Geographic Information Systems Tools for Stocks and Flows of Ecosystem Services

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What are GIS tools?

Geographic Information Systems (GIS) are computer based systems environment in which spatial information can be stored, manipulated and visualized. They are a generic environment which is used in a wide range of sectors, from planning to environmental assessments. In this environment, there are a set of tools which have been specifically tailored to capture, quantify and assess ecosystem goods and services reflecting the underlying natural processes and properties.

When and why should I use the tool?

These tools form the basis and first step of any 'ecosystems' approach in that they quantify the current stocks and flows of ecosystem goods and services for any given area. They are in essence the first step in any ecosystem approach as they assess the state of the ecosystem under consideration and natural service it delivers, i.e. they supply the information on the state of natural environment needed for the subsequent decision support tools such as multi-criteria analysis (MCA), cost benefit analysis (CBA) and many others (Impact Assessments etc.).

Natural processes are complex, and background information on the stock and flows of ecosystem goods and services is usually incomplete or uncertain. These tools are based (with different degrees) on data and understanding of the natural processes operating in the geographic area under consideration. These tools are therefore of varying complexity requiring some data support and do need specialist input. A practitioner would consider whether to use such a tool when:

i. there is little available information (e.g. analogous studies) available to serve as a basis for decision making,
ii. there are comparable studies, but these need to be tailored to represent the system under consideration,
iii. robust, evidence based decision support is needed for difficult or controversial planning or decision making.

What is its relevance to the ecosystem approach and ecosystem services?

For any given geographical area, the quantity and supply of ecosystem goods and services at any given moment in time depends on the underlying natural capital. Natural capital is, in this sense, the capacity of the natural system to deliver ecosystem goods and services now and but also into the future. It is therefore a measure of both current capacity and future potential. Natural systems deliver ecosystem good and services through the processes and properties that constitute these systems and these goods are services are delivered spatially. These tools capture and represent in a spatial context the stocks and flows of ecosystem goods and services and so form the evidence basis for many of decision support and planning tools used in the ecosystem approach (i.e. they quantify ecosystem services).

How does one work with the tool in practical steps?

What we present is a generic workflow for an ecosystem stocks and flows assessment and highlight in this flow considerations, decision points and end points. The technical detail of this work, mostly within a GIS framework, can be found in the references at the end of the guidance. In it, we give examples of specific software (or GIS toolkits) that are currently available to practitioners.

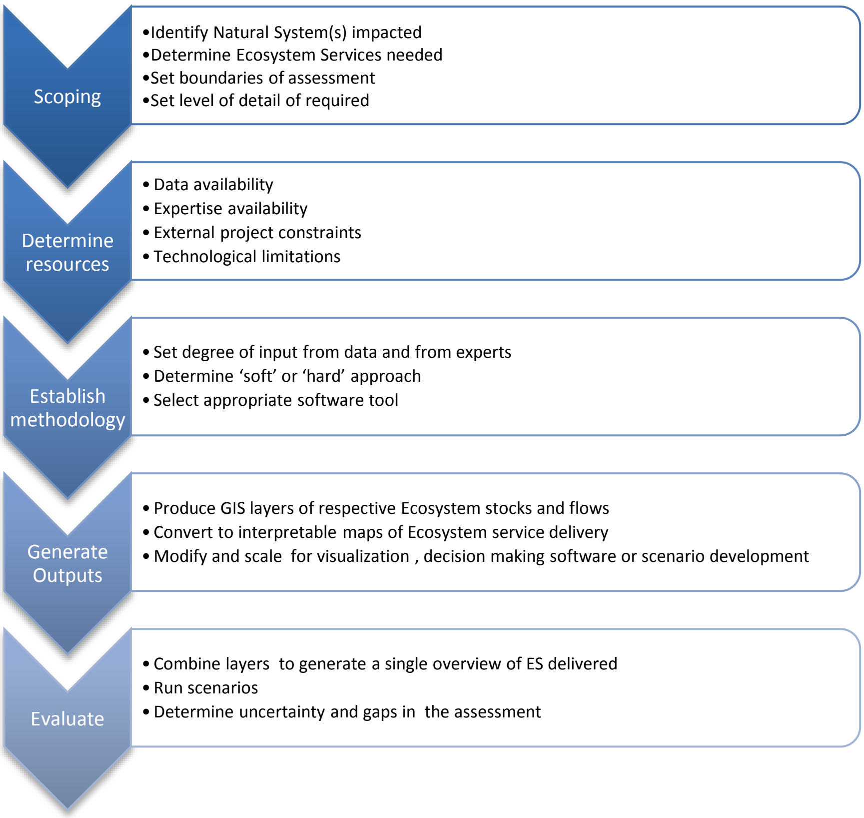

Figure 1: An example of a typical workflow to determine stocks and flows for ecosystem services

1. Scoping the natural system

In general terms, this first step (and many of the subsequent steps) will have considerable overlap with general project management. However, here we emphasize that the object of the study is the natural system itself and wider considerations (such as stakeholders etc) have impact and contribute but are not the object under consideration (which is the ecosystem being evaluated). There are two key elements that need to be achieved here;

1) A clear and comprehensive description of the natural systems on which the evaluation is going to be based. This is not a trivial task as any given geographic area may have multiple systems operating at different spatial scales (e.g. an area with a river, wetlands woodland and arable land which is also a key wildlife corridor). Inputs here can be land use/land cover maps, stakeholder inputs, national and regional biodiversity, ecological and wildlife maps.
2) An unambiguous statement on the limits of the study. Natural systems are complex, dynamic, multi-scale systems. It is neither realistic nor feasible to try to capture this completely. A clear statement, based on sound judgement (e.g. with stakeholders, organisations involved, clients) of the spatial limits, temporal limits and scale and resolution of the evaluation (e.g. bird but not soil microbes) and level detail required (global water movement but not effect of tillage on water infiltration) is critical to both ensure cost (and time) effective delivery of the assessment but also to ensure its reliability.

Finally, there is the consideration of which ecosystem services are being evaluated. The millennium ecosystem assessment lists a significant number of services and it is rare to evaluate and consider all the possible ecosystem services. It is current practice to limit these based on either the nature of the project under consideration (e.g. flood defences will primarily consider water regulation function) or equally often as a result of resource constraints or focus of particular project (e.g. culture services that do not consider regulation services).

2. Determining resources

This is obvious within a larger project management context, so here we focus on a number of specific resources to the use of these particular tools. The inputs needed to do these types of evaluation are often a mix of data and expert knowledge. Expert knowledge is needed to help inform the scope, limits and level detail needed; but can also be used to inform the actual level of service provision (the 'soft' approach). Data requirements and considerations are also a key resource, an evaluation that is based on 'hard' data carries with it a degree credibility and can be used to inform ecosystem process based models, which have advantages (described in the next section). In the UK there is wealth of environmental data (use/land cover maps, national and regional biodiversity, ecological, wildlife, soil, geology, hydrological maps, ordinance survey maps, digital terrain models, etc.) but not all of it will be at level of quality needed, either it is dated, not at the adequate resolution, contains uncertainty or is only available under licence. Finally, a further resource requirement will be software and computing availability. Although increasingly less of a concern, certain GIS operations can still be computer intensive and a GIS environment is the basis for much of these operations and visualization, so this specialist computing environment is needed.

3. Establishing the methodology

There are, broadly speaking, to main approaches to modelling ecosystem goods and services:

Empirical, or semi-empirical, based approaches which attempt to represent the underlying processes to some degree. Modelling individual ecosystem functions is not a novel exercise and there are countless models of functions in the scientific literature. These models can be captured in a GIS environment, in which they can be embedded and their outputs aggregated (i.e. some weighted averaging or addition of the different services for a given area; e.g. carbon sequestration + water storage + biodiversity) to generate an assessment of the current state of Ecosystem Service delivery. In this same environment, different scenarios can then be introduced to assess the impact of decision making or climate change. Advantages of this type of modelling environment is that it is generally based on the 'physical principals' of how the system operates, and therefore there is a clear underlying scientific basis to the Ecosystem Service assessment, the outcomes are therefore more 'defensible' if challenged under policymaking or decision making processes. The outcomes are also easier to explain, and where the tool fails, diagnostics (what natural process did we fail to capture? what data are we missing?) are easier to apply. The disadvantage of this type approach is that detailed representations of natural systems require detailed knowledge and ample data on the state and dynamics of the natural system in the area of interest. As this is rarely available, the underlying process models are often simplified into functional models tend to be more operationally defined. They are simpler models derived to obtain a process outcome as simply and as efficiently as possible, which often functions effectively but loses somewhat on scientific rigour. Tools that fall in this category are Invest and Polyscapes.

Expert knowledge based approaches. In many cases, collecting, collating and combining data and processes over diverse ecosystems is not a cost effective or practical approach. In this case, the alternative is to survey experts in the particular ecosystems, and collate their knowledge on this system. This can then be represented in a GIS environment for decision making. Representation of this expert knowledge can still be within a 'cause effect' modelling framework, where statistical modelling environment is in all likelihood the most effective way to represent the 'expert opinion' on the factors and controls which determine the supply of ecosystem goods and services within given areas. Advantages of this approach is that it can based on sparse data and simple models, so can readily give estimates of ecosystem goods and services delivery in most situations. It is clear though, that the disadvantage of this approach is that it ultimately based (to a degree) on opinion, and therefore is less scientifically robust (or can be perceived to be less robust). A second limitation to this method is that every time a new factor needs to be considered (e.g. climate change, planning changes), unless these have been considered in the original expert knowledge elucidation, a follow-up has to be executed. Current, state of the art, approaches, is to capture the expert opinion is a 'belief network', which graphically represents the relationships between the drivers and supply of Ecosystem Goods and Services but underlying this is a probabilistic environment which can supply some of the computation and numerical rigor which is usually associated with empirical models. Tools that fall with this category is MIMES and ARIES

4. Generate Outputs & Evaluate

Each of these methods will generate a set of GIS layers (or maps) of the current stocks and or flows of an ecosystem service. There follows from this a set of manipulations which are necessary but need to be carefully mapped out and described. The simplest approach retains the original basis of stocks and flows, and considers the current state and impact of a change in the landscape on each individual stock and flow. The summary statement that flows from this will be a discursive assessment of the impact of the change. However, many of the decision making tools and planning tools seek a single assessment of ecosystem stocks and flows at a given spatial location. This will require placing all 'stocks and flows' assessments on a common scale. Methods to do so go from valuing tools to MCA (e.g. Invest uses MCA), which each contain assumptions on the relative importance of a given service. It should be noted though, that it is not an immediate translation from stocks and flows to service. For instance, biodiversity can be expressed in numerous ways and based on a number ecosystem compartments (birds, plants, insects), so conversion of the 'stock' biodiversity to the provisioning service 'genetic resources' can require assumptions that need to be documented.

Wider considerations and assumptions of good practice and pitfalls that the user needs to be aware off.

1. Uncertain understanding and incomplete data. Natural systems are complex, and our understanding of their functioning (e.g. climate) is imperfect. Beyond this, even if we were to fully capture the complexity of natural processes in a model (or tool), applying this locally requires accurate, current information on the state of the system (e.g soil conditions, vegetation type and coverage, species composition, etc) . This is rarely available and so this makes an accurate assessment of the current state of delivery of ecosystem goods and services difficult and uncertain.
2. Spatial and temporal scales. Natural systems have intrinsic scales; that is to say, scales at which they naturally (or artificially) operate, for example seasons, river water sheds or fields. These are not necessarily the scales at which management interventions occur at (time) or over (space). Moreover, the point or scale at which the service is created (e.g. a field of winter wheat crop) is very rarely the scale at which it is consumed (city/nationally). The clearest example of this is, for instance, the movement of water from the Northwest of England to the South East during periods of drought. A final consideration here is that all tools have operational scales, which again can be different to the production scale and consumption scale (e.g. a GIS layer with polygons reflecting biodiversity, their scale is often operationally defined).
3. Interactions. Any given ecosystem will, at a given point in time and at any given location in space, supply numerous ecosystem functions and their interactions will be complex. The consequences of interactions between the ecosystem functions, both in terms of the spatial and temporal "inputs" of environmental properties and processes and also the "outcomes" for EsA will be of particular significance to understanding the resilience of ecosystem functions and consequently sustainable social and economic development.

Useful links

Invest (http://www.naturalcapitalproject.org/InVEST.html)

Mimes (http://www.ebmtools.org/mimes.html)

Aries (http://www.ariesonline.org/)