assets - they are physical and are extracted from the ecosystem when used. However, there is a key difference in *production boundary* for the ecosystem goods and service when compared to the SEEA-CF. In the Central Framework, cultivated natural resources are considered to be within the economy, whereas natural biological resources are considered part of the environment (SEEA-CF 3.54). In our conceptual framework, all ecosystem goods that enter the economy, regardless of whether they are cultivated or not, are considered to be extracted from ecosystem assets. For example, in the SEEA-CF, crops are not considered environmental assets, therefore when extracted, no transaction between the environment and the economy has taken place. However, in our approach, extracting crops will result in a transaction between the economy and the ecosystem.

30. Adjusting the production boundary reflects that ecosystem goods are provided by all units of land, regardless of their 'naturalness'. This enables the account to show not only that the economy directly extracts ecosystem goods (as in the SEEA-CF), but the economy can also add products to the ecosystem to directly improve the supply of ecosystem goods and services. By reporting the total output from ecosystems and the total input to ecosystem, the 'value add' of each ecosystem can be estimated.

31. Table 3 below provides a summary of the links between ecosystem goods and services, their stage, the user, the accounting system and the account.

Table 3: Ecosystem services and accounting system

Stage	Ecosystem Function (Goods and services)	User	Accounting system	Account
Intra	Services	Ecosystem	SEEA	Asset by condition/capacity indicators
Inter	Services	Ecosystem	SEEA	Asset by (condition/connectivity)
Intra	Goods	Ecosystem	SEEA	Asset by condition/capacity indicators
Inter	Goods	Ecosystem	SEEA	Asset by (condition/connectivity), Physical supply and use table
Final	Goods	Society	SNA	Asset by final goods, Physical supply and use table
Final	Services	Society	SEEA	Recreation and tourism

2.6 Flows of ecosystem goods and services

32. The total flow of ecosystem goods and services is analogous to Gross Domestic Product using the production approach. To estimate GDP there are three steps: (i) estimate the gross output of economic activities, (ii) determine intermediate consumption and (iii) take the difference between the two. To create a similar estimate of Gross Ecosystem Product three steps are also required: (i) estimate the gross value of ecosystem goods from an asset, (ii) determine the consumption of ecosystem goods and services used by the same asset and (iii) take the difference between the two. The sum of all the differences is Gross Ecosystem Product (see Table 4 below for a summary of the steps).

Table 4: Link between GDP and GEF

Step	Gross Domestic Product (GEF)	Gross Ecosystem Goods (GEG)
1	Estimate the **Gross Value** of domestic Output in various economic activities	Estimate the **Gross Ecosystem Goods and Services** from an ecosystem asset
2	Determining the **intermediate consumption**, i.e., the cost of material, supplies and services used to produce final goods or services	Determining the **inter use** of GES by the asset, i.e., pollination, habitat, water, nutrients used to produce inter ecosystem goods or services
3	Deduct intermediate consumption from Gross Value to obtain the Net Value of Domestic Output	Deduct inter consumption from Gross ecosystem goods and services to obtain the Net Value of Ecosystem Flows

33. Figure 3 provides a conceptual view of the GEP for the flow of ***inter*** ecosystem goods and services. The larger area represents a catchment (watershed) or ecosystem asset. Within the catchment there are many ecosystem assets (see callout in Figure 3). There are flows between each ecosystem asset and there is a net flow out of the catchment. In this example, the sum of all ***inter*** water flows within the catchment are 1,000ML; the net inter flow of water out of the catchment is 250ML, which may flow into another ecosystem or to the economy, or both. As a result, the total ***inter*** water flows are 1,250ML, which can be termed GEP-Water.

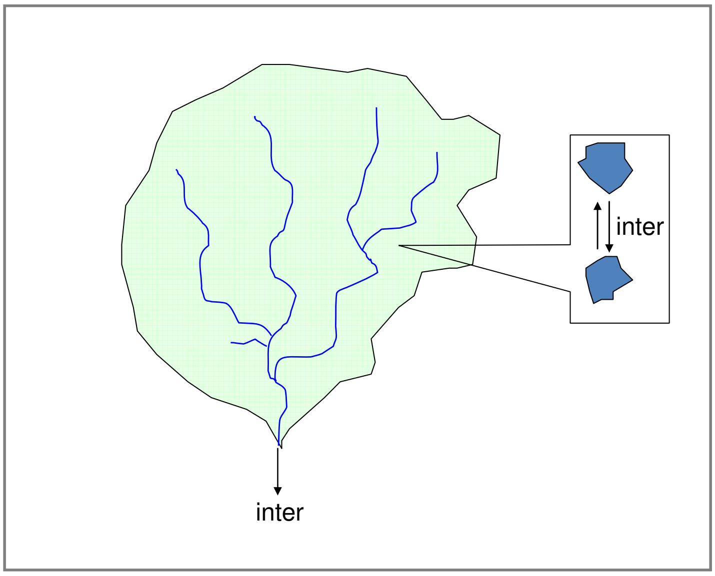


Figure 3: Conceptual view of inter ECOSYSTEM GOODS AND SERVICES

2.7 Joint production of ecosystem services[2]

34. In traditional SNA accounting each unit of land has a predominate use or management that is used to allocate it to an industry class. This approach recognises the production of one good say sheep from grazing in the agricultural sector. However, the sheep farm in question may contain land that is considered marginal for sheep production but is lightly treed and provides cover and protection for the sheep in inclement weather. The lightly treed area also provides other **intra** and **inter** ecosystem goods and services such as habitat, water regulation, etc.

35. Conveying tradeoffs and synergies between different forms of ecosystem goods and services, and between economic and environmental production should be an objective of ecosystem accounts. The accounts need to provide information in a useful form in order to allow decision makers to assess current and future trade-offs resulting from investments in all ecosystem services, including those currently reported as goods in the SNA.

2.7.1 Benchmark assessment of indicators

36. Reference condition accounting (RCA) has been proposed for ecosystem accounting to allow the comparison and aggregation of heterogeneous ecosystem assets, goods and services (Cosier, 2011) by facilitating the non-monetary valuation of ecosystem services. This approach measures the condition of assets and the flows of goods and services relative to an ideal state (reference condition). In RCA, the natural state is generally considered the ideal state as it represents millions of years of natural ecological optimisation.

37. We propose that RCA represents the ***ecological utility*** of the flow of goods and services within and between ecosystems. RCA assumes that ecosystems have a preference for the flow of

[2] Discussion of *joint production* is limited in this paper. The authors are preparing a manuscript on the topic.

goods and services to be at a natural state. If the flow of goods and services within an ecosystem diverges from this natural state there will be a loss of ecological utility. However, ecological utility is not the only utility associated with environmental-economic accounting. The economic or societal[3] utility for ecosystem services should also be reflected to allow environmental and economic trade-offs to be made.

38. An additional challenge with RCA is in reflecting that multiple stable states characterize most ecosystems. Disturbances or perturbations often occur that drive an ecosystem away from its ideal state, without significantly altering the ecosystem function. The sustainability of a disturbance is dependant on the ecosystem's regulatory feedback mechanisms working to maintain ecological function. If an activity does not change the long-term function of an ecosystem, it is sustainable; if the activity changes the long-term function of the ecosystem or puts it on a downward trajectory, it is not sustainable. Therefore we suggest that a sustainable threshold for ecosystem goods and services is indicated alongside benchmark condition (Figure 4). If the flow of goods and services is within this threshold, the ecosystem is sustainable, if flows are beyond this threshold, the ecosystem is not sustainable.

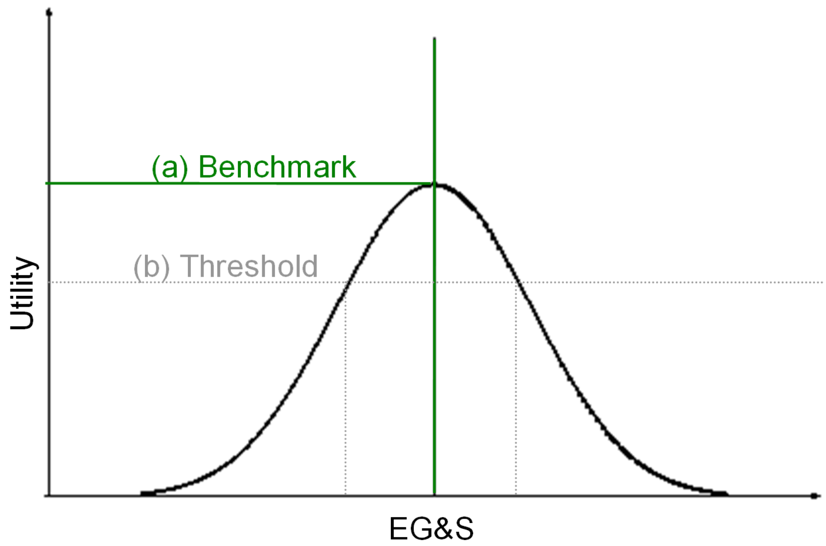


Figure 4: Ecological utility

39. Figure 5 gives an example of this concept for timber harvesting from a natural forest. The left chart shows the impact of extraction on the intra ecosystem function. The x-axis shows the number of trees per hectare, with the natural state representing the benchmark; the y-axis shows the utility provided by trees to the intra ecosystem function. This chart shows that by extracting trees for timber harvest, the number of trees per hectare drops below the sustainable threshold and the ecosystem will no longer be able to provide the intra ecosystem services required to regenerate the trees.

[3] Which may include ethical, legal, spiritual, cultural etc

40. The second column of charts show the impact timber extraction has on the ecosystem inter goods and services. The x-axis in these charts show the output of goods and services by the ecosystem; the y-axis shows the utility of this output to adjacent ecosystems. In this example, although water output has increased and pollination output has decreased, neither is beyond the sustainable threshold. This means that timber extraction will not change the function of the adjacent ecosystems.

41. Finally, the last column shows the economic utility of the extraction. This key difference in this chart is that the y-axis indicates **economic utility**. The chart shows that the economy has a preference for extracting more timber. It also shows the natural benchmark and sustainable threshold to highlight the tradeoffs between economic and ecosystem utility.

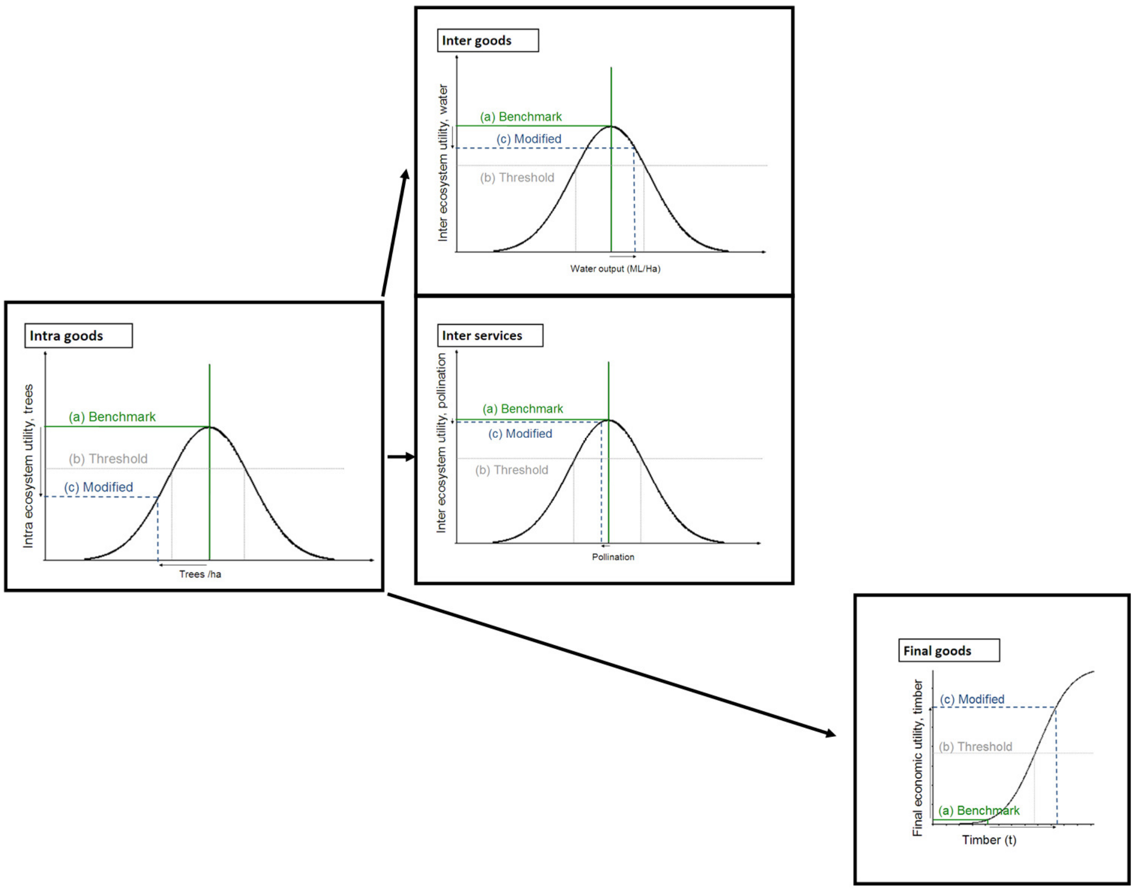


Figure 5: Ecosystem utility example - timber harvest

3 Proposed approach

42. An operational approach is required in the practical application of the SEEA Experimental Ecosystem Accounts. An operational approach translates the fundamental principles into empirical guidelines for the classification, measurement and reporting of ecosystem assets and services. The aim is to create tangible instances of the fundamental principles. It is our opinion that many of the

uncertainties around the SEEA principles are due to the lack of tangible instances in which to anchor discussion and debate. An operational approach can highlight ambiguities in the articulation of the principles, test the interpretation for flaws and inconsistencies, and facilitate the validation and refinement of the underlying assumptions.

43. The conceptual framework discussed in Section 2 defines the scope necessary to formulate an operational approach to the SEEA Experimental Ecosystem Accounts. The conceptual framework is inclusive of all land in the accounting of ecosystem assets, and allows for the joint attribution of multiple ecosystem goods and services to an ecosystem asset. An area of land and everything on it are regarded as a functional "unit" generating ecosystem goods and services, rather than as independent parts which happen to be co-located on the same area of land. Our conceptual framework links the ecosystem accounts to the economic accounts through the final ecosystem goods and services, and through financial transactions that change the stock of ecosystem assets or their capacity to generate ecosystem goods and services.

44. This section discusses an operational approach developed for implementation in the Victorian ecoMarkets Programme. The approach applies the conceptual framework to the three key activities in general accounting practice: classification, measurement and reporting. Classification requires clear specification of the boundaries that define an item to be classified, and of the characteristics that determine which class an item belongs to. Measurement requires an empirical methodology for quantifying the attributes that characterise every item within the scope of accounting. Reporting requires a tractable and efficient process for summarising and presenting the results of classification and measurement, particularly in a manner that can be utilised when making decisions about trade-offs and flow-on effects in both the environment and the economy.

3.1 Classification

45. Classification is an important part of general accounting practice. Each item within the scope of accounting is a discrete unit that needs to be categorised correctly into a class. The interpretation of the measurements and reporting rely on the correct classification of the items. In financial accounting, for example, the integrity of the measurements and credibility of the reporting rely on standards that define what constitutes an "item" or "unit" (e.g. a unit of stock, a transaction item, etc), and strict guidelines for the correct classification of each item (e.g. debit, credit, asset, liability, etc).

46. The classification of ecosystem assets and ecosystem goods and services for accounting purposes is a challenging problem. There appears to be a general understanding of the concept of ecosystem assets of various types (e.g. woodlands, wetlands, etc), as well as the concept of ecosystem goods and services of various types (e.g. provisioning, regulation and maintenance, etc). However, the ecological underpinnings of those concepts do not sit well in an accounting exercise where a "unit" of ecosystem asset, good or service needs to be discrete with well-defined boundaries. The transition from an ecosystem of a particular type into an adjacent ecosystem of a different type is often gradual with no discernible boundary. The complex bio-physical interactions that generate ecosystem goods and services can be local or global in scale, span a wide range of time

scales, and vary over a continuum of possible states. These complications make it difficult to define and classify a "unit" of ecosystem asset, good or service.

47. Many schemes and taxonomies have been proposed for classifying ecosystem assets and ecosystem services (e.g. De Groot et al., 2002, Haines-Young and Potschin, 2011; Ojea et al., 2012), but the need to identify the boundaries that define a "unit" of ecosystem asset or service prior to classification is often overlooked. In our conceptual framework, however, the scope of ecosystem accounting is inclusive of all land. This exposes the operational need to partition the land into discrete areas, each defining the boundary of a "unit" of ecosystem asset, before the assets can be classified. The asset boundaries are also needed to determine the interface for goods and service delivery, which is a pre-requisite for defining and classifying a "unit" of ecosystem service. The next section describes our approach to defining the boundaries of ecosystem assets and economic units to allow classification to occur.

3.1.1 Analytical units

48. *Analytical units* are the building blocks in our approach to define a "unit" of ecosystem asset. An analytical unit is an artificial construct that satisfies the following properties:

a) The analytical units are mutually exclusive and collectively exhaustive coverage of the scope of accounting (i.e. all land).

b) The analytical units have a common spatiotemporal scale (e.g. 100m x 100m, annual).

c) The spatial and temporal scales should be at a resolution that is sufficient to assume homogeneity within the analytical unit. The standard practice in statistical classification is to assign an analytical unit to exactly one class in any given classification scheme. This requires the spatiotemporal scale to be sufficiently small so that each analytical unit is either homogeneous or can be classified based on pre-dominant characteristics with minimal magnitude of error.

d) The spatiotemporal extent of each analytical unit is fixed, but can be repartitioned hierarchically to create finer resolution analytical units.

e) Each analytical unit can be assigned a "universally-unique" identifier.

49. The analytical units are constructed by partitioning the landscape into fine-resolution grid cells. The grid cells sum to the total area of land. Draft versions of SEEA Part 2 Chapter 2 refer to an analytical unit as a "spatial constructor" or a "basic spatial unit". In this paper, we shall refer to the grid cells as "analytical units" to reflect the fact that they have both spatial and temporal dimensions. Also note that we define the spatial extent of an analytical unit to be a 3-dimensional cuboid – that is, it includes the land surface, airspace and subsurface unit (Figure 6). For consistency with economic accounts, the airspace and subsurface limits are as stipulated by laws on land ownership.

50. Each unit is presumed to be homogeneous so that a unit is assigned exactly one class label in any given classification scheme for accounting. The spatiotemporal scale of an analytical unit also determines the scale of the ecosystem services generated by that unit. For example, if the

spatiotemporal scale of the analytical units is 1 ha per year, then a "unit" of mass flow regulation can be defined as a unit tonne per hectare per year.

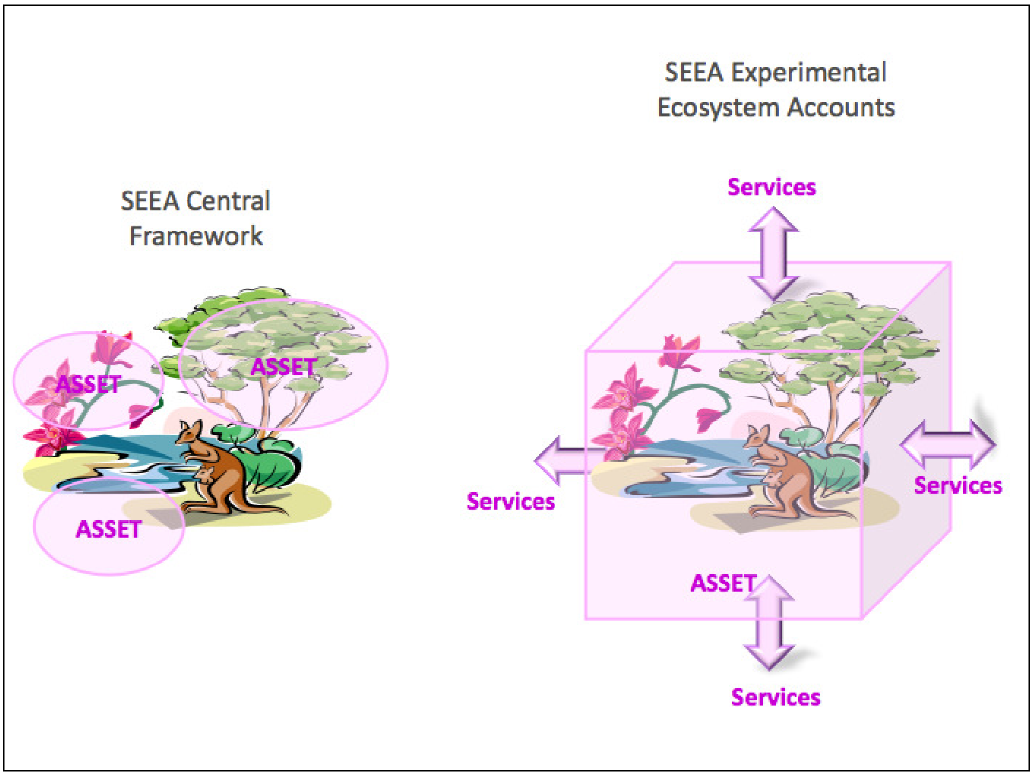


Figure 6. The boundaries of an ecosystem asset also define the interface for ecosystem services.

51. In our operational approach to ecosystem accounting, each analytical unit is considered a "unit" of ecosystem asset for accounting purposes. We acknowledge that this can cause some consternation. The boundaries of an analytical unit are arbitrary delineations motivated by operational necessity rather than ecological principles. However, note that analytical units are cohesive building blocks that can be configured to form larger units. It is possible to indicate the ecologically based boundaries of an ecosystem asset by assigning the same class label to all the analytical units that belong to that asset. In Figure 7, for example, the analytical units that are considered to be part of the same ecosystem asset are labelled with the same colour. The "jaggedness" of the boundaries between different colours can be reduced by choosing a finer resolution for the analytical units.

3.1.2 Goods and services interface

52. The spatiotemporal extent of an analytical unit serves as the "production boundary" or "interface" for the ecosystem goods and services generated by that unit (Figure 6). In our conceptual framework, all the elements within the analytical unit's boundary constitute a functional unit that generates goods and services. Information on those goods and services is based on the exogenous inputs and endogenous outputs that cross the boundaries of that unit. This includes information on natural inputs (e.g. rainfall, run-on, transient fauna, airborne pollen, etc), human inputs and

influences (e.g. labour, herbicides, nutrients, wastes, disturbance, etc), natural outputs (e.g. run-off, sediments, oxygen, etc), and harvested or produced outputs (e.g. timber, crops, aquaculture, etc). The boundary of a unit is the interface that determines the accounting of the goods and services generated.

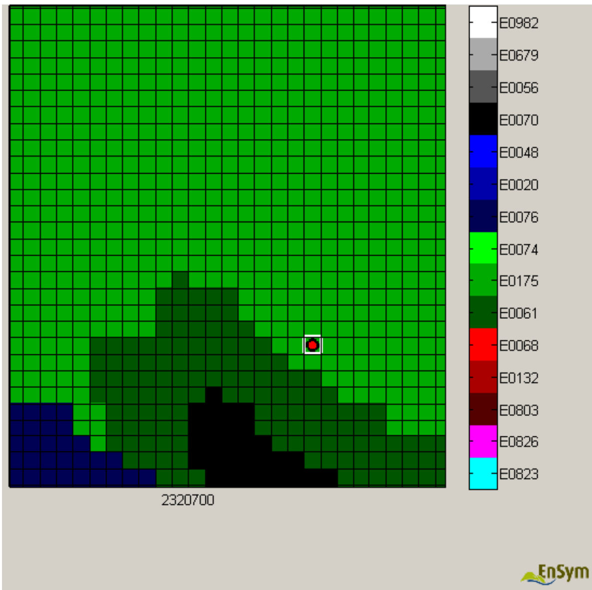


Figure 7: Analytical units labelled according to the ecological boundaries of ecosystem assets.

53. The differential in the inputs and outputs that cross the boundaries of a unit (i.e. an analytical unit or an ecologically-defined unit of ecosystem asset) indicates the ecosystem goods and services generated by that unit. For example, the difference in the amount of nutrients that enters a unit (e.g. either as directly-applied fertilisers, or dissolved in run-on from an upstream adjacent unit) and the amount of the nutrients leaving the unit (e.g. dissolved in run-off to the downstream adjacent unit) is indicative of its nutrient cycling service. Similarly, the differential in the headwinds and the tailwinds on the boundaries of a unit indicates its airflow regulation service. The differential in parts of carbon per volume of air through the boundaries of a unit is indicative of its carbon sequestration service or its carbon storage service (i.e. preventing the release of the carbon it currently stores). The differential in biomass that enters and leaves the unit boundary as goods (e.g. timber, crops, stock) is indicative of the unit's provisioning services.

54. Our conceptual framework acknowledges that elements within a unit can provide goods and services to other elements within that unit. Drafts of SEEA Part 2 refer to these as "intra-ecosystem" flows. However, how we account for those goods and services is a question of granularity. In our operational approach, the analytical unit (rather than its elements) is the lowest level of granularity.

3.1.3 Attributes

55. *Attributes* are the basic pieces of information in our approach to the classification of ecosystem assets, goods and services. Having defined the spatiotemporal boundary of an analytical unit, the classification of that unit depends on its characteristics. An attribute is an empirical description of a specific characteristic of an analytical unit. Table 5 lists some example attributes that we have selected for illustration purposes in subsequent sections.

Table 5: Examples of attributes and the information they provide

Attribute	Information	Example attribute values (for analytical units with spatiotemporal scale of 1 hectare and 1 year)
Aspect	Inputs	Numeric: degrees from North, e.g. "40.5 degrees" Categorical: orientation, e.g. "northeast"
Asset name	Identifier	Nominal: e.g. "Wilsons Promontory National Park"
Biomass	Composition	Numeric: carbon in tons/ha/yr
Bioregion	Processes	Categorical: IBRA Codes, WWF Ecological Land Classification Codes
Character species	Composition	Categorical: e.g. "Eucalyptus spp"
Climate	Processes	Categorical: Koppen-Geiger, e.g. "BWh"
Connectivity	Configuration	Numeric: index, percentage relative to reference, etc Categorical: e.g. "low", "high"
Conservation status	Rarity	Categorical: e.g. "endangered", "rare"
Elevation	Processes	*(similar to "Rainfall")*
Erosion	Outputs	*(similar to "Rainfall")*
Fire – likelihood	Risk	Numeric: fuel load, probability estimates Categorical: "likely", "high"
Industry – primary	Economic activity	Categorical: ANZSIC Codes
Industry – secondary	Economic activity	Categorical: ANZSIC Codes
Land cover	Configuration	Categorical: FAO Land Cover Classification Codes
Land use	Economic activity	Categorical: ALUM Codes
Large trees	Structure	Numeric: DBH (e.g. "70 cm"), density (e.g. "20 stems/ha") Categorical: e.g. "DBH=50-70cm; density=15-25 stems/ha"
Ownership	Economic activity	Categorical: Victorian Standard Parcel Identifiers
Rainfall	Inputs	Numeric: mean gauge, e.g. "455mm/yr" Numeric: volume, e.g. "52.1 ML/ha/yr" Categorical: range, e.g. "400-600 mm/yr" Categorical: descriptive, e.g. "low", "below average"
Regional authority	Reporting	Categorical: Catchment Management Authority
Soil type	Composition	Categorical: Northcote (1979), e.g. "Db4-31"
Surface run-off	Outputs	*(similar to "Rainfall")*
Tenure	Jurisdiction	Categorical: "public", "private"
Veg. Quality	Structure and composition	Numeric: Habitat-Hectares Categorical: "poor", "good"
Vegetation type	Structure and composition	Categorical: Ecological Vegetation Class

56. Attributes can be quantitative or qualitative. For example, "rainfall" is a quantitative attribute, whereas "tenure" is a qualitative attribute. Quantitative attributes can be expressed numerically (e.g. mean annual rainfall), or categorically using qualitative descriptions (e.g. "low", "below average") or using ranges (e.g. "400-600 mm/yr"). Qualitative attributes can be represented as numbers (e.g. FAO LCC code "33" for terrestrial cultivated shrubs) but it does not make that attribute quantitative because mathematical operations on those numbers are meaningless (e.g. adding 1.5 to FAO LCC code "33" does not make sense). Two attributes can be represented using

the same set of possible values. For example, "Industry - primary" and "Industry - secondary" can both be represented using ANZSIC codes, but they are considered two different attributes.

57. Categorical expressions of quantitative attributes often imply an interpretation of the absolute numerical measures. For example, whether a band of annual rainfall is "low" or "high" may be relative to the historical median or mean annual rainfall. The range of absolute values that fall within a category is often relative to a point of reference, such as a benchmark or percentile ranking that aids the interpretation of the numerical values. The range or width of that band may also depend on historical deviations from the point of reference. The absolute numerical values can be categorised in different ways, depending on the information required to interpret those values.

58. Attributes can represent endogenous or exogenous characteristics. For example, "soil type" and "vegetation quality" are endogenous characteristics of an analytical unit. "Connectivity", on the other hand, is an exogenous characteristic representing the spatial relationship of an analytical unit to its neighbours. "Asset name" can be regarded as an exogenous characteristic identifying an analytical unit as being part of a larger ecosystem unit. There are also attributes, such as "fire – likelihood", that are composites of endogenous and exogenous characteristics.

59. Attributes can also represent ecosystem goods and services generated by an analytical unit. For example, "erosion" can be expressed as differential quantities – i.e. the expected amount of sediment added to surface water that enters and leaves the boundaries of the analytical unit. These attribute values indicate the regulation and maintenance services in terms of absolute differential quantities.

60. In our operational approach, each attribute must satisfy the MECE (mutually exclusive, collectively exhaustive) principle. That is, for any given attribute, every analytical unit must have exactly one attribute value. This follows from our conceptual framework where the scope of accounting includes all land. Each analytical unit is assumed to be homogeneous according to its spatiotemporal scale and pre-dominant characteristics. Special attribute values, such as "Not Applicable" and "No Data", are assigned to analytical units where the attribute does not apply, or where the attribute values are unknown.

3.1.4 Classes

61. *Classes* are groupings of analytical units that have the same characteristics. Classes determine how the characteristics of the analytical units are interpreted and reported. For example, analytical units that have the same structure, composition, configuration and processes can be labelled as belonging to the same group (e.g. "vegetation type", "land use", etc.) A c*lass label* identifies each group. A *classification scheme* is a system of grouping and labelling the analytical units based on a logical set of rules that satisfy the MECE principle. The rules can be based on a single attribute (e.g. range of annual rainfall) or combinations of attributes (e.g. "climate" is a composite of rainfall, temperature, elevation, etc.) Hierarchical classification schemes are constructed by re-labelling groups of analytical units to form larger groups.

62. Several classifications schemes can be used concurrently, depending on the information required for accounting purposes. In our operational approach, classes are regarded simply as

qualitative attributes (e.g. "public", "cropping") or as descriptive labels of quantitative attributes (e.g. "above average", "high"). As such, classes in one classification scheme can be combined with other attributes to form another classification scheme (Figure 8). For example, "bioregion" classifications are often based on "climate" (which is a composite of "rainfall", "elevation", etc.) in combination with various attributes on the vegetation structure and composition. This "bottom-up" approach to the construction of classification schemes (as opposed to a "top-down" approach) helps ensure that the resulting scheme is based on clearly-specified attributes and explicitly-defined rules or criteria.

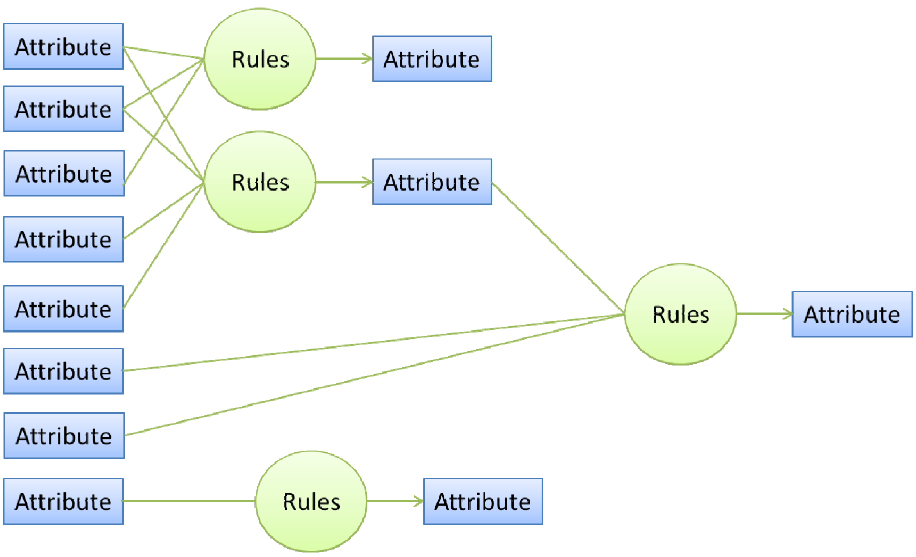


Figure 8: Classes are attributes constructed based on a logical set of rules.

63. The class label of an analytical unit represents an interpretation of its characteristics either in relation to a point of reference (e.g. benchmark, annual average), or in relation to the characteristics of other analytical units (e.g. proximity, percentile ranking). For example, whether the "vegetation type" of an analytical unit is "woodland" or "grassy woodland" depends on a set of attributes containing sufficient information so that a set of objective criteria can discriminate between the two types consistently across all analytical units. The criteria or rules for the classification scheme are based on the similarities and differences in the attribute values of the analytical units. These similarities and differences are summarised using class labels. In a hierarchical classification scheme, the similarities and differences between the classes also determine their grouping to form larger classes. The next section discusses how the classifications relate to the measurements of attribute values.

3.2 Measurement

64. Measurement is the process of determining the attributes values of the analytical units. In our conceptual framework, each analytical unit has to be assigned an attribute value for each

attribute, including class labels. In practice, however, it is often infeasible to conduct measurements on each analytical unit to determine its attribute values. Moreover, some attributes might not be directly observable. Many ecosystem functions and process span vast areas and timescales well beyond the spatiotemporal scale of the analytical units. This section discusses our operational approach to determining the attribute values of the analytical units.

3.2.1 Observation

65. Each attribute needs to be observed and measured at the spatial and temporal scale appropriate to that attribute. For example, suppose it is known *a priori* that the colours in Figure 7 are the appropriate scales at which certain ecosystem attributes should be observed. In which case, those attributes should be measured at that scale using valid sampling protocols (e.g. transects, quadrats, etc) and then extrapolated to the extent of that scale. Implicit in the extrapolation is the statistical imputation of the measurements to each analytical unit within that extent. Note that the colours in Figure 7 represent an *a priori* attribute classifying the analytical units into groups, and that the class labels determine the sampling and extrapolation of the measurements. In cases where an *a priori* classification is unknown or inappropriate, then other sampling protocols (e.g. lattices, tessellations) will have to be applied as methods for observation.

66. The spatiotemporal scale of the analytical units determines how the measurements are normalised. We acknowledge that measurements of some ecosystem characteristics (e.g. composition, structure, configuration, processes, etc) can vary in cyclic patterns over areas and timescales that may be smaller or larger than the spatiotemporal scale of the analytical units. However, the accounting discipline requires a clearly defined scope and accounting period. General accounting practice adopts on-going measurement regimes with interim as well as long-term reporting periods that provide information on change and trends. We apply this practice in our operational approach to ecosystem accounting. The spatiotemporal scale of the analytical units determines the scope and accounting period (e.g. per ha/year) to which the measurements are normalised, but short-term interim reporting periods provide sensitivity to detect change, while long-term reporting periods provide information on trends and cycles.

3.2.2 Indicators

67. Indicators are attributes that provide indirect measurements of ecosystem characteristics that cannot be observed directly or empirically. For example, “aspect” is a descriptive surrogate for the degree and variation of solar input to ecosystem functions and processes. In some cases where the characteristics can be measured empirically (e.g. “erosion”, “runoff”), it might not be feasible to do so for the entire scope of accounting. Our operational approach requires explicit assumptions on the statistical relationships (causal and associative) between indicators and the characteristics they represent. In the Victorian ecoMarkets Programme, the causal and associative relationships are encoded as ensembles of computational models in an integrated environmental modeling platform called EnSym[4].

[4] https://ensym.dse.vic.gov.au

68. Indicators are particularly important in the measurement and reporting of ecosystem services. Unlike ecosystem assets and goods, services are intangible and difficult to measure empirically. In our operational approach, services are inferred using computation models involving tangible indicators, both exogenous and endogenous to the analytical units. In Section 4, we shall show some examples of indicators used to measure ecosystem goods and services in the Victorian Experimental Ecosystem Accounts.

69. Note that our operational approach does **not** attempt to prescribe the method of measurement, the spatial and temporal scale for observation, or the techniques for estimation and imputation. However, it may be necessary at some stage to have agreed standards or guidelines for these scales and methods, particularly with regards to the indicators of ecosystem services.

3.2.3 Interpretation

70. Implicit in classification is an interpretation of the measurements. A class label represents a descriptive interpretation of the measurements of the characteristics which constitute that class. Correct classification is necessary to make accounting reports informative and relevant.

71. Our operational approach regards the measurement and the interpretation of those measurements as distinct steps. For example, our conceptual framework regards all inputs and outputs of ecosystem assets as goods and services. They are measured in absolute numerical quantities or in categorical terms, whether directly or indirectly using indicators and surrogates. The anthropocentric classification of those inputs and outputs is a secondary step. For example, whether those goods and services are “beneficial”, “final”, “economic”, etc is an interpretation involving the rules and criteria for the appropriate classification scheme.

72. An important aspect of our conceptual framework is the use of benchmarks or reference condition to interpret the measurements. This is particularly relevant in differential measurements that are indicative of ecosystem services. For example, the differential in the sediment load that enters and leaves the boundaries of an analytical unit can increase, remain constant or decrease. An increase in sediment load is generally interpreted as a disservice. However, a moderate increase can be part of a natural cycle that is beneficial to some ecosystems downstream. A substantial decrease can even be detrimental to some ecosystems downstream that depend on seasonal deposits of sediments. The fundamental assumption in our conceptual framework is that the natural state of ecosystems generates outputs (goods and services) at levels that are most beneficial to all ecosystems and to humanity. Given the inadequate understanding of the complex interactions and interdependence between ecosystems (i.e. inter-ecosystem goods and services), the benchmarks provide a reference point for interpreting whether the measurements indicate levels that are beneficial to ecosystems overall.

3.3 Reporting

73. The classification scheme determines how the measurements are reported. In the simplest form, accounting reports are tabulations of the number of analytical units that belong to a particular class. The tabulated entries should sum to the total units in the scope of accounting (i.e. the entries

should "balance" to the sum). Table 6 illustrates a tabulation of the analytical units based on two classification schemes: "vegetation quality" and "erosion". In this example, the tabulation can provide some information about the current overall state of the landscape. The cross-tabulation of the two classification schemes shows the number of analytical units that are of concern (low vegetation quality and high levels of erosion, highlighted in red) compared to the number of analytical units that are in a desirable state (highlighted in green).

Table 6: The entries in the tabulation are in units of account.

	Vegetation Quality (% relative to benchmark)					
Erosion (tons per ha per year)	**<20 (Low)**	**20-40**	**40-60**	**60-80**	**80-100 (High)**	**Total Ha**
<0.5	3	4	15	10	8	**40**
0.5-1.0	10	6	12	8	3	**39**
1.0-1.5	13	10	8	4	2	**37**
1.5-2.0	40	14	7	3	1	**65**
>2.0	80	16	5	2	1	**104**
Total Ha	**146**	**50**	**47**	**27**	**15**	***285***

74. Note that in the sample tabulation, the entries are expressed in the spatiotemporal scale of the analytical units (i.e. ha/yr). In financial accounting, the "unit of account" is in a common currency (e.g. dollars) over the same fiscal year. In ecosystem accounting, the spatiotemporal scale of the analytical units serves as a common unit of account which makes it possible to compare information from cross-tabulations of various combinations of classification schemes. This is particularly important in the reporting of goods and services. The entries have the same unit of account even when the classification schemes on the rows and columns are based on attribute values with different units of measure (e.g. tons, percentage, etc).

75. The level of aggregation in the reports depends on the granularity of the information required. For example, it would be possible to filter the entries in Table 6 for only those analytical units whose "conservation status" is "endangered", or whose "tenure" is "private". Hierarchical classification schemes enable various levels of aggregation for reporting purposes.

3.3.1 Aggregation

76. Aggregating is not a simple matter of adding numbers together or grouping the analytical units together in an arbitrary way. Instead, aggregation has to be based on something meaningful. For example, adding analytical units that belong to the same class that is informative (e.g. same jurisdiction, etc).

77. In our operational approach, we prefer a stronger set of criteria for aggregating analytical units. For example, when accounting for ecosystem capital, the aggregation should be based on the strengths of the interdependence between the analytical units. That is, analytical units are

aggregated into a unit of ecosystem capital based on the strength of the exchange of inter-ecosystem goods and services between those analytical units. The strength of the criteria enables the aggregation of analytical units in a way that accounts for the multi-scale characteristics of ecosystem capital, such as resilience, degradation, etc.

3.3.2 Links to SNA through the Land Accounts

78. Of particular interest is the aggregation of the analytical units according to a classification scheme that identifies economic transactions involving ecosystem assets, goods and services. Our conceptual framework considers an analytical unit as one ecosystem without making a distinction as to which components within that unit are economic assets or not. It is through economic transactions that result in goods and services entering/leaving the analytical unit boundary that we establish the link between economic activity and the ecosystem assets, goods and services.

79. In the Land Accounts (ABS 2010), for example, the cadastre parcels are the statistical units. Every piece of land asset belongs to a parcel, which has an "ownership" attribute that assigns an economic agent – an establishment or household – to that parcel. Land assets are owned, leased or used by governments, businesses and individuals for a variety of purposes and activities. Essentially all economic activities involve the use of some land and their economic transactions related to land either directly or indirectly (ABS 2010). The price of land as an asset is reflected in the SNA measured in $/Ha. The Land Accounts also attribute the parcels with "industry" based on the primary and secondary economic activities reported by the owners.

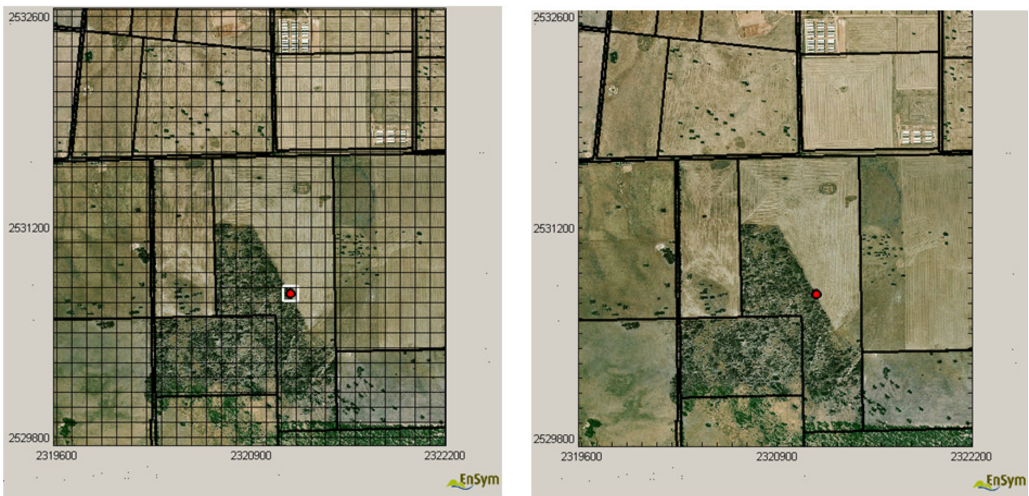


Figure 9. Aggregation of analytical units into parcels (statistical units for Land Accounts)

80. In our operational approach, each analytical unit is assigned an attribute value (e.g. Victorian Standard Parcel Identifier) that identifies the parcel that the analytical unit belongs to. This makes it

possible to aggregate the analytical units according to various parcel information and SNA classifications available through the Land Accounts. The SNA classifications may include the monetary valuations of the economic transactions attributed to the land. Once imputed to the analytical units, the information can be cross-tabulated with various classifications of ecosystem assets, goods and services. As in the sample table above, the aggregated entries can be filtered depending on the information required (e.g. filter based on classifications such as “intra”, “inter” or “final” goods and services). Note however, that this cross-tabulation does **not** represent a valuation of the ecosystem assets, goods and services.

3.3.3 Links to SEEA Central Framework

81. This section discusses how our operational approach to ecosystem accounting compares with the SEEA-CF physical supply and use accounts. The physical supply and use table within the SEEA-CF shows the total volume of environmental assets leaving the environment and entering the economy and the total volume of residuals leaving the economy and entering the environment (SEEA-CF Table 2.3.2). The table excludes all cultivated biological resources because they are not considered natural resource inputs and are instead treated as growing within the economy. We believe this view of natural resource inputs is not sufficiently inclusive to serve as a systems approach to ecosystem accounting. Our view is that all final ecosystem goods (wheat, sheep, beef, clean water, wood, etc) must enter the economy from the ecosystem and be reflected in the physical supply and use table.

82. The general form and principles SEEA-CF physical supply and use account do not need to be adjusted for the purposes of ecosystem accounts as ecosystem goods behave like environmental assets - they are physical and are extracted from the ecosystem when used. However, there is a key difference in *production boundary* for the ecosystem physical supply and use account when compared to the SEEA-CF. In the Central Framework, cultivated natural resources are considered to be within the economy, whereas natural biological resources are considered part of the environment (SEEA-CF 3.54). In our proposed physical supply and use ecosystem accounts, all ecosystem goods that enter the economy, regardless of whether they are cultivated or not, are considered to be extracted from ecosystem assets. For example, in the SEEA-CF, crops are not considered environmental assets, therefore when extracted, no transaction between the environment and the economy has taken place. However, in our approach, extracting crops will result in a transaction between the economy and the ecosystem.

83. Adjusting the production boundary reflects that ecosystem goods are provided by all units of land, regardless of their ‘naturalness’. This enables the table to show not only that the economy directly extracts ecosystem goods (as in the SEEA-CF), but the economy can also add products to the ecosystem to directly improve the supply of ecosystem goods and services. By reporting the total output from ecosystems and the total input to ecosystem, the ‘value add’ of each ecosystem unit can be implied.

84. By changing the production boundary, the SEEA table in its existing form needs some minor adjustments. The following changes have been made to the SEEA-CF table and are reflected in Table 7 below.

1) Change from environment to *'Ecosystem assets'* to reflect all ecosystems not just environmental assets
2) Reflects all flows from ecosystem assets to the economy and other ecosystems
3) Change in the text from 'environment' to 'ecosystem'
4) & 5) reflect the distribution of provisioning services to the economy – as final, and to other ecosystems – as intermediate. For instance, water may be stored in a dam for later use in the economy or be piped to a wetland to support the generation of regulation and maintenance services.
6) Reflects the ability of products to move from the economy and be used by ecosystems. The table then reflects that there are flows of provisioning services into the ecosystem from the society (households, enterprises and government). For example, fertiliser may be added to improve the final ecosystem service of wheat, or a fence may be added to improve natural regeneration. To account for this transfer the SEEA-CF supply and use table structure can remain as it.
7) Is a change in text from 'environment' to 'ecosystem'

Table 7: Physical Supply and Use (*changes from SEEA italicised*)

	Industries (inc. govt)	**Households**	**Accumulation**	**Rest of the world**	***(1) Ecosystem Asset***	**Total**
Supply table						
Natural inputs					(2) All provisioning flows from the ***ecosystem***	Total supply of natural inputs
Products	Output			Imports		Total supply of products
Residuals	Residuals generated by industry	Residuals generated by final household consumption	Residuals from scrapping and demolition of produced assets	Residuals received from the rest of the world	(3) Residuals recovered from the ***ecosystem***	Total supply of residuals
Use table						
Natural inputs	(4) Extraction of natural inputs (final ecosystem services)				(5) Intermediate ecosystem services	Total use of natural inputs
Products	Intermediate consumption	Household final consumption	Gross capital formation	Exports	***(6) Ecosystem use of products***	Total use of products
Residuals	Collection & treatment of waste and other residuals		Accumulation of waste in controlled landfill sites	Residuals sent to the rest of the world	(7) Residual flows direct to ***ecosystem***	Total use of residuals

85. By applying the accounting concept of balancing inputs and outputs to ecosystems, it is possible to build a supply and use account that applies to all goods moving across the landscape, thereby showing the flow-on impacts of economic extractions of ecosystem goods.

4 Victorian experimental ecosystem accounts

86. The Victorian government has invested in many programs that provide incentives to economic owners of land to minimise negative environmental externalities (nutrient runoff, erosion etc) or maximise the capacity of the land to provide both **intra** and **inter** ecosystem goods and services. For example, the Victorian ecoMarkets program invests in actions (e.g. building a fence) that result in the generation of ecosystem goods and services (e.g. clean water, improvement in catchment condition and habitat). [5]

87. The tables presented below use the proposed approach outlined in Section 3 to build accounts based on the SEEA asset structure to show the changes in ecosystem function, goods and services over time. These accounts demonstrate how the grid approach enables the aggregation and cross classification of data. It also shows how changes in flows of ecosystem goods and services can be attributed to economic activity. However these accounts are by no means comprehensive. In order to produce a complete picture of ecosystem-economic accounts further information on the physical supply and use of ecosystem goods and services by the economy is required.

4.1 Land asset account

88. The land asset account presented in Table 8 is no different from an account that would appear in the SEEA-CF. The account classifies the land according to land use and measures land by area, in Hectares (Ha). It shows the change in land use as a result of an environmental tender that took place in the West Gippsland region, Victoria, Australia. Importantly, it shows how 1,263 ha of agricultural land was reclassified from “Agriculture” to “Land used for maintenance and restoration of environmental functions” as a result of the landholders entering into environmental management contracts.

89. Note that our operational approach does not restrict the classification of the flows between open and closing stock to those in Table 8. For example, it may be possible to construct a hierarchical classification scheme that breaks down the changes labelled as “Acquisitions” into smaller subclasses (e.g. by investment, by decree, etc). Similar sub-classifications can be created for “Reduction”. The classification scheme may depend on the information required. The class labels are attributed to each analytical unit for tabulation.

[5] For more detail on the Victorian ecoMarkets program see Appendix 1: The Victorian ecoMarkets approach to ecosystem investment.

Table 8: Land Asset account, classified by land use

Land - Physical (ha)	Agriculture	Forestry	Aquaculture	Use of built up and related areas	Land used for maintenance and restoration of environmental functions	Other uses of land	Land not in use	**Total**
Opening stock	739,687	120,430	-	82,359	758,572	3,400	9,371	1,713,819
Additions to stock								
Acquisitions								
Reclassification					1263			
Reduction in stock								
Natural losses								
Reclassification	-1263							
Closing balance	738,424	120,430	-	82,359	759,835	3,400	9,371	1,713,819

4.2 Ecosystem utility account (intra, inter)

90. An obvious limitation of the land asset account is that it does not reflect the change in flows of ecosystem goods and services that have occurred as a result of the program. Table 9 gives an example of how the ecosystem accounts can present this information. This table is classified according to land use, as in Table 8, but now the unit is ecosystem utility. Utility is represented by the Environmental Benefits Index, EBI, which is the product of ***intra*** and ***inter*** ecosystem goods and services flows relative to a natural state. This table shows that net ecosystem utility on “Agriculture” land declined over the period, whereas ecosystem utility on “Land used for maintenance and restoration of environmental functions” increased as a result of active management.

Table 9: Ecosystem utility account, classified by land use

Environmental Benefits Index (EBI)	Agriculture	Forestry	Aquaculture	Use of built up and related areas	Land used for maintenance and restoration of environmental functions	Other uses of land	Land not in use	Total
Annual EBI Flow to 30 June 2010	271,304,904							271,304,904
Increase in EBI flow due to:								
Acquisitions					35,855,034			35,855,034
Reclassification					270,155,361			270,155,361
Reduction in EBI flow due to:								
Natural losses	(84,838)							(84,838)
Reclassification	(270,155,361)							(270,155,361)
Annual EBI Flow to 30 June 2015	1,064,706				306,010,395			307,075,101
Change in annual flow								***35,770,196***

4.3 Ecosystem utility accounts by ecosystem type

91. The ecosystem utility account does not necessarily have to be classified by land use. Table 10 shows the impact of the environmental program in the target region (as in Table 9), but now ecosystem utility is classified by ecosystem type: terrestrial, river or wetland. The first row shows the utility of ecosystem goods and services in the target sites for each ecosystem type. Row two shows the increase in utility as a result of action undertaken on contracted sites. Row three shows the loss in utility as a result of no change in management on the sites that were not contracted. The net position after the program is shown in the final row.

Table 10: Ecosystem asset account by condition, classified by ecosystem type

	Terrestrial ecosystems	**River ecosystems**	**Wetland ecosystems**
Opening ecosystem utility	**61,769.5**	**22,919.7**	**2,381.6**
Additions to ecosystem utility - Growth in terrestrial services	7,130.1	3,837.6	241.2
Reduction in ecosystem utility - Normal loss of stock	-141.4	-51.7	-0.0
Closing ecosystem utility	**68,785.2**	**26,705.6**	**2,622.6**
% change	*11%*	*17%*	*10%*

4.4 Ecosystem utility account (intra)

92. To give an idea of the flows of services within an ecosystem, regardless of its context, an intra ecosystem utility account can be built. Table 11 below provides an example of an intra ecosystem utility account for all terrestrial assets across Victoria from 1994 to 2004, classified by land tenure.

93. In this account intra ecosystem utility is measured using the Habitat Hectares approach (Parkes et al 2003). This measure represents the terrestrial condition of a site relative to its natural state, using indicators such as extent and site quality. Additions to intra ecosystem utility can be a result of growth in terrestrial assets through improved management and revegetation, discoveries of new terrestrial assets (e.g. what was thought to be wetland is actually terrestrial habitat), upward reappraisals (e.g. due to improved data) and reclassifications (in this instance if public land transferred to private land). Losses in intra ecosystem utility can be a result of extractions (e.g. due to clearing), normal losses as a result of natural degradation (change in ecosystem goods and service flow inputs), catastrophic losses (e.g. shocks to ecosystem that result in it changing state), downward reappraisals and reclassification.

94. By analysing this table it is possible to draw a number of conclusions. First of all, in the ten year period from 1994 to 2004, there was a minor net reduction in terrestrial ecosystem utility (-0.65%). Loss of terrestrial ecosystem utility was largely a result of vegetation degradation (174,000HHa). Vegetation clearing is a minor concern with a relatively small loss of 1047 HHa. Gains in terrestrial ecosystem utility were largely a result of managed improvement (131,970HHa). Revegetation provided only minor gains (1,180). Disaggregating this information can inform strategies to improving future gains in ecosystem goods and services.

Table 11: Ecosystem utility account (intra)

Terrestrial intra utility (Habitat Hectares), VICTORIA	Public land	Private land	*Net*
Benchmark (~1750)	7,846,932	14,852,415	*22,699,347*
Opening stock of terrestrial services (~1994)	**5,153,437**	**1,733,806**	*6,887,243*
% benchmark (~1994)	66%	12%	30%
Additions to stock			
Growth in terrestrial services			
• Managed improvement - remnant	87,600	44,370	*131,970*
• Revegetation	-	1,180	*1,180*
Discoveries of new terrestrial g&s	-	-	-
Upward reappraisals	-	-	-
Reclassifications	-	-	-
Total additions of terrestrial services	*87,600*	*45,550*	*133,150*
Reductions in terrestrial services	-		
Extractions of terrestrial services			
• Vegetation clearing	- 1,047	-	- *1,047*
Normal loss of stock			
• Fragmented landscapes	- 28,500	- 145,500	- *174,000*
• Largely intact landscapes	- 3,070	-	- *3,070*
Catastrophic losses	-	-	-
Downward reappraisals	-	-	-
Reclassifications	-	-	-
Total reductions in stock	- *32,617*	- *145,500*	- *178,117*
Closing stock of resources (~2004)	**5,208,420**	**1,633,856**	*6,842,276*
% change	1.07%	-5.76%	*-0.65%*
% benchmark (~2004)	66%	11%	30%

95. Using the proposed spatial grid approach, Table 11 can be further disaggregated and generated for each individual ecosystem **services** that makes up the Habitat Hectares index. Comparing multiple ecosystems **services** side by side will show how the same events will impact assets in different ways. For example, a flood might be detrimental to some **services** (e.g. it may destroy vegetation that provides clean air), whilst beneficial to others (e.g. by adding nutrients to soil). This information will enable decision makers to monitor and assess the impacts of change on varying components of a dynamic landscape.

96. For example, Table 12 shows how the indicators collected in Victoria can be used as to measure services under the CICES classification scheme.

Table 12: CICES classifications linked to service indicators for accounting

Theme	Service class	Service group	Service Type	Service Indicator	Attributes Per/ha
Regulation & Maintenance	Regulation of waste & pollution	Bioremediation	Remediation using plants/algae etc	*Vegetation quality*	Avg. age and diversity of trees, shrubs, etc/ha
				Vegetation extent	Ha
			Remediation using microorganisms	*Soil quality*	Tbd
		Sequester	Dilution	*Soil quality*	Tbd
			Filtration	*Vegetation quality*	HHA
			Sequestration and absorbtion	*Vegetation extent*	Ha
			Recycle		Tbd
	Flow regulation	Air flow regulation	Wind breaks, shelter belts	*Tree cover/density*	trees/ha
				Tree condition	HHA
		Water flow regulation	Attenuation of runoff and discharge	*Recharge*	ML/yr/ha
				Runoff	ML/yr/ha
		Mass flow regulation	Attenuation of soil (and other solids)	*Erosion*	tonnes/yr/ha
	Regulation of physical environment	Atmospheric regulation	Climate regulation	*Carbon sequestration*	CO2 equiv/ha
		Water quality regulation	Water purification	*Recharge*	ML/yr
			Water purification	*Runoff*	ML/yr
			Water purification	*Nutrient runoff*	t/tr/ha
		Pedogenesis and soil quality regulation	Maintenance of soil fertility	*Soil Erosion*	Tonnes/yr
			Maintenance of soil structure etc	Tbd	Tbd
	Regulation of biotic environment	Life-cycle maintenance	Pollination (bees)	*Vegetation quality*	HHA
			Seed dispersal	*tbd*	Tbd
			Stream flow / flooding of wetlands	*Stream flow*	ML/yr/ha
			Flooding of wetlands	*Volume / Frequency*	ML/yr/ha
			Refuge	*Landscape connectivity*	Index/ha
		Habitat maintenance and protection	Habitat to maintain biotic organisms	*Vegetation extent*	Ha
				Vegetation extant	Index/ha
				Vegetation significance	BCS
				Bird counts	birds/ha
				Conservation significance	BCS/ha
		Pest and disease control	Biological control mechanisms	*Vegetation quality*	HHA
				Vegetation extent	Ha
				Vegetation significance	BCS/ha
		Gene pool protection	Maintaining nursery populations	*Vegetation significance*	BCS/ha
				Extent	Ha
			Seed dispersal	*Vegetation quality/condition*	*HHA*
			Landscape migration	*Landscape connectivity*	*Index/ha*

4.5 Joint production

97. Using the proposed approach, information in the ecosystem accounts can be presented in various ways with ease. For instance, Table 13 and 14 shows an example of the joint-production of intra and inter ecosystem goods and services for a landscape. To generate this table, every ecosystem cell is assigned both a habitat quality score and a connectivity score. The area of land assigned to each cross category score interval is added to the relevant cell in the table. Cells in the top left show the amount of land not producing much intra and inter ecosystem utility; cells in the bottom right shows the amount of land producing both high intra and inter ecosystem utility. The ability to build joint production tables will be particularly useful when trading off economic and ecosystem utility.

Table 13: Cross-reference of intra and inter ecosystem utility

	Connectivity (inter utility)					
Habitat quality (intra utility)	**<20 (Low)**	**20-40**	**40-60**	**60-80**	**80-100 (High)**	**Total Ha**
0-20 (Low)	23	52	22	5	52	**154**
20-40	34	5	5	5	2	**51**
40-60	43	5	55	45	81	**229**
60-80	4	54	255	585	2	**900**
80-100 (High)	3	9	8		47	**67**
Total Ha	**107**	**125**	**345**	**640**	**184**	**1401**

Table 14: Summary ecosystem service report – 'Habitat Quality / Connectivity'

Low/Low	Low/High	High/Low	High/High
8%	6%	8%	77%

5 Conclusion

98. This paper has shown that it is possible to develop an operational ecosystem accounting approach that is consistent with traditional accounting practices. It has shown that by thinking about ecosystems as units that have ecosystem goods and services flowing through them, they can appear like economic units that have economic inputs and outputs. By thinking of ecosystems like economic units, this approach also allows us to apply national accounting concepts like GDP to the represent net flows across the landscape and report them as GEP. This approach also allows us to make trade-offs between ecosystem and economic objectives by associating ecosystem flows with either ecosystem or economic/societal utility.

99. To operationalise these concepts, this paper has highlighted the need to translate the fundamental principles into empirical guidelines for the classification, measurement and reporting of ecosystem assets and services. It has shown by regarding an area of land as a functional "unit" the ecosystem accounts can link to economic accounts through the final ecosystem goods and services,

and through financial transactions that change the stock of ecosystem assets or their capacity to generate ecosystem goods and services.

100. This methodology has successfully been applied to build a number of accounts using Victorian data. It has shown that data can be aggregated and disaggregated with ease. Data can also be classified and reclassified according to any defined ecosystem attribute. As long as information on ecosystem transactions is collected spatially, any change in flows of ecosystem goods and services can be attributed to a point in the landscape.

6 References

Boyd, J., Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63 (2-3), 606-626.

Cosier, P., (2011) Accounting for the Condition of Environmental Assets. Wentworth Group of Concerned Scientists. London meeting on SEEA experimental ecosystem accounts.

De Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002. Typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41, 393-408.

Eigenraam, M., L. Strappazzon, N. Lansdell, A. Ha, C. Beverly and J. Todd (2006). EcoTender: Auction for multiple environmental outcomes. National Action Plan for Salinity and Water Quality, National Market Based Instruments Pilot Program, Final Report.

Eigenraam, M., L. Strappazzon, N. Lansdell, C. Beverly and G. Stoneham (2007). "Designing frameworks to deliver unknown information to support market-based instruments." Agricultural Economics 37(S1): 261-269.

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

Haines-Young R. and Potschin M. (2011) Common International Classification of Ecosystem Services (CICES): 2011 Update. European Environmental Agency. London meeting on SEEA experimental ecosystem accounts.

MA, Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being:current state and trends. Island Press, Washington, DC.

Ojea, E., Martin-Ortega, J., Chiabai, A., 2012. Defining and classifying ecosystem services for economic valuation: the case of forest water services. Environmental Science and Policy 19-20, 1-15.

Stoneham, G., Chaudhri, V., Ha, A. and Strappazzon, L. (2003), Auctions for conservation contracts: an empirical examination of Victoria’s BushTender trial. Australian Journal of Agricultural and Resource Economics, 47: 477-500.

TEEB, The Economics of Ecosystems and Biodiversity, 2010. Ecosystem valuation, a sequential decision support system and quality assessment issues. Annals of the New York Academy of Sciences 1185, 79-101.

Wallace, K.J., 2007. Classification of ecosystem services: problems and solutions. Biological Conservation 139 (3-4), 325-246

Appendix 1: The Victorian ecoMarkets approach to ecosystem investment

'Inter' and 'intra' ecosystem services are generally considered outside the market economy, therefore there has been no requirement for them to be defined in terms of quality and quantity. Over the past 10 years, the Victorian Department of Sustainability and Environment have been developing systems to incorporate the generation of ecosystem goods and services into the marketplace, thereby requiring clear articulation of their quality and quantity (Eigenraam et al 2007, Eigenraam et al 2006, Stoneham et al 2012).

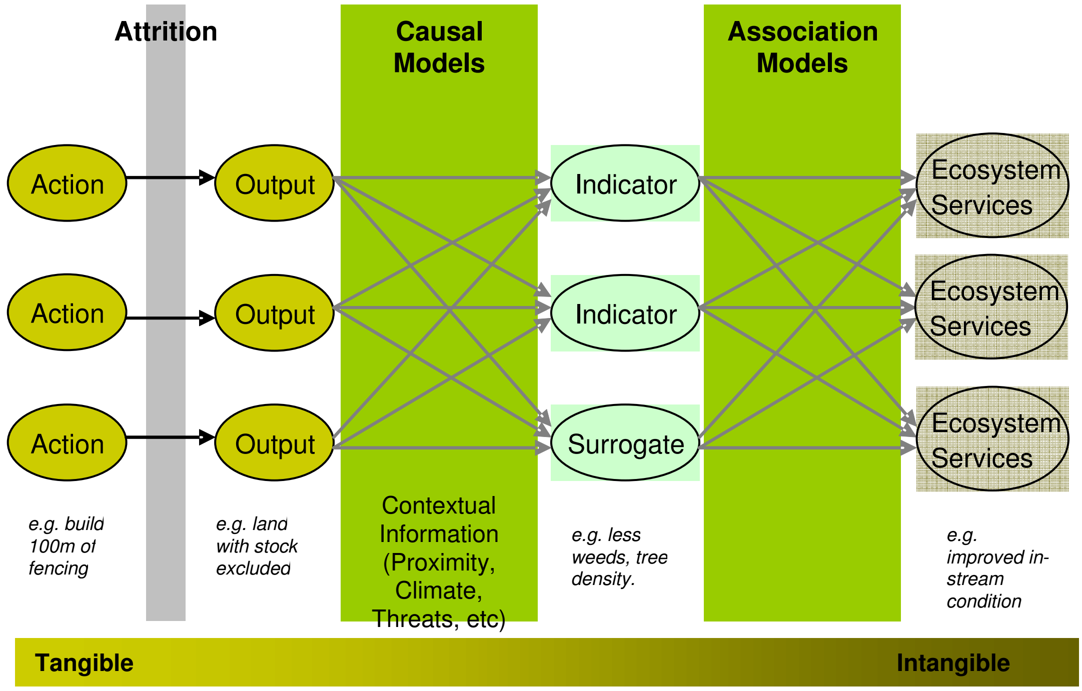
In this marketplace, the government[6] invests in actions (e.g. building a fence) that result in the generation of ecosystem goods and services (e.g. clean water, improvement in catchment condition and habitat). To show the interactions between actions and the resulting ecosystem goods and services, association models have been developed. Figure 10 is a schematic representation of the framework used to link on-ground actions with the generation of ecosystem gods and services:

1. **Actions** are the works that are undertaken on land by economic units (households etc). The economic unit receives payments for the actions (works). For instance a unit may be contracted to build a 100m fence to protect an ecosystem asset from stock (cows and sheep).
   - Attrition reflects those that discontinue their contract to undertake actions
2. **Outputs** are the result of the action. In the fence building case, the output is an area of remnant bushland (ecosystem asset) that has stock access excluded from it. For markets to operate effectively the actions and outputs need to be observable to enforce contract obligations.
   - Causal models provide link between actions and indicators
3. **Indicators** are measurable and tangible features of the ecosystem asset that indicate the capacity of an ecosystem to function. how the generation of ecosystem services will change as a result of actions. In this case the land has had stock removed by erecting a fence. An observable indicator may be a change in the density of young indigenous plants as a result of stock exclusion.
   - Association models provide the link between indicators and the exchange of ecosystem goods and services.

[6] The approach does not exclude private firms from investing. The market is in its infancy and it is expected that with time it will expand into the private sector. We expect that the adoption of comprehensive ecosystem accounting will provide an inducement for that to occur.

4. **Ecosystem services** are an empirical aggregate of the indicators. In the Victorian context several indicators are combined and understood that by association that they result in the exchange of ecosystem goods and services.

Figure 10. Linking economic transactions to the generation of ecosystem services



In this marketplace, ecosystem services are defined by the investor and are generally intangible. The investor is responsible to government for making investments in specific ecosystem assets to improve their condition and extent. Metrics have been developed that aggregate a number of indicators to measure the ecosystem services in question. It is assumed that the condition of the ecosystem, along with its landscape context (e.g. connectivity) is correlated with the level of ecosystem services provided.

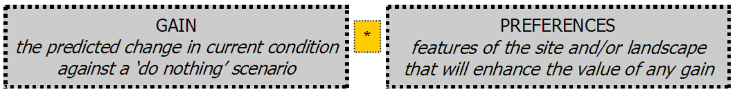
Applying metrics to estimate change in ecosystem goods and services

Directly measuring ecosystem goods and services is generally infeasible due to our limited understanding of ecosystem processes and how human interventions influence them. However, indicators for ecosystem goods and services can be used as proxy measures of service (Dale & Polasky, 2007, Ojea et al., 2012).

The Victorian Environmental Metric Framework quantifies ecosystem goods and services generated by actions undertaken by economic units through two calculations. The first is to assess the gain in ***intra*** ecosystem goods and services through an estimate of the change in ecosystem asset condition provided by the actions and the second is to determine the significance of the asset in the landscape and its ability to provide **inter** ecosystem goods and services. The product of these two values is the overall change in the generation of ecosystem services. The logic underlying this model is used in

EcoTender[7] ecosystem service calculators which include Terrestrial, Wetland, Rivers and Catchment estimates of change in both intra and inter ecosystems goods and services..

Figure 11: Environmental Metric Framework



Gain in intra ecosystem goods and services

The gain score used in Environmental Metric Framework is measured by taking the difference between the condition in period one and the condition in period two. This approach has a number of underlying assumptions:

1. Current condition will deteriorate over time if no action is taken do natural processes
2. If a land manager undertakes a series of 'maintenance' actions, the asset will retain its current condition
3. If a land manager undertakes a series of 'improvement' actions, the site will improve its current condition

Under the Environmental Metric Framework gain scores are predicted using input based models. The actions are converted to changes in outputs which include stock exclusion, removal of weeds and pests and supplementary planting. The casual models (see Figure 10 link those outputs to expected changes in indicators. Finally the indicators are combined via association models (see Figure 10) to predict the change **intra** ecosystem goods and services. The change in those is made up of improvement and or maintenance gain.

Landscape Significance

Having calculated the ***intra*** ecosystem goods and services gain score, the second step is to determine the significance of the ecosystem asset within the landscape. The significance measure provides a proxy for the use of **inter** ecosystem goods and services the asset has the potential to provide to other ecosystem assets.

In Victorian EcoTender and most environmental investment programs, there are a number of ecosystem asset features that determine the level of **inter** ecosystem goods and services. Features include the presence of and proximity to rare or threatened species, proximity to rivers, physical landscape connectivity, hydrological landscape connectivity, etc. The higher the significance score of these features, the higher the relative value of the **inter** ecosystem goods and services being generated by the asset.

For example, Asset A and Asset B, are estimated to have the same **intra** gain score due to landholder actions, but they have different significance scores. Asset A has high physical connectivity (high significance) with others assets and Asset B has little or no physical connectivity. The relative value of actions on Asset A are higher than those on Asset B due to their different connectivity scores

[7] EcoTender is a reverse price auction employed in Victoria for the procurement of ecosystem services.

(significance). The potential for Asset A to provide **inter** ecosystem goods and services is greater for Asset A than Asset B.

Each of the ecosystem service calculators (terrestrial, wetland and rivers) have been designed to collect indicator information that is specific to their asset class. For instance, the river calculator has indicators specific to river bank condition and the wetland has information specific to the hydrological conditions (altered or natural, etc). In the case of the wetland calculator information is also collected about the characteristics of land upstream of the asset (land connected via hydrological processes upstream of the wetland). This indicates the level of **inter** ecosystem goods the wetland may be receiving in the form of residuals and water.

In aggregate the Victorian calculators report on the total **intra** and **inter** ecosystem goods and services an ecosystem asset can generate.