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Further development of a spatial framework for mapping ecosystem services

Briefing paper 4 - Mapping ecosystem service opportunities

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1 Mapping ecosystem services opportunities

1.1 What are "ecosystem services opportunities" and what are the benefits of mapping them?

In ecosystem service assessments, the notion of 'opportunity' encompasses situations where ecosystem services output might be enhanced by modification of the current management regime.

Mapping ecosystem services opportunities provides policy makers with a systematic method to identify and communicate where the output of particular services might be expected, based on a range of inputs, such as habitat type, substrate, management and geographic location. In common with other "suitability" mapping methods decision makers can explore 'what-if' questions in a decision support role and predict the varying level of service output under differing scenarios. The outputs can be described as 'opportunity maps' in the sense that they might help identify where a particular ecosystem service might be enhanced by modifying one, or more, of the inputs (e.g. management) through some kind of intervention.

1.2 Concepts behind "opportunity" mapping

Opportunity mapping, broadly depends on the idea of a 'production function' (which is a term used in ecosystem services literature); this means that it is a method that uses information about the structure and function of ecosystems to estimate the output of an ecosystem service.

1.3 Techniques

The terms 'opportunity' mapping is a fairly loose one, being part of a broader set of ecosystems service mapping methods, including benefit mapping (see paper 2). Both are part of a larger family of GIS methods that use a variety of analytical tools to combine layers of geographical or environmental data to make an assessment of some kind and so are examples of spatial modelling. These separate data layers can be considered as a set of constraints which when combined through rule-based map overlay techniques can be used to predict the varying level of service output (Figure 1).

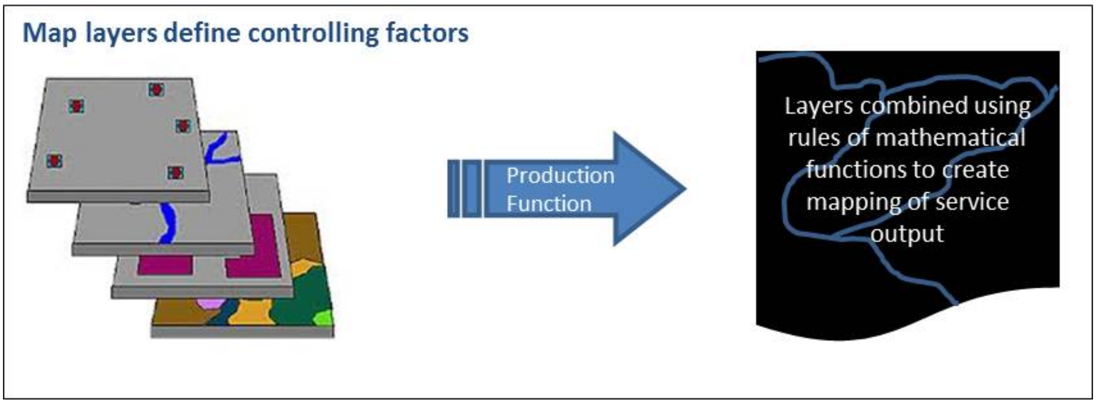

Figure 1. Overlay approaches for benefit and opportunity mapping

Such rule-based approaches can involve weighting the influence of the different map layers, and the analytical approaches applied can be complex. Although the different methods that can be used for opportunity mapping are not readily classified, there are four basic types, though they are not mutually exclusive; all of those described here can probably be used in combination and people mix and match methods:

Overlay mapping: Overlay analysis is one of the most basic, and well-established methods available in the GIS toolkit. It is easy to implement using standard GIS tools and easy to understand, especially by the non-specialist. Overlay methods have been widely used to produce land suitability maps of different kinds but tend to oversimplify processes and often focus on the things that can be represented in a GIS, rather than the factors that really influence things ‘on the ground’.

Multi-criteria analysis: uses explicit ‘decision rules’ often designed by the user, who can assign a ‘relative importance’ to each. The rules define relationships between multiple inputs and outputs and are transparent allowing the rationale for outcomes to be traced back through the decision logic to the data underpinning the analysis. The methods available are often employed to identify opportunities for managing ecosystem services sustainably, to find the most efficient or cost-effective pattern of land use and to generate a range of alternative planning scenarios.

Artificial intelligence: (which includes fuzzy logic and Bayesian Network models) are amongst the most novel that are available and claimed to be particularly appropriate when dealing with complex problems that involve using exploratory methods, because they attempt to mimic the kinds of problem solving approaches used by people. There are a range of techniques that can begin to capture both the complexity and uncertainties associated with the ‘real world’ and they start to address the limitation that conventional Boolean algebra is ‘too crisp’ given the nature of environmental data and the uncertainties associated with them, ‘fuzzy logic’ seeks to extend the approach by allowing partial or probabilistic membership to particular classes or sets. Bayesian methods do a similar thing (see Haines-Young, 2011)[1]. Their disadvantage is that they are resource intensive. Although they can be rich in the theoretical insights they offer, more expertise is needed both to develop and use them in a decision support role.

Participatory mapping methods: are increasingly being reported in the ecosystem service literature and depend on some kind of knowledge elicitation with stakeholders. They can be useful when dealing with complex situations that are not amenable to solutions based on modelling approaches. Their ‘popularity’ partly reflects the belief that stakeholder involvement in making management decisions is essential if they are to be effective, and also that consultation is fundamentally part of ‘good governance’ as represented by the Ecosystem Approach. Mapping methods usually depend on some kind of knowledge elicitation with stakeholders. This can be done by informal methods involving walking the land with the people who use or manage it, to using base maps to capture locations with particular characteristics that people value.

These techniques are described more fully in Haines-Young and Potschin (2013)[2]. The limitations identified apply to spatial modelling techniques in general. It is important to recognise that it is not so much the underlying techniques that determines the differences between approaches such as opportunity and benefit mapping, but rather the thematic areas in which they are applied. It is therefore important to recognise the different types of application when deciding a mapping approach that will assist with decision making.

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[1] HAINES-YOUNG, R., 2011. Exploring ecosystem service issues across diverse knowledge domains using Bayesian Belief Networks. *Progress in Physical Geography*, **35(5)**: 681-700.

[2] HAINES-YOUNG, R., & POTSCHIN, M, 2013. *Multi-benefit and opportunity mapping: a briefing paper.* Fabis Consulting Ltd.

1.4 In which situations is it best to use opportunity mapping?

Opportunity mapping is well-suited to those situations where the intention is to predict where a particular ecosystem service might be anticipated and look at spatial variations in some 'final ecosystem service' derived from a set of underlying functional relationships. It is particularly valuable for testing "what if" scenarios in two of the situations addressed by this project:

- determining where the best and worst place for action might be; and
- determining the best strategy for improving or 'optimising' the output of ecosystem services.

1.5 Examples of "opportunity" mapping

Overlay methods have been widely used to produce land suitability maps of different kinds, as a prerequisite to, and basis for, opportunity mapping. For example, carbon sequestration has been estimated based on using standard carbon densities for different habitat or land cover types and area or stock estimates[3,4]. More complex modelling operations are illustrated by the estimation of soil erosion potential (and hence the mitigating effects of land cover or habitat on such hazards) using the universal soil loss equation[2].

A study that mapped the opportunity for conversion to perennial energy crops in Yorkshire[5] illustrates some of the key features of multi-attribute mapping methods. A land suitability model was developed to assess the opportunities associated with perennial energy crops. Following an analysis of the uncertainties associated with the input data and model assumptions, a land allocation algorithm was developed that took account of soil and topographic influences and identified the opportunities for energy crop conversion area given various environmental constraints, such as targets for nature protection, food production priorities and land capability values. Although these studies emphasise the preliminary nature of the work, they found that the analysis suggested that the opportunities for expanding energy crops was fairly restricted.

In the Frome and Piddle catchment in Dorset opportunities mapping[6] of the best places to restore habitat in terms of its effect on biodiversity, water regulation opportunities and carbon storage was undertaken and the results used to encourage land managers to establish new habitat patches in the optimum places.

The use of fuzzy logic and especially Bayesian methods is now fairly common-place in the ecosystem services literature. The ARIES[7] (ARtificial Intelligence for Ecosystem Services) system, for example, specifically highlights the use of Bayesian methods in its construction, because they are able to communicate uncertainty about inputs to outputs and can be used

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[3] JACKSON, B. *et al*, 2013. Polyscape: A GIS mapping framework providing efficient and spatially explicit landscape-scale valuation of multiple ecosystem services. *Landscape and Urban Planning*, **112(1)**: 74-88.
[4] CCW and Environment Systems, 2012. *SCCAN: A practice application of SCCAN in Bridgend.* Countryside Council for Wales. Bangor.
[5] TENERELLI & CARVER, 2012. Multi-criteria, multi-objective and uncertainty analysis for agro-energy spatial modelling. *Applied Geography*, **32(2)**: 724-736.
[6] MEDCALF, K., TURTON, N., SMALL, N., & YANDALL-THOMAS, M., 2012. *Ecosystem Service Mapping for the Frome and Piddle Catchments*. A report produced by Environment Systems for Wessex Water.
[7] http://www.ariesonline.org/docs/ARIESModelingGuide1.0.pdf; see also https://learning.conservation.org/SouthAmericaEcosystemServices/Documents/ES%20Articles%20and%20Documents/2009%20Villa%20et%20al.%20ARIES%20-%20BioEcon%202009.pdf

in 'data-scarce conditions where deterministic models cannot run'. Multi-objective management strategies for ecosystem services have been designed at the catchment scale in a study of southern Illinois.[8] Alternative management solutions for each catchment in the study area sought to optimise the output of selected ecosystem services for a given set of constraints. The aim was to assess the role of agricultural landscapes in generating improved ecosystem services through reducing diffuse pollution while maximising income from land management. The analysis integrated a watershed model with an "evolutionary algorithm", an artificial intelligence technique. These techniques are 'adaptive' in the sense that they are designed to search for a solution from a (usually large) population of solutions. Rather than seeking an optimal solution from the outset, evolutionary algorithms are used to compare alternative scenarios and eliminate what are judged to be poor solutions. The algorithms are also capable of recombination and mutation procedures that enable the software to generate new solutions that are biased towards those regions of the solution space for which good outcomes have already been discovered.

Haines-Young and Potschin (in press)[9] have considered the wider use of participatory mapping methods, and document an example of how people were able to map locations in marine space used by different stakeholder groups. This enabled stakeholders to work together to make recommendations for the design of a set of Marine Conservation Zones in the seas around south-west England, as part of a wider network of Marine Protected Areas (MPAs).

A spatially explicit assessment of the benefits of water services at the scale of Europe[10] mapped simple indicators for water provision, water regulation by soils, and water purification by river networks. Both the capacity to provide services, as well as the actual flow of services, was quantified in biophysical terms.

[8] BEKELE, E. G. & NICKLOW, J. W., 2005. Multiobjective management of ecosystem services by integrative watershed modeling and evolutionary algorithms. *Water Resources Research*, **41(10)**: W10406-10410.
[9] HAINES-YOUNG, R. & POTSCHIN, M., (in press). The Ecosystem Approach as a framework for understanding knowledge utilisation. *Environment and Planning C.*
[10] LIQUETE, C. *et al*, 2011. Securing water as a resource for society: An ecosystem services perspective. *Ecohydrology and Hydrobiology*, **11(3-4)**: 247-259.