Issue 3 paper – Ecosystem statistical and accounting units, land cover, remote sensing and adjustments

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A. Introduction

1. The purpose of this paper is to address concepts and questions raised in *Issue 3: Land cover mapping, land cover classifications, and accounting units* within *SEEA Experimental Ecosystem Accounts: A Proposed Outline, Road Map and list of issues*[5]. This paper also refers to the *Building blocks for land and ecosystem accounting*[6] paper and assumes the reader has access to that paper.

1. Background notes drawn from SEEA Experimental Ecosystem Accounts: A Proposed Outline, Road Map Issue 3 discussion (our emphasis and alternative wording added)

- The fundamental units in the ecosystem accounts should proxy basic functional units of the environment that have the capacity, in their own right, to provide services to humanity
- As in the SNA, the units of ecosystem accounts need to be defined according to a set of simple rules that approximate their principle functions, behaviour and objectives.
- The ~~accounting~~ [statistical] units are distinct from [accounting or] reporting [output] units, which could be virtually any type of aggregation of the ~~accounting~~ [statistical] units on a spatial frame.
- The approach should build upon existing studies, such as EEA's Simplified Ecosystem Accounts.
- The SEEA land cover classification developed within the Central Framework is applicable but more details on 'operationalization' for ecosystem accounts are needed, both for the purpose of establishing [statistical and accounting] units and for deriving (and in some cases re-scaling) statistics.
- To achieve some commonality in approaches will require an understanding of what is feasible given current remote sensing technology and data availability internationally.

2. This paper's structure

2. Based on the notes and the tasks listed above, this paper explores key questions and makes some proposals regarding the core concepts and approaches for identifying and defining 'ecosystem' statistical units. It does so as follows:

a. Considers the case for a broad based, all-purpose ecosystem statistical unit
b. Presents a simple pathway to assist with determining statistical and accounting units
c. Proposes a simple rule set (criteria) for defining specific purpose ecosystem statistical and accounting units
d. Discusses spatial, thematic and temporal considerations for defining a statistical unit
e. Discusses some key methodological issues relevant to ecosystem accounting
    i. Remote sensing concepts
    ii. Adjustments for variability

[5] http://unstats.un.org/unsd/envaccounting/londongroup/meeting17/LG17_9a.pdf

[6] Ref needed

B. Statistical units of the environment

1. Setting out the challenges and introducing solutions

3. To assist with definitions, we refer to the difference between the statistical (observational) unit and the accounting (and reporting) unit where the *statistical unit* is a base unit (e.g. for measuring production) and the *accounting unit* is a transformation (e.g. aggregation) of the base statistical units amenable to statistical output (refer to Issue 2 paper[7]; also ABS[8] and UN[9,10]). The accounting unit may be in the form of tables or maps and the same underlying statistical units can be used at multiple scales via different types of accounting units (e.g. local to national). We note that many ecosystem assessments use a spatially based measurement unit[7].

4. The requirement for a crisp, spatially discrete, mutually exclusive statistical "unit" for environmental accounting purposes[11] poses a series of challenges when it comes to practical implementation. Firstly, for purposes of discussion, it is proposed that no single spatial unit can be relevant to all ecosystem phenomena, and, hence, not all phenomena can be measured and reported with a single consistent spatial unit. The inherent characteristics of ecosystems make the definition of a single all-purpose spatial unit problematic (see reasoning below). This means that a single, stable, spatially-defined "ecosystem unit" is not a feasible construct, though it is considered "ecosystem units" can be developed for specific purposes.

5. By way of working towards a solution to this challenge, we firstly focus on the **statistical unit**. We agree with the proposition presented in EEA (2011[8]) that "SES ["socio-ecological system"] and ecosystem production units *are defined* by their capacities to generate services, on a range of spatial and temporal scales [our emphasis added]." One reading of this is that the "ecosystem production unit" could be interpreted as a "statistical unit" and that its characteristics are *dependent* on the types of products or services of interest required for the account. Thus, statistical units, and the accounting units they build, are likely to be defined differently for aquatic ecosystems services to those for terrestrial carbon sequestration services. One consequence of this approach is that it privileges "ecosystem goods and services" over the concept of "ecosystems" when defining statistical units. More ideas on solutions below.

6. Secondly, a challenge arises regarding the **spatial stability** of the *statistical unit* over a number of accounting periods. Given that there a likely to be changes in the ecosystem boundaries e.g. by forest restoration or clearing, any *statistical unit* with a spatial definition that is *dependent* on the ecosystem itself will also be subject to boundary change. This is not necessarily a concern, if either consistent *statistical units* are able to be produced (i.e. for stable phenomena) or, possibly, older/historic data can be re-processed with the new or current statistical units (It is not a concern for *accounting units* as spatial change is one dimension they are intended to measure and they can be aggregated according to the measure of interest and changes accounted (e.g. hectares of change from wetland to agriculture in a land account)).

7. One option is to use a tessellated statistical unit with stable spatial characteristics that are *independent* of the ecosystem's spatial variability, though capable of resolving the phenomena of interest e.g. a standard (say, 1 ha or 1 km) grid (as per EEA, 2006[12]; more on this later).

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[7] Vardon et al. (2011) "Towards an integrated structure for SEEA ecosystem stock and flow accounts" http://unstats.un.org/unsd/envaccounting/seeaLES/egm/Issue%202_Aus.pdf

[8] Vardon et al., (2011) "The Building Blocks for Land and Ecosystem Accounts" http://unstats.un.org/unsd/envaccounting/londongroup/meeting17/LG17_9c.pdf

[9] UNSD October (2007) "Statistical Units" paragraph 14: http://unstats.un.org/unsd/isdts/docs/StatisticalUnits.pdf

[10] International Recommendations for Water Statistics

[11] EEA (2011) "An experimental framework for ecosystem accounting in Europe"

[12] EEA (2006) "Land accounts for Europe 1990-2000"

8. Other sources of instability include changes in relevant classification schemes (e.g. CICES) and accounting methods (e.g. ecological index algorithms). For example, ecosystems are themselves derived units that reflects specific socio-ecological consideration. They are not therefore universal entities that are necessarily stable or appropriate to needs. We are not clear how these other sources of instability can be resolved and ask that it be addressed.

9. As a contribution to solutions, it is proposed that

a. for any specific combination of *accounting purpose*, *phenomena of interest (i.e. account subject)* and *accounting period,* a **pathway** (or process) be set out to define the statistical and accounting units based on <u>ecosystem goods and services</u> as the central concept (e.g. specific goods and services produced by ecosystems, such as biomass, carbon, water, regulating or cultural services), rather than ecosystem assets (e.g. forests, wetlands, grasslands), and that

b. a **simple set of rules (criteria)** be established to support the definition and identification of statistical units.

In the rest of this section, following a discussion of the issues around identification of ecosystem statistical units, the criteria (rule set) for determining ecosystem accounting units are considered in terms of spatial, temporal and thematic factors.

2. Identification criteria for an ecosystem statistical unit

10. We propose that, for the purposes of defining an *ecosystem statistical unit* for ecosystem accounting, an "ecosystem" *per se* is not a useful construct as it does not exist as a separable, discrete entity. The basis of that assertion is, in essence, that ecosystems are too complex and the boundaries, or edges, of ecosystems are notoriously hard to define as a crisp boundary in space or time. The following ecosystem characteristics mitigate against using the concept of an ecosystem for identifying a spatially discrete ecosystem statistical units:

b. Different ecosystem services derive from overlapping (non-discrete) functions and processes at overlapping (non-discrete) spatial locations, overlapping times and at overlapping scales (resolutions)

c. Complexity of systems – the complexity of ecosystems, society and socio-ecological interactions mean it will be necessary to identify specific aspects for attention (i.e. "ecosystems" in their entirety are too complex to engage with as they overwhelm our current information management capacity)

d. Changing technology – constant improvement in technology will enable new units

e. Changing understanding – new theory and research findings will change what is accounted. Ecosystems are themselves derived units that reflect specific socio-ecological considerations.

f. Relevance – ecosystems can be regarded as an entity that does not reflect the complexity of socio-ecological systems and processes.

g. Changing accounting methods – new concepts and best practice accounting methods will emerge that, for example, will enable enhanced reprocessing of historical data sets (e.g. remote sensing imagery) to extract accounts over several accounting periods that allow appreciation of trends.

11. The following is proposed as an ecosystem goods and services accounting **pathway** to illustrate a relationship between statistical units and accounting units that is based on the *ecosystem goods and services* of interest rather than on the concept of the *ecosystem* or *ecosystem asset*.

For each specific account purpose and accounting period, identify the subject of the account (phenomena of interest) via the *ecosystem goods or services of interest* (e.g. via CICES)

a) Define the *statistical unit* (use the simple rule set detailed below)

b) Derive statistical measures via the *statistical units*

   i) Link the statistical units to the knowledge base (e.g. identify linkages between the ecosystem goods and services with ecosystem classes/types, functional classes, biodiversity etc.

   ii) Access environmental information and data – models, observations, etc.

   iii) Apply statistical methods including spatial science and remote sensing techniques

   iv) Generate ecological indices etc.

c) Transform (e.g. aggregate/disaggregate) from *statistical units* to *accounting units* for reporting of *ecosystem goods and services* via tables and maps and to generate the output *accounting unit* areas and maps, such as:

   i) **Ecosystem type/entity** (e.g. land cover - wetland, grassland, forest, etc.) for producing ecosystem areas and maps

   ii) Ecological regions (e.g. IBRA[13])

   iii) Physical units (e.g. catchments)

   iv) Administrative units (e.g. local government, Natural Resource Management regions)

   v) Socio-ecological types (e.g. SELU)

   vi) Statistical output/reporting units (e.g. statistical areas)

   vii) Economic units (e.g. farms, parks)

12. As can be seen, it is proposed here that the ecosystem may be represented as a spatial *accounting* or *reporting unit* after it is measured with the *statistical unit*. While the **aspatial** dimensions of an ecosystem (e.g. defined as a class or type) can be used to assist in defining the thematic characteristics of the statistical unit for measurement purposes (e.g. in b above), and the dimensions of the phenomena of interest will inform the *statistical unit's* size, the intention is to reduce or eliminate the need to spatially define ecosystems for the reasons provided in paragraph 10 above.

13. The following criteria are proposed for consideration for informing the representation (*statistical unit*) for any particular set of ecosystem characteristic/s for ecosystem accounting purposes (e.g. carbon accounting or aquatic regulation service accounting). It is proposed that the unit also needs to at least meet specific spatial, temporal and thematic criteria, as discussed below.

14. The following is proposed as a **simple rule set** that provides guidance to the statistical unit selection process. The *'ecosystem' statistical unit* must be:

a. defined according to the accounting *purpose*, which must specify the *ecosystem good or service of interest*

b. capable of resolving and enable measuring the phenomena of interest (subject of the account)

c. mutually exclusive spatially, temporally (e.g. bounded by the accounting period) and thematically

d. capable of credible transformation to the accounting (reporting) unit (e.g. aggregation, disaggregation)

e. ideally, "aware" or cross boundary connections or flows (e.g. externalities; EEA, 2006)

f. ideally, capable of linkage to the responsible economic unit/s in order to derive economic data on transactions that contribute to a change in its overall condition or capacity to provide ecosystem goods and services.

[13] Interim Bioregionalisation of Australia

3. Spatial criteria for selection of ecosystem accounting units

15.The statistical units should be

a. capable of spatially resolving and enable measuring the phenomena of interest,

b. exclusive to the phenomena of interest and spatially non-overlapping (mutually exclusive),

c. capable of credible transformation to the accounting or reporting units (e.g. aggregation, disaggregation).

16. Ideally, the *statistical unit* should be the minimum size required to capture the phenomena that is being reported. This applies to both vector and grid based statistical units aggregated to form accounting units. A linear feature, such as a river or wildlife corridor, may not be adequately captured by a grid, for example. Appropriate methodologies need to be applied by spatial data experts to ensure that the representation of the phenomena is suitable for the purpose. This may include applying a weighting to important classes to ensure they are represented in the resulting grid, or buffering polygons of high importance.

17. Ecosystem *accounting units* must be built from the basic *statistical units*. The phenomena of interest within the statistical unit can be measured by a range of means and represented spatially and non-spatially, though for spatial analysis they will generally be represented as a vector (e.g. cadastral parcel) or grid (e.g. 1 km x 1 km or 0.1 km x 0.1 km (1 ha)) based. This should be determined by the available input data, the geoprocessing capability available and be appropriate to the phenomena being accounted. The EEA state that the most widely-used grid for accounting purposes is 1 km x 1 km and that a 1 ha grid can also be used. In Australia these grid sizes are relevant to national, state and regional reporting requirements and there is a standard multi-scale national grid emerging[14].

18. Besides the grid format, the land (cadastral) parcel (a vector layer) is considered a suitable statistical accounting unit for spatially linking economic activity to the land[8]. Either of these statistical units can generally be easily aggregated for reporting at many levels, including the aggregation of grid units to cadastral parcels provided the spatial resolutions are suitable. Generally, where spatially explicit assessments are required, the grid format is preferred for *statistical units* from the perspective of efficient transformation of large data sets to multiple reporting units[11].

19. Spatial analysis using GIS enables data from disparate data sources, including both vector and raster data types, to be analysed. Therefore multiple data types and sources can be used as the basis of *statistical units* from which to generate *accounting units*. The data, sources and capability will also change through time and new approaches will emerge in the future, so a static spatial definition for the *accounting unit* is not considered necessary, rather the *accounting unit* should be more driven by the reporting requirements i.e. phenomena of interest and management needs.

20.The size of the statistical unit (e.g. 1 ha or 1 km^2) is a factor in determining the size of *accounting units*. For example, if the *statistical unit* is smaller than the minimum reporting unit, credible aggregation methods need to exist that can combine the measures to the reporting unit size. Alternatively, coarser resolution measurements must be able to be credibly allocated to reporting unit, for example, rainfall estimates in the form of a surface grid can be meaningfully allocated to smaller units within a single grid cell in circumstances where topographic features are adequately accounted for.

21.It is suggested that, if required, a useful minimum reference size for *statistical units* for ongoing time series output over large areas (national or international) is one hectare (1 ha). This allows for long-term data, such as widely available Landsat remote sensing imagery, to be used as a consistent base for reporting. As technology improves and models become more advanced, it is possible to both re-interpret historical data using consistent methods, and to aggregate higher resolution data to a

[14] e.g. http://www.spatialvision.com.au/index.php/national-data-grid-ndg.html

one hectare (1 ha) grid. Note that this methodology will not be applicable for all environmental phenomena, but provides a useful reference for accounting purposes as applicable.

22. In general, it is preferred that reporting or output areas are matched to management needs. For example, in Australia, the INFFER methodology and the Wentworth Group NRM Environmental Accounting Trial methods recommend identifying spatially explicit "environmental assets" in area of approximately 1's to 10's of square kilometers. The South East Queensland ecosystem services project[15] identified units of this magnitude. In the marine environment, the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) regions (1000's square kilometers) are considered too large for optimal use in fisheries management[16].

23. Given issues of spatial and temporal variability is there an "optimum" spatial resolution for remote sensing data for developing ecosystem accounts at the national level as part of an internationally standardised system? The following two paragraphs explore this question from the perspective of the availability and resolution of remote sensing data sets for the international community.

24. There is a wealth of public good satellite imagery available at various resolutions along with elevation and terrain data which have a 30 m resolution. Given this, a standardised international grid and nested grid with a resolution of 25 m to 1 km can be easily supported, with base mapping of terrain and land cover captured.

25. Higher resolution products could be maintained in their native resolution and summarised for the coarser reporting units. High temporal frequency data products such as daily MODIS or MERIS could be interpolated onto standardised 250 m, 500 m and 1 km grids. Sparse point-based datasets could be interpolated onto these standardised grid using environmental predictors where appropriate.

26. Standard metadata elements should be reported, such as accuracy and precision.

4. Thematic criteria for selection of ecosystem accounting units

27. The classification driving the identification of ecosystem accounting units needs to

a. be capable of thematically resolving and measuring the phenomena of interest,

b. be mutually exclusive and

c. be relevant to the accounting purpose.

d. have a defined hierarchical classification structure and

e. have a defined thematic "change" classification structure (flow)

These criteria are expanded below.

28. Hierarchical classification structures make aggregation of spatial and accounting datasets relatively simple to scale up or scale down depending upon the need or the level of detail required. The SEEA "Classification of Land Use" is a hierarchical classification structure which ranges from a coarse land use classification at the three digit level i.e. 001 Agriculture to a finer land use classification at the five digit level i.e. 01111 cereals.

29. The provisional land-cover flow (change) classification used in Europe for SECA provides an excellent change classification. It is relatively simple having only 16 classes (including no land cover change) and yet it still provides information on the previous land cover and the present land cover.

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[15] Maynard et al. (2010) "The development of an ecosystem services framework for South East Queensland" http://www.australia21.org.au/pdf/SEQ%20ES%20Framework%20EM.pdf

[16] Hilbert, D. W., L. Hughes, et al. (2007). Biodiversity conservation research in a changing climate, Australian Government Department of the Environment and Water Resources: 72.

30. Many land cover classifications combine land cover and some aspects of land use these result in a wide variety of individual land “cover/use” classes, which are mainly applicable to the country or continent of origin. Australia has developed and uses separate classifications for land cover, land use, land management practices and land tenure (see Table 1). These classifications can be easily adjusted to make them globally applicable and relevant, or alternatively land cover and land use information collected for Australia can be adapted to suit the classification of Land Use and the Listing of Land Cover Types as adopted by SEEA Volume 1.

Table 1 Differentiating land cover, use, management and tenure

Land cover	The physical surface of the earth, including vegetation types, soils, exposed rocks and water bodies, as well as human-caused elements such as agriculture and built environments. Different classes of land cover can usually be discriminated characteristic patterns using remote sensing.
Land use	The purpose to which the land cover is committed. Some land uses, such as agriculture, have a characteristic land cover pattern and usually appear in land cover classifications. Other land uses such as nature conservation, are not readily discriminated by a characteristic land cover pattern. For example, where the land cover is woodland, land use may be timber production or nature conservation.
Land management practices	The approach taken to achieve a land use outcome – the ‘how’ of land use. Some land management practices (e.g. cultivation practise, such as minimum tillage and direct drilling). Some land management practise (e.g. stubble disposal practices and tillage rotation systems) may be discriminated by characteristic land cover patterns and linked to particular issues
Tenure	The form of an interest in land. Some forms of tenure such as pastoral leases or nature conservation reserves relate directly to land use and land management practices.

31. Separating out land cover, land use, land management and tenure classifications provides robust and detailed information that can be applied to ecosystem goods and services, regardless of the ecosystem framework adopted[17]. It also provides an underpinning suite of data which can be incorporated or omitted (as required) into an ecosystem framework, rather than using other classifications which combine and confuse both land use and land cover. The use of four classification schemes also provides the basis for an enduring environmental accounting system.

5. Temporal criteria for selection of ecosystem accounting units

32. The temporal dimension needs to

a. be capable of temporally resolving and enable measuring the environmental phenomena of interest,

b. be mutually exclusive and

c. bounded by the accounting period.

33. An Australian Dynamic Land Cover map[18] is based on 16 day enhanced vegetation index composite using the Moderate Resolution Imaging Spectroradiometer satellite (MODIS). Currently

[17] Australian Bureau of Agricultural and Resource Economics and Sciences, 2011, *Guidelines for land use mapping in Australia; principles, procedure and definitions,* fourth edition, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

[18] http://www.ga.gov.au/earth-observation/landcover.html

MODIS imagery is captured both in the morning and afternoon, making it possible for accurate and timely updates of Dynamic Land Cover maps and associated products. The temporal resolution of MODIS allows remote sensors to observe changes in land cover, due in some instances to land management practices i.e. fallow land and green flushes from irrigation. This provides an excellent example of a temporally valid data set, which can be applied globally.

C. Remote sensing of land cover, land use and land management for accounting purposes

34. Remote sensing and geospatial technologies have a key role to play in the development and implementation of ecosystem accounting and ecosystem services frameworks. The following is intended to identify some of these technologies potential and limitations and refers to the previous discussion in Section B.4 about the value of distinguishing between land cover, land use and land management in relation to ecosystem accounting units.

35. Care must be taken when applying remote sensing methods as, for example, *land cover* information derived from remote sensing does not necessarily equate to *land use*. For example, while a forest area may be classified as a single type of *land cover*; the *land use* within the same forest may be divided into wood production and conservation. *Land use* may also be a poor surrogate for quantifying changes in ecosystem condition or ecosystem services. For example, within a single *land use* class of dryland cropping, it will be the form of *land management* (the "how" of land use), such as the extent of minimum tillage or stubble retention, that leads to improvements to soil carbon, reduced sedimentation of streams and wind erosion. In this example, ground cover[19] management may be a strong indicator (or proxy) for improved *land management*. Ground cover indices can be derived from remote sensing (please also refer to the example at end of this sub-section).

36. To date, the development of *SEEA* land accounts and ecosystem accounts has relied significantly on remote sensing of land cover and to a lesser extent land use mapping. The *FAO Land Cover Classification System Version 3* (LCCS3) has underpinned much of this work, and been used to derive *Land Cover Functional Units* (LCFU) for simplified experimental ecosystem accounts and ecosystem services. *Socio-Ecological Landscape Units* (SELU) based on land cover types and relief classes[11]. We suggest that distinguishing between land cover, use and management will assist with making this approach more workable in a variety of circumstances globally.

37. In Australia, remote sensing is a key input to the production of the catchment scale and national scale land use data sets. For example, the *Australian Land Use and Management Classification V7* (ALUM) is a mature hierarchical classification for land use that utilises remote sensing to produce land use maps and change maps (flow). Importantly, this classification also provides direct links to the Australian commodity classification used by the Australian Bureau of Statistics[20].

38. Advances in remote sensing are providing new opportunities for routinely measuring, mapping and monitoring seasonal changes in terrestrial, atmospheric and aquatic environments. Biophysical parameters, such as *Leaf Area Index* and *Fractional Cover* of photosynthetic and non-photosynthetic vegetation, provide new methods that contribute to deriving land cover, land use and land management information.

39. These methods allow outputs from multiple sensors and sensor resolutions to be seamlessly integrated to monitor seasonal changes in primary land cover. An example follows, focussing on ground cover. Ground cover is affected by farmers and graziers through their daily management. Management practices that reduce ground cover degrade the soil and water assets that support agricultural production and biodiversity.

[19] ground cover provides the protective layer of living and decaying plant material on the soil surface

[20] Australian Land Use and Management Classification Version 7 (May 2010) <http://adl.brs.gov.au/landuse/index.cfm?fa=main.classification>

40. In Australia, remote sensing methods are being "operationalized" to monitor ground cover and surface water extent in arid to semi-arid rangelands (i.e. covering approximately 80% of Australia). Monthly, seasonal and annual monitoring of ground cover from remote sensing is being used to monitor erosion risk and as a proxy for measures of soil carbon, soil condition and biodiversity conservation. In this case, sustainable land management targets are aiming to maximise ground cover and production outcomes, using specific grazing practices (e.g. cell grazing) and targets. Ground cover accounting via remote sensing will provide feedback on the success or otherwise of these management practices.

D. Adjustments for variability in seasons, technology and methods

41. Need for adjustments. Accounting for economic stocks and flows based on a specific accounting period at a business, enterprise of establishment level is relatively straight forward and well-accepted practice including adjustments of value where needed. There are also adjustments that must be considered for land, ecosystem or ecosystem service accounting that will have major impacts on the reliability of the accounts.

42. Remote sensing change methods. To date the land cover and land use information used to derive environmental accounts has generally been based on a "snap-shot" approach. That is, mapping based on imagery or other information sources from a single date or range of dates for a region. Estimates of change have been either based on comparing two output mapping products derived independently or updating mapping by directly identifying changes in imagery.

43. Remote sensing data variability. Often different remote sensing platforms are used between dates, particularly as sensor resolutions increase or methods change. For example moving from 25 m Landsat to 10 m SPOT is likely to allow smaller forest patches to be mapped resulting in reporting of increased forest area even though there may have actually been significant land clearing or disturbance events. Remote sensing and geospatial methodologies frequently change between reporting periods. It is therefore important to ensure that, as land and ecosystem accounts develop over time, procedures are developed to adjust and remove biases.

44. Data sampling frequency. In cloudy areas (e.g. tropics) it may take more than a single dry season to collect the imagery, so for a 5 year reporting period the starting and ending periods may span 4 years. In regions with summer and winter cropping seasons a single snapshot for the start and end of the accounting period will miss an entire crop production cycle. It is often difficult If not impossible to avoid these issues; however, it is critical that periodic reporting takes account of these issues and adjustments are applied in a transparent manner. Again, it would be appropriate to develop consistent processes and procedures to adjust and remove biases in these circumstances.

45. Seasonal and climatic variability. In regions which exhibit significant seasonal and annual climate variability, such as Australia, there is a need to consider methodologies for adjusting the accounts over the relevant period e.g. seasonally adjusted accounts. Differences in seasonal conditions between reporting periods may result in highly misleading changes in stocks and flows for seasonal land cover types such as ephemeral wetlands, cropping or ground cover.

46. Resolving the phenomena of interest. Simple "snapshot" reporting at the start and end of a reporting period may be completely unrepresentative of the intervening period, and lead to incorrect interpretation of state and condition of ecosystems. For example, decline and/or impact on Australia's rangelands natural resource base which cover 80 percent of the nation are hard to discern due to highly variable environmental conditions.

47. Attributing change. Separating changes that are due to management from those caused due to the very high natural variability is an on-going issue. Improving ground cover is seen as means of improving soil condition, productivity, soil carbon and biodiversity. Increasing ground cover will also reduce soil erosion and the incidence and severity of dust storms which affect urban populations hundreds of kilometres away.

48. High variability ecosystems. From an ecosystem services and apparent landscape condition perspective, these highly variable landscapes must be monitored at least annually using moderate to high-resolution imagery, within the same season over long time periods (decades) and within seasons using high temporal frequency imagery (at least monthly) to provide un-biased estimates of condition. Periodic reporting should then use statistics that describe trends in the full time-series (no different to economic accounts), not simply snapshots at the start and end of the reporting period.

49. Management of uncertainty. As science and understanding improves the need and ability to re-process time-series data and expect that estimates of state and change are likely to vary, rather than transferring "errors" from one period to the next. SEEA will need to develop the necessary frameworks, processes and procedures for consistently applying "seasonal, climatic and technological adjustments" to measurements.

E. Questions for discussion

50. The following are offered as a basis for discussion:

a. Given the reasons presented in this paper (paragraph 10), is it feasible to define an "ecosystem entity" that can be reported against "in its own right"?

b. Is the presented **pathway** a useful set of steps to assist in clarifying the relationship between *statistical units* and *accounting units*?

c. Is the proposed **simple rule set** a useful starting point for defining *statistical units?*

d. Sources of unit instability through time include changes to relevant classification schemes (e.g. CICES is redefined) and accounting methods (e.g. changes to ecological index algorithms). We are not clear how these sources of instability can be managed when accounting and ask that it be addressed.

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