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Further development of a spatial framework for mapping ecosystem services

Briefing paper 2 - Mapping ecosystem service trade-offs

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Contents

1 Spatial Framework for Ecosystem Services

The natural environment provides society with many hidden benefits as well as the overt provisions that come from the land. Ecosystem service mapping provides a way of looking at the benefits the biotic and abiotic environment gives, which can form part of the evidence base for decision making. Taking into account the environmental, economic and cultural aspect of policy decisions will ensure that both society and the natural environment remain resilient now and for future generations. This integrated management of land is captured within the 12 principles of the ecosystem approach (CBD, 2004)[1].

A better understanding of what services are being provided by a given parcel of land, landscape or region[2] is essential to inform sustainability policy. Conducting a spatial assessment on ecosystem services encourages a fuller perspective about the landscape, ecosystems and the processes going on and also helps to identify the sets of benefits which humans receive from the natural environment. The spatial framework approach focuses on giving information on a wide variety of ecosystem services in an integrated manner. This provides evidence on the principles of the ecosystem approach, rather than focusing on individual components in isolation.

An initial step in conducting a spatial assessment of ecosystem services is to create an inventory which identifies the benefits and ecosystem services being provided within the area of study.

The inventory phase of a spatial ecosystem service assessment incorporates the following stages:

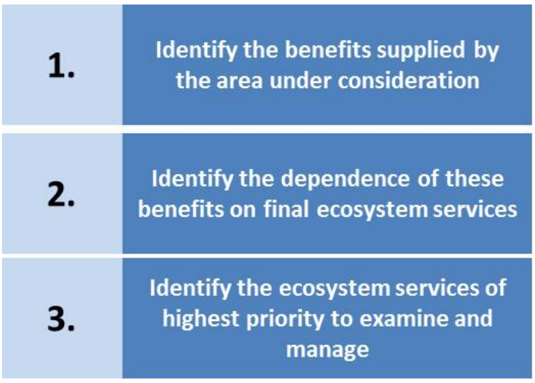

Figure 1. Principal stages for conducting a spatial ecosystem services inventory (adapted from Shelton *et al* 2001)[3].

Creating a spatial inventory of ecosystem services is a starting point to understanding the current situation and starts the process of quantifying the supply of ecosystem services within the chosen study area. Understanding the stocks of natural capital and documenting it by facilitating the use of an inventory is a perquisite to being able to further the analysis and spatially examine the different decision type situations.

[1] CBD, 2004. CBD Guidelines: The Ecosystem Approach, Secretariat of the Convention on Biological Diversity, Montreal.
[2] CROSSMAN, N, D., BURKHARD, B., NEDKOV, S., WILLEMEN, L., PETZ, K., PALOMO, I., DRAKOU, E, G., MARTIN-LOPEZ, B., McPHEARSON, T., BOYANOVA, K., ALKEMEDE, R., EGOH, B., DUNBAR, M, B., & MAES, J, 2013. A blueprint for mapping and modelling ecosystem services, *Ecosystem Services*, **4:** 4-14.
[3] SHELTON, D., CORK, S., BINNING, C., PARRY, R., HAIRSINE, P., VERTESSY, R., & STAUFFACHER, M, 2001. Application of an ecosystem services inventory approach to the Goulburn Broken Catchment. In: *The third Australian stream management conference: the value of healthy streams*, Brisbane, 27-29th August 2001, Cooperative Research Centre for Catchment Hydrology.

This project addressed four different situations in which the use of spatial inventory ecosystem services mapping is likely to help in decision making at local and regional scales, namely in:

INVENTORY PRODUCTION: making an inventory of ecosystem services;

BEST / WORST CASE SCENARIO MODELLING: determining where the best and worst place for action might be;

IDENTIFYING OUTPUT CHANGES: identifying the changes in ecosystem service output arising from planned change; and,

IMPROVING OUTCOMES: determining the best strategy for improving or 'optimising' the output of ecosystem services in a given area.

The decision making needs that these situations give rise to can be addressed by a range of approaches. Three policy papers describe and explain the approaches that are being developed for application in these situations. These include trade-off analysis, ecosystem service opportunity mapping, multi-benefit mapping and monetary valuation of ecosystem services. All of these methods give a value to the land for the service under consideration, but only the last addresses the monetary value of the services.

Suitability of ecosystem services mapping approaches to addressing particular policy needs

Type of ecosystem services mapping approach	**Ecosystem Services and Policy needs**			
	Inventory Production	**Best/Worst case scenario modelling**	**Identifying Output changes**	**Optimising outcomes**
Ecosystem Services Trade Offs	Prerequisite	Suitable	Suitable	Suitable
Ecosystem Service Opportunities	Prerequisite	Suitable	Suitable	Suitable
Areas with Multiple Benefits from Ecosystem Services	Prerequisite	Not Suitable	Not Suitable	Suitable
Monetary valuation of Ecosystem Services	Prerequisite	Suitable	Suitable	Not Suitable

2 Mapping ecosystem service trade-offs

2.1 What is a "trade-off" in the context of ecosystem services?

Most ecosystems are capable of delivering more than one ecosystem service and can therefore be regarded as 'multi-functional'. While management interventions can enhance the output of some services, it is apparent that in some situations not all services can be delivered simultaneously. It is in this context that the notion of a "trade-off" occurs and consequently can change the type, magnitude and mix of services delivered by an ecosystem[4].

2.2 Typology of different trade-offs

In the ecosystem service literature there are general definitions of a "trade-off" (Table 1), with most commentators following the definition provided by the Millennium Ecosystem Assessment. There are also more refined definitions of "trade-offs" that describe the interactions between ecosystem services that arise as a result of management choices. Synergies between services are often identified as part of the same process. Synergistic interactions allow for the enhancement of multiple services, a 'win-win' situation. Successful management of synergisms aims to increase the supply of ecosystem services and is a key component of any management choices[5].

Table 1. Definitions of "trade-offs" and "synergy" in the context of ecosystem services.

Definition	Source
Trade-offs: Management choices that intentionally or otherwise change the type, magnitude, and relative mix of services for that destination.	National Ecosystem Assessment (2011)[6]
Trade-offs: Management choices that intentionally or otherwise change the type, magnitude, and relative mix of services provided by ecosystems.	MA (2005) and TEEB website (accessed 27.5.2013)[7]
Trade-offs of ecosystem services: The way in which one ecosystem service relates to or responds to a change in another ecosystem service.	TEEB (website, accessed 27.5.2013)
Ecosystem service trade-offs arise when the provision of one service is enhanced at the cost of reducing the provision of another service.	Raudsepp-Hearne *et al* (2010)[16]
Synergy: Enhancement of multiple ecosystem services. Increasing the supply of one service contributes to the enhancement of others.	Haase *et al* (2012)

[4] RODRÍGUEZ, J. P., BEARD JR., T. D., BENNETT, E. M., CUMMING, G. S., CORK, S., AGARD, J., DOBSON, A. P., & PETERSON, G. D., 2006. Trade-offs across space, time, and ecosystem services. *Ecology and Society* **11**(1): 28.
[5] HAASE, D., SCHWARZ, N., STROHBACH, M., KROLL, F., & SEPPELT, R., 2012. Synergies, trade-offs, and losses of ecosystem services in urban regions: an integrated multiscale framework applied to the Leipzig-Halle region, Germany. *Ecology and Society* **17(3)**: 22.
[6] National Ecosystem Assessment, 2011. The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, Cambridge.
[7] Millennium Ecosystem Assessment (MA), 2005. Ecosystems and Human Well-being: Synthesis. Washington, DC: Island Press.

2.3 Benefits of assessing trade-offs when weighing up land use decisions

Identifying solutions when changes are proposed, invariably involves identifying and assessing alternative outcomes or choices. Ecosystem services are interconnected and taking a spatial approach will reveal what could happen if particular land management decisions are made on the ecosystem services being examined. “Win–win solutions" that result in the conservation of biodiversity and increased human well-being are difficult to achieve, and generally ‘trade-offs and the hard choices they entail are the norm’[8] (for example socio-economic and conservation objectives may need to be traded off).

Recognition of the trade-offs and synergies that may arise in different ecological contexts is a key management task, providing the opportunity to identify different political, economic, environmental or social ends that may benefit or disadvantage different individuals or groups.

2.4 When is it best to use the method?

Analysis of trade-offs is particularly valuable for testing “what if” scenarios and clearly has implications in three of the situations addressed by this project, which are in fact closely linked:

- determining where the best and worst place for action might be;
- identifying the changes in ecosystem service output; and
- determining the best strategy for improving or ‘optimising’ the output of future supply of ecosystem services.

Recognition of which situation provides the ‘best’ and ‘worst’ context for action requires some knowledge of what the consequences of ecosystem change are for those who benefit from the different services. Given that there may be choices that can be made between the different ‘bundles’ of services that might be affected by some management action, then different strategies might need to be considered to ensure that the different stakeholder groups are willing to support the measures proposed.

2.5 Concepts behind mapping trade-offs

In practical terms trade-offs can only be identified in the context of particular types of management action or policy measure. That is, they represent the marginal changes in service output that result for a particular type of intervention. They cannot therefore be mapped in the abstract, but require some notion of a baseline against which any changes in a particular service can be judged. The need to take account of the ‘before’ and ‘after’ situations therefore makes the mapping task more complex than when dealing with a single service.

Baseline data such as habitat, soil, geology, landform and management maps should be used along with the development of ecosystem service indicators to map the services under consideration. Mapping the spatial distribution of each ecosystem service reveals their individual patterns and by using a spatial approach, the user can identify and localize areas of change in ecosystem services provisioning synergies and trade-offs.

[8] McSHANE *et al* (2011) Hard choices: Making trade-offs between biodiversity conservation and human well-being. *Biological Conservation* **144**: 966-972.

2.6 Appropriate scale

Trade-offs amongst ecosystem services can be grouped into three categories of scale: spatial, temporal and reversibility[4].

Trade-offs are location specific and spatial scale refers to whether the effects of the trade-offs are felt locally or at a distant location. When analysing trade-offs and synergies, it is worth deciding whether the impacts of a decision are to be examined within the chosen area of study only, or also to consider the effects on provision of services outside of the study area too. Impacts outside the study area are known as off-site effects[9] or spatial trade-offs[4] and should be acknowledged during land management decisions, particularly for cross-boundary collaboration. For instance, land management interventions may lead to the transfer of knock on effects on systems further afield. Such off-site effects become crucial at broader scales which can lead to solutions at a landscape that feedback negatively at the local scale (Seppelt *et al* In press)[9] .

Temporal scale refers to whether the effects take place quickly or slowly and reversibility refers to the likelihood that the simplified service may return to its original state if the exploitation/degradation stops. Currently it is uncertain how trade-offs between services act at differing scales under different management interventions and whether any altered ecosystem services can return to an original state (Rodríguez *et al* 2006 and Ruijs *et al* 2013)[4] [10].

There needs to be a better understanding of the conditions and threats to different ecosystem services in order to recognise the relationship between biological factors and the resilience of ecosystem services to change and identify tipping points in ecosystem service delivery. Those relationships, together with how services interact across different temporal and spatial scales, are not currently well known[4].

2.7 Techniques

Cluster analysis is a powerful tool for the analysis of trade-offs and synergies. There are also other, possibly simpler, approaches to mapping trade-offs that work by attaching some metric (say the ratio of two sets of indicator services) to a spatial unit such as a habitat or a catchment, and mapping the patterns using some key. This latter approach works best if there is some prior knowledge about what the trade-offs involve (i.e. which indicators to compare); where this kind of information is not available then cluster mapping seems the most appropriate way of exploring the data.

Users can begin to understand and visualise trade-offs through the use of GIS tools available. Current tools in existence are used to examine and identify synergies and trade-offs between different ecosystem services, for instance, the Land Utilisation Capability Indicator (LUCI) examines trade-offs from individual field through to catchment scale (Jackson *et al*, 2013)[11].

In addition to mapping indicator variables, using spatial units to summarise the patterns of change, more aggregated ways of displaying trade-off data include the use of 'rose' or

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[9] SEPPELT, R., LAUTENBACH, S., VOLK, M. (In Press) Identifying trade-offs between ecosystem services, land use, and biodiversity: a plea for combining scenario analysis and optimization on different spatial scales, *Curr Opin Environ Sustain*, **5**: 1-6.
[10] RUIJS, A., WOSSINK, A., KORTELAINEN, M., ALKEMADE, R., SCHULP, C.J.E., 2013. Trade-off analysis of ecosystem services in Eastern Europe, *Ecosystem Services*, **4:** 82-94.
[11] JACKSON, B., PAGELLA, T., SINCLAIR, F., ORELLANA, B., HENSHAW, A., REYNOLDS, B., MCINTYRE, N., WHEATER, H., EYCOTT, A., 2013. Polyscape: A GIS mapping framework providing efficient and spatially explicit landscape-scale valuation of multiple ecosystem services, *Landscape and Urban Planning*, **112**: 74–88.

'radar' diagrams such as those employed by Rodríguez *et al* (2006)[4] in their analysis of trade-offs across the four global MA scenarios (see Figure 2). Systems such as ARCMap allow symbols such as these (e.g. Pi-diagrams) to be constructed and displayed for defined spatial units or points, and so this kind of analysis represents an alternative way that trade-off issues can be communicated.

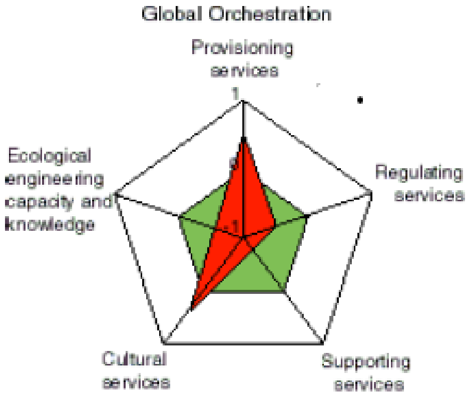

Figure 2. Relative change in provision of ecosystem services (ES) in the four MA scenarios (after Rodríguez *et al* 2006). Red polygons ("stars") indicate the state of each ES at the end of the scenario storyline relative to a starting point of zero (indicated by green stars).

2.8 Examples of analysis of trade-offs and use of techniques to map them

The process of identifying and assessing trade-offs and synergies in ecosystems services is relatively well established but quantifying these and producing spatial outputs is not yet commonplace and the examples provided are therefore drawn from recent research. Some authors have provided guidance on the use of techniques: Mehaffey *et al* (2011)[12] demonstrate how to construct a detailed land cover classification and link it to yield and agricultural practices to allow the modelling of ecological responses and trade-offs. Casalegno *et al* (2013)[13] describe an approach for evaluating a cultural service, based on the perceived aesthetic value of ecosystems, quantified using geo-tagged digital photographs uploaded to social media resources. This approach considered trade-offs between cultural services and carbon and agricultural production.

2.8.1 Other trade-off examples

A study of polices for biofuel production[14] in a German catchment identified many trade-offs for consideration, arising from objectives for food and fodder production, goals for water quantity, water quality and biodiversity. An algorithm was developed to allocate land between different uses via a set of crop rotations with the objective of maximising harvested yield (of the food crops and bioenergy plants) whilst maximising water volume under low flow conditions and minimising the average nitrate concentration of the water. The authors argued that for the study area, intermediate levels of the energy crop rapeseed, did not lead

[12] MEHAFFEY, M., *et al*, 2011. *Developing a dataset to assess ecosystem services in the Midwest United States.* International Journal of Geographical Information Science **25(4)**: 681-695.

[13] CASALEGNO, S., *et al*, 2013. *Spatial Covariance between Aesthetic Value & Other Ecosystem Services.* PLoS ONE **8(6)**.

[14] LAUTENBACH, *et al*, 2013. Optimization-based trade-off analysis of biodiesel crop production for managing an agricultural catchment. *Environmental Modelling and Software* **48**: 98-112.

to significant trade-offs with water quality and low flow, if a reduction of food and fodder production could be accepted. Similar levels of bioenergy crop production could be achieved under different scenarios whilst either seeing a 'win-no change' or 'no change' in terms of other services.

A trade-offs analysis by Haines-Young *et al* (2012)[15] explored the consequences of land use change scenarios for service output at the European scale using a multivariate classification of service trajectories to map trade-offs. The data were used to define clusters or groupings of spatial units with distinct patters of change. Eight clusters were identified and mapped, ranging from those where the mix of services was predicted to be stable over two time periods to others which either showed a shift to cultural services at the expense of provisioning or vice versa.

Cluster analysis was used to map trade-offs of twelve ecosystem services in a mixed use landscape covering 137 municipalities in Quebec, Canada[16]. The authors looked at the spatial patterns in the different combinations of services, rather than at any specific change. They argued, however, that these existing patterns reflected the effects of different types of ecosystem management that had produced 'desirable or undesirable sets of ecosystem services' in different locations.

2.8.2 Practical application

In practical terms trade-offs can only be identified in the context of particular types of management action or policy measure. That is, they represent the marginal changes in service output that result for a particular type intervention. They cannot therefore be mapped in the abstract, but require some notion of a base-line against which any changes in particular service can be judged. The need to take account of the 'before' and 'after' situations therefore makes the mapping task more complex than when dealing with a single service.

Cluster analysis is a powerful tool for the analysis of trade-offs and synergies, clearly other approaches to mapping trade-offs are possible. However, generally they would work by attaching some metric, say the ratio of two sets of indicator services, to a spatial unit such as a habitat or a catchment, and mapping the patterns using some key. This approach works best if we have some prior knowledge about what the trade-offs involve (i.e. which indicators to compare); where this kind of information is not available then cluster mapping seems the most appropriate way of exploring the data.

[15] HAINES-YOUNG, R., POTSCHIN, M., & KIENAST, F., 2012. Indicators of ecosystem service potential at European scales: Mapping marginal changes and trade-offs. *Ecological Indicators*, **21**: 39-53.

[16] RAUDSEPP-HEARNE, *et al*, 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *PNAS*, **107**: 5242–5247.