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Topic: Ecosystem services in biophysical terms – ecosystem capacity

Title: Defining ecosystem capacity first requires criteria from the definition of extent of ecosystem types

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Abstract

The characteristics used to define the extent of ecosystem types and the change in extent over time also determine how ecosystem capacity is defined and quantified within the ecosystem type. The classification of ecosystem types is based on ecological understanding of the composition, structure, and function of ecosystems. However, this classification must also support practical implementation of defining spatial distributions and detecting change over time based on measurement of variables. Assessing the capacity of the ecosystem to supply an ecosystem service is fundamentally linked to how the ecosystem type is defined and measured. Additionally, the interpretation of capacity is influenced by the current and future expected management of the ecosystem. We explore this issue through examples of defining ecosystem types for various forest and woodland ecosystems. How the types are measured affects the outcomes for assessing their capacity to supply ecosystem services. Defining the extent of forests and woodlands is necessary for many international policy applications, such as the UNFCCC, CBD, SDGs, and national policies such as conservation of threatened ecosystems or maintaining proportional representation of ecosystem types. However, the variables that need to be measured to quantify an ecosystem type definition, either theoretically or practically, require significant consideration. Their quantification is used to define the reference condition for the ecosystem type, and hence the distance between current measured variables and thresholds across which a change in ecosystem extent (i.e. a conversion from one ecosystem type to another) would occur. We suggest that solutions require compromises between encompassing many ecological characteristics in definitions and the measurements required for practical implementation. Within this compromise, it is possible to ensure maintenance of the essential criteria for the robust principles of accounting and ecological science.

Introduction

Ecosystem capacity is defined in the SEEA EA:

> "the ability of *an ecosystem* to generate *an ecosystem service* under *current ecosystem condition*, *management and uses*, at *the highest yield or use* level that does *not negatively affect the future supply of the same or other ecosystem services* from that ecosystem. (para. 6.141)

The emphasis *in italics* is added to highlight the key determinants of ecosystem capacity.

The definition of ecosystem capacity is very complex, involving the assessment of the extent, condition, and ecosystem services derived from an ecosystem, as well as its current and future management and use. Current management and use are relatively easy to assess with, for example, databases of protected area networks, land use and land tenure. Future management is more problematic; for practical purposes it may be assumed that current management will continue, but information in ecosystem accounts is also highly relevant for evaluating the impacts of changes in management and use in the future.

The SEEA-EA does not provide an example ecosystem account for capacity and the relationships between ecosystem extent, condition, capacity, services, and management and use remain unclear in conceptual and practical terms. The complexity of the definition and its reliance on the measurement of all biophysical aspects of the ecosystem poses practical problems and challenges for implementation of ecosystem accounts.

Significant conceptual elements and practical definitions within ecosystem accounting influence how ecosystem capacity is defined and applied:

- the purpose of developing the ecosystem accounts,
- the definition of extent of ecosystem types,
- the relationships between individual and multiple ecosystem services
- the relationship between capacity and the ecosystem reference condition.

We suggest that both identifying the purpose of the accounts and defining the extent of ecosystem types are essential before the capacity and services of ecosystems can be usefully described. Defining ecosystem types is based on ecological characteristics, that must be identified spatially and need criteria to define a change over time.

We explain the interrelationships between extent, condition, capacity and services implicit in their definitions, and then show how each of these four components can be considered and offer solutions for their practical implementation.

Interrelationships between components of ecosystem accounts

To understand the notion of ecosystem capacity it is necessary to refer to the understanding of the definitions of terms embedded either explicitly or implicitly in the definition of ecosystem capacity:

> *Ecosystem type reflects a distinct set of abiotic and biotic components and their interactions. Indicators of condition and services will commonly vary by ecosystem type* (para. 2.11). Therefore, defining the types and the criteria for their classification has implications throughout ecosystem accounting.
>
> *Ecosystem extent is the size of an ecosystem asset in terms of the spatial area of ecosystem types* (para. 2.13). This is a quantity descriptor of the stock.
>
> *Ecosystem condition is the quality of an ecosystem measured in terms of abiotic and biotic characteristics* (para. 2.13). This is a quality descriptor of the stock that may reflect multiple values and is assessed with respect to composition, structure and function which underpin ecosystem integrity. Condition indicators are measured across a range of spatial and temporal scales.
>
> *Ecosystem services are the contributions of ecosystems to the benefits that are used in economic and other human activity* (para. 2.14).

The definition of ecosystem capacity embodies many components related to these interrelationships between definitions that all need to be considered in implementing the concept. Ecosystem capacity:

- refers to an ecosystem asset
- refers to the supply of a single ecosystem service for which capacity is being assessed
- refers to the flows of other ecosystem services which are to be maintained in conjunction with the flow of the individual ecosystem service for which capacity is being assessed.
- related to the balance between supply and use of ecosystem services
- measures of capacity are in the same units as the flows of ecosystem services, e.g. rate per year
- measurement of capacity requires consideration of the management of the ecosystem asset as a whole
- can refer to the current ecosystem asset inclusive of variability due to disturbance regimes, or to expected future changes in the asset (e.g. due to climate change)
- change in ecosystem condition may or may not be directly or positively related to change in capacity and may vary for different ecosystem services.

Assessment of capacity can support the interpretation and application of the ecosystem accounts in terms of current and future patterns of supply and use for ecosystem services and the current and future state of ecosystem assets.

The definitions of extent and condition are based on physical characteristics of the ecosystem assets. There is a shift in the definitions of ecosystem capacity and ecosystem services in that they also require the inclusion of human management and use (Figure 1). This creates a tension in describing two-way feedbacks, that is the effect of use of ecosystem services on the condition and extent of ecosystem types. Here, land use and management become relevant in terms of how the impacts are described. We suggest that this concept of two-way information needs to be more fully recognised and included in the accounting framework. Practically at the initiation account production, the purpose of the accounts and definition of ecosystem types need to be carefully considered. Articulating the purpose of the ecosystem accounts, the underlying reasons for their compilation and how the outputs will be used are crucial to guide decisions about implementation, interpretation and application.

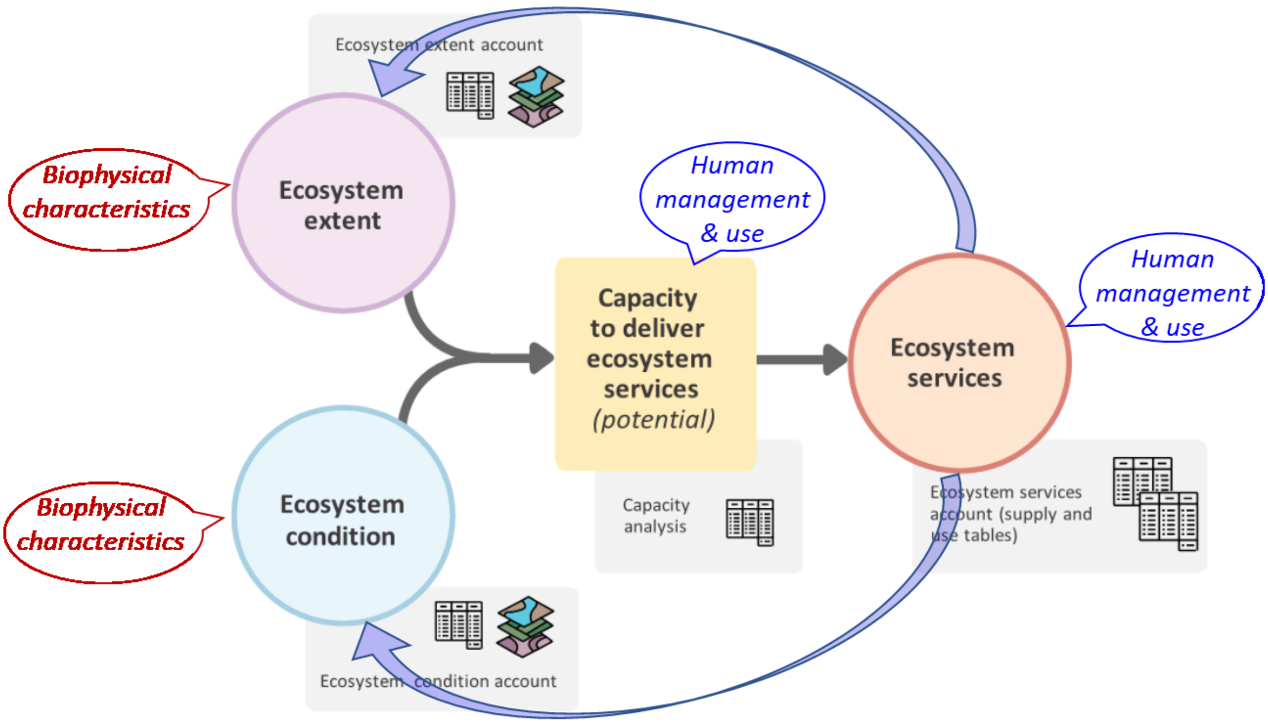

Figure 1. The role of ecosystem capacity in ecosystem accounts, showing the link between extent and condition of ecosystem assets with the flow of ecosystem services, the shift in characteristics used to define each component from physical to inclusive of human management and use, and the two-way feedback of the impacts of the use of services on the ecosystem extent and capacity. [Adapted from SEEA EA Figure 6.1, p. 151]

The definition of capacity and ecosystem services as being used by humans necessarily restricts the concepts that can be linked back to the ecosystem assets with their assessments of extent and condition. This is illustrated by the diagrammatic representation of the multiple values that are represented in the purposes of ecosystem condition accounts (Figure 2). The purpose of ecosystem condition accounts encompasses the continuum from intrinsic to instrumental values and from ecocentric to anthropocentric worldviews (Keith et al. 2020). Ecosystem condition is assessed with respect to ecosystem integrity in reference to natural ecosystems. An important purpose of ecosystem accounts is to consider and document ecosystems in their own right independent of human interests. However, the link between ecosystem condition, capacity and services necessarily has instrumental and anthropocentric perspectives. We explore the consequences of the more restricted perspective of ecosystems (ecocentric and intrinsic) when related to the capacity, supply and use of ecosystem services on the accounts for ecosystem assets.

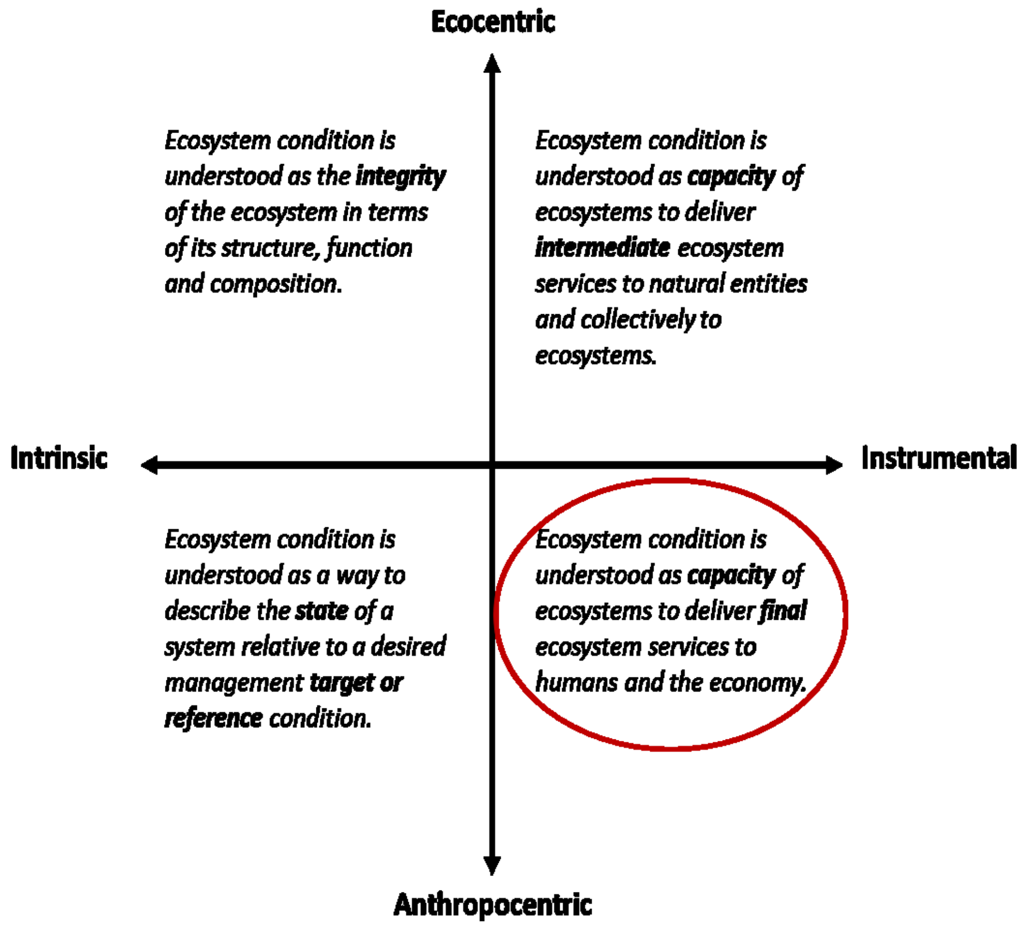

Figure 2. The spectrum of purposes for ecosystem condition accounts that reflect multiple purposes (Keith et al. 2020).

Defining ecosystem types

Ecosystem types are defined and classified by sets of abiotic and biotic components and their interactions between them and within them. It is based on ecological characteristics of the composition, structure, and function of ecosystems that are assessed by biophysical measurements (SEEA EA 2021, IUCN 2020). The classification and description of the ecosystem types are founded on ecological principles but must also support practical implementation, including:

- defining the spatial distribution of the ecosystem,
- detecting change over time based on measurement of variables,
- identifying variables that are feasible to measure at appropriate spatial and temporal scales, and
- providing the basis for linking the information on extent, condition, capacity and services of ecosystems.

Indicators of ecosystem condition and services commonly vary by ecosystem type. The capacity of the ecosystem to supply a flow of ecosystem services is fundamentally linked to how the ecosystem type is defined and measured (and managed). Therefore, defining the types and criteria for their classification has implications throughout the system of ecosystem accounting.

Issues related to defining and classifying ecosystem types occur in relation to measurements at appropriate spatial and temporal scales. The following are considerations about how to determine a change in extent from one ecosystem type to another, i.e. ecosystem conversion.

- What are the characteristics that would define a conversion of an ecosystem asset resulting in a reclassification of the ecosystem type?
- What are the intrinsic characteristics that define one ecosystem type as distinct from another?
- The relevant characteristics are often those that describe ecosystem condition.
- Does the change need to be in one or more condition variables? Is there a hierarchy or order of priority?
- Thresholds of the measured variables need to be set for these characteristics.
- Is there a time period over which the change needs to be maintained, or that can be considered permanent?
- Conversions are commonly due to land use change, but changes due to natural processes can be more difficult to define.
- If an ecosystem coverts from one type to another, should the measure of condition change (especially if it changes from a “natural” to a human-modified ecosystem (e.g. agriculture, plantation forests and urban areas)?

A key issue in defining ecosystem types is whether, or how, to include the effects of human modifications to ecosystems, and then how to relate these to changes that have occurred over time, or potentially could occur in the future. Defining current ecosystem types, as observed, implicitly entails acknowledgement of their use, and hence modification by humans. Ecosystems are commonly defined in terms of their natural state, and this is used to set the natural reference condition from which change in variables is assessed over time. In some classifications, human-modified ecosystems are included as separate classes. For example, the IUCN Global Ecosystem Typology consists of most classes that are natural ecosystems with a detailed scale of classification, but also includes a small number of intensive land-use systems such as croplands, pastures, plantations and urban. In fact, there is a continuum of human modification of ecosystems which needs to be incorporated within the practical application of ecosystem extent and condition accounts. This means that some differences due to human land use may be counted as different ecosystem types within the extent account, and some differences may be counted as levels of indicators within the condition account. We explore this issue using two examples – from forests and woodlands.

Forest ecosystem types

The way forest ecosystem types are defined and classified is determined by their ecological characteristics of composition, structure and function. This is done in many national and international ecosystem classification systems. However, as well as these characteristics of the natural ecosystems, there are effects of the degree of human modification and this range is illustrated in Figure 3. This shows broad classifications used by different international systems for different purposes. Criteria that are relevant for these classifications include tree species (native or exotic), stand origin (self-sown, artificially sown or planted), origin (natural or man-made), processes and structures (primary forest, secondary forest or plantation), management (conservation or production), human activities (minimal intervention or forestry harvesting).

Many classification systems separate plantations from other forest types, but this is based mainly on the criteria of trees being planted. Many other criteria are also relevant and there is often little difference between an intensively managed native forest, using artificial seeding, thinning, fertilizing, application of pesticides and weedicides, with that of a plantation, or indeed many examples along the range in human modification.

There are many details in these criteria that can be important in determining the composition, structure and function of forest ecosystems. For example, regeneration of harvested forests can use artificial seeding which changes the mix of species, native species may be native to the continent but not local, management can selectively change the species mix, changes in forest structure influence habitat for other species.

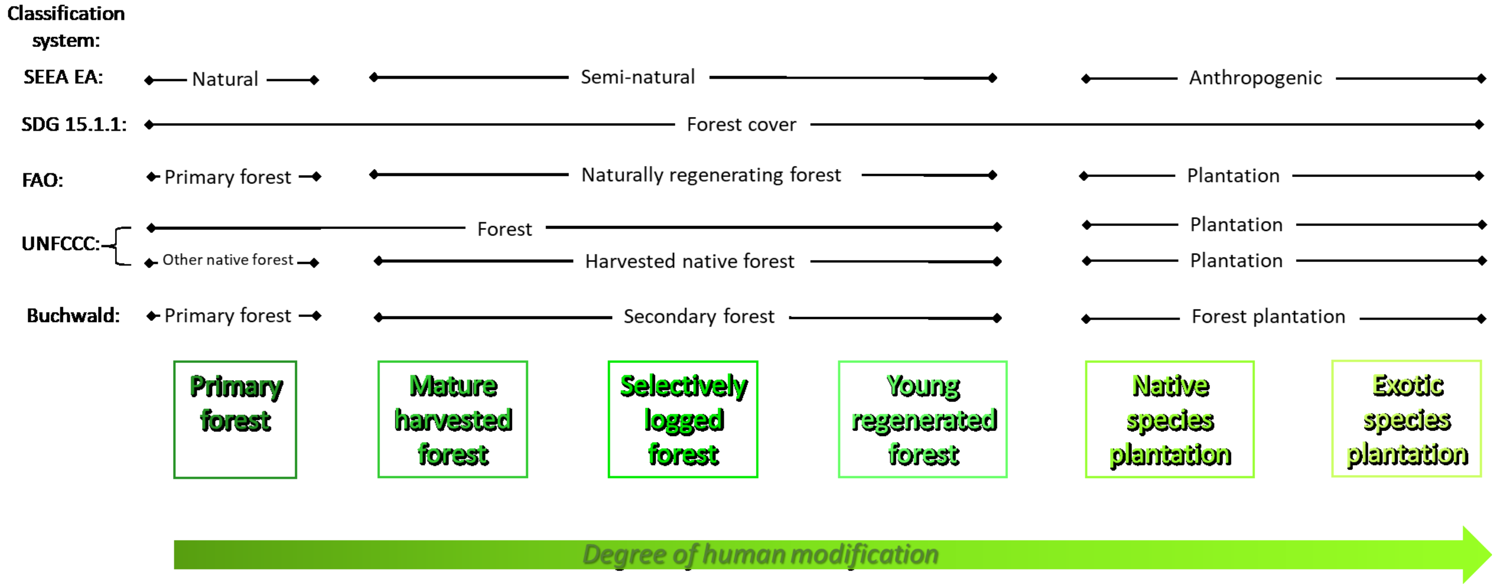

Figure 3. Forest classification systems based on the degree of human modification [U.N. 2021, U.N. 2019, FAO 2020, IPCC 2019, Buchwald 2005]

For the practicalities of accounting, decisions are needed about what differences constitute a different ecosystem type and hence when a conversion occurs. This requires identification of the relevant criteria and the thresholds in measured variables that define the boundaries of these criteria. The criteria depend on the purpose of the accounts and the applications for informing policy. Accounts compiled from bottom-up data would be of most use for local management and employ the most detailed information about local ecosystem types, which are then aggregated in different forms to suit the application.

The following are examples of variables and their thresholds that may be used to define the characteristics of forest ecosystem types. It is critical that these variables are feasible to measure both spatially and temporally.

1. Rules for physical changes in the characteristics that determine spatial extent of a forest ecosystem type, based on the measured variables of percent canopy cover and tree height:
   - Change from trees to shrubs due to fire frequency
   - Clearfell logging that leaves bare ground
   - Clearing forest to produce grassland
   - Reduction in canopy cover due to drought that is below the cover threshold for a forest
   - Selective logging of trees
2. Rules for the time period of change to be counted
   - Permanent means irreversible change, but the time scale may not be possible to determine
   - Change in ecosystem variables may be related to climatic variability that is reversible
   - Recording short term changes in accounts can be informative

- Temporal variability may also reflect trends

3. Rules for the spatial scale at which change is needed to define a conversion
   - an ecosystem is a spatial entity as an ecosystem asset, but the scale of reporting varies due to the basic spatial unit of the data. Individual ecosystem assets of the one type are usually aggregated and included in ecosystem extent accounts as a single column.

The following suggestion is made for reporting in account tables to show the change from the original extent of natural ecosystems to the current extent and historical changes.

Table 1. Ecosystem extent account (units of area)
Table A shows the change from the original extent of natural ecosystem types to the start date for recording that is used for the compilation of annual (or periodic) ecosystem accounts.

Table A	Ecosystem type										
	Temperate montane forest	Deciduous temperate forest	Oceanic cool temperate rainforest	Warm temperate laurophyll forest	Temperate pyric humid forest	Temperate pyric sclerophyll forest	Cool temperate heathland	Derived semi-natural pasture	Plantation	Cropland	Total
Opening extent - original	100	100	100	100	100	100					600
Additions to extent											
Managed expansion								50	50	75	
Unmanaged expansion											
Reductions in extent											
Managed reduction			50	50	75						
Unmanaged reduction											
Net change in extent	0	0	-50	-50	-75	0	0	+50	+50	+75	0
Closing extent - current	100	100	50	50	25	100	0	50	50	75	600

Table A shows that land use change has created managed expansions and reduction in ecosystem types:

- half of Warm temperate laurophyll forest had been converted to Derived semi-natural pasture
- three-quarters of Temperate pyric forest had been converted to Cropland
- half of Oceanic cool temperate forest was converted to Plantation

Table B shows the change in extent during the accounting period which begins with both natural and human modified ecosystems.

Table B	Ecosystem type										
	Temperate montane forest	Deciduous temperate forest	Oceanic cool temperate rainforest	Warm temperate laurophyll forest	Temperate pyric humid forest	Temperate pyric sclerophyll forest	Cool temperate heathland	Derived semi-natural pasture	Plantation	Cropland	Total
Opening extent - original	100	100	50	50	25	100		50	50	75	600
Additions to extent											
Managed expansion								25	50		
Unmanaged expansion							50				
Reductions in extent											
Managed reduction	50	25									
Unmanaged reduction						50					
Net change in extent	-50	-25				-50	+50	+25	+50		0
Closing extent - current	50	75	50	50	25	50	50	75	100	75	600

Table B shows that continued land use change plus natural disturbances have created both managed and unmanaged expansions and reductions:

- half of Temperate pyric sclerophyll forest was changed to Cool temperate heathland due to successive wildfires that prevented regeneration of trees
- half of Temperate montane forest was converted to Plantations
- quarter of deciduous Temperate forest was converted to Derived semi-natural pasture

Including these two accounting tables clearly shows the change from the natural ecosystem types, and then the detailed timeseries for which historical data exist. Even if detailed information about original extent and types is not available, this presentation of the data shows what has changed due to human activities, and conversely the potential for restoration. Based on these two extent tables, similar ecosystem condition account tables can be compiled that use the reference condition for the natural ecosystem in Table A, and if needed a reference condition for the human-modified ecosystem in Table B. Tables can be constructed for each ecosystem asset making up the full extent of the ecosystem type, which would make accounts useful at local levels.

The advantage of having both Tables A and B is that the natural reference condition is defined for all ecosystem asset areas and can be referred to in assessments of degrees of change in ecosystem condition. Where there is uncertainty about the most appropriate criteria and thresholds of variables to define a change in ecosystem type, the change in both extent and condition from the original natural ecosystems can be identified.

The change in ecosystem types due to managed expansions and reductions are the result of land use or management activities. Hence, management or use is being introduced into the definition of the ecosystem type.

Woodland ecosystem types

Woodland ecosystems are defined in terms of their characteristics of composition, structure and function, for example in national vegetation classification systems. However, these ecosystems are often heavily modified by humans for a range of agricultural land uses. Criteria that are most commonly used to assess the change in condition of woodlands and potential conversion of ecosystem type is the percent canopy cover. For example, woodland trees may exist as single remnant trees in a paddock, scattered individual trees, or a multi-layered woodland (Figure 4).

Figure 4. Illustrations of the change in percent canopy cover of woodlands under a range of human modification.

A limitation of the variable of canopy cover is that it must be defined for a specified area, such as 1 ha, but in fact the landscape context is important as well. It is not only the canopy of individual trees that is required, but also their extent and spatial distribution. Composition is difficult to identified from the remotely sensed data that is usually needed to assess spatial extent and change over time. Changes in composition are likely in the tree species, removal of understorey and replacement of native grasses with exotic grasses. A criterion that is often used in defining these ecosystem types, whether natural woodlands or managed agricultural systems, is the animals that graze – whether native (e.g. kangaroos in Australia) or exotic (e.g. cattle in Australia).

Conclusions

Including the original definition and classification of natural ecosystem types and recording of the data on their extent and condition is critical for understanding the changes that have occurred in ecosystems and the potential for change in the future. For many policy applications this assessment of past degradation and potential for future restoration is important. Recording the data in two account table provides greater transparency about the changes in ecosystem types but maintains the accounting format and recognises the influence of human use on areas that cause ecosystem conversions.

Defining change in ecosystem types will require compromises between encompassing many ecological characteristics in definitions and the measurements required for practical implementation to detect spatial extent and change over time. Within this compromise, it is possible to ensure maintenance of the essential criteria for the robust principles of accounting and ecological science in determining ecosystem extent and condition. This enables the practical definitions of ecosystem extent and condition to be applied in account production. As well as the practical advantage of recognising the human uses and impacts on ecosystems, this treatment more robustly links ecosystem extent and condition to ecosystem capacity and ecosystem services.

References

Buchwald E. 2005. A hierarchical terminology for more or less natural forests in relation to sustainable management and biodiversity conservation. Third Expert Meeting on Harmonizing Forest-related Definitions, Rome.

FAO FRA 2020. *Global Forest Resource Assessment* 2020, Rome, Italy, 184 pp.

IPCC 2019 Refinement to the 2006 IPCC guidelines for national greenhouse gas inventories. https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

Keith H, Czucz B, Jackson B, Driver A, Nicholson E, Maes J 2020. A conceptual framework and practical structure for implementing ecosystem condition accounts. *One Ecosystem* 5: e58216. doi: 10.3897/oneeco.5.e58216

U.N. 2019. *The Sustainable Development Goals Report 2019*. New York, USA.

U.N. 2021. System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing (United Nations)