Appendix 5: Exploring the Future: Review of Spatial Decision Support Tools (sDSTs) (Milestone 3.2.)

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Introduction

Decision making in the context of multiple competing demands on land use is not simple. The processes and dynamics of ecosystem science are also complex and need to be understood; issues of time, space and scaling must be addressed. A key requirement in decision making for ecosystem services is for tools that allow non-specialist users to explore trade-offs to achieve adaptation options at a variety of scales. Perhaps most challenging is implementation at the scale of a parish, catchment or Nature Improvement Area (NIA) where stakeholders may have an intimate knowledge of particular aspects of the area but lack specialist sectoral advice, and key datasets are unavailable at fine resolution. Hence tools must make the most effective use of extant data but alert the user to key knowledge gaps and include intuitive ways of conveying uncertainty. This review looks at the main existing spatial decision support tools, and their ability to support a range of functions necessary for future spatial decision making in the UK.

Objectives

To undertake a brief review of existing spatial decision support tools (sDST) including applications relevant to terrestrial and aquatic systems.

Typology of sDST

SDSTs cover a wide range of functionality, complexity and applicability. Here we review a selection of tools that have relatively high profile either nationally or internationally, particularly the USA where thinking and application of tools has progressed most rapidly. A selection of different tools are discussed in detail below, together with web-based or downloadable applications which are not strictly spatial decision support tools but provide part of the functionality of displaying and assessing information about biodiversity and potentially competing uses of land.

SDSTs have also been reviewed in other studies. A reasonably comprehensive list is compiled by The Redlands Institute, University of Redlands\(^1\) which covers a range of tools and applications with a North American focus. The tools they describe range from fully functioning software applications to toolboxes and add-ons available within GIS software which allow spatial calculations relevant to the calculation or scaling of spatial data. A summary of their review matrix is reproduced in Appendix 1. A recent review of spatial decision requirements was conducted (Pagella 2012) linked to the development of an emerging UK tool aimed at local- to regional-scale decision support called LUCI/Polyscape (Jackson et al. in press). Tools and models relevant to large scale (global to regional) integrated assessment were reviewed by IEEP et al. (2009). From a business accounting perspective, there are a number of reviews of tools assessing the potential for tools to assist with environmental accounting and credits (BSR 2010; 2011a; 2011b).

Introduction to review approach:

**Overview:** Provides a brief overview of the capability of each tool

**Applications:** Current uses of the model for decision making.

**Services modelled:** Describes the ecosystem services, functions, biological processes or ecosystem characteristics currently modelled by the tool.

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\(^1\) [http://www.spatial.redlands.edu/sds/ontology/tools/](http://www.spatial.redlands.edu/sds/ontology/tools/)
Model design: Brief description of how the ecosystem service and other models are constructed and parameterised.

Scenarios: Description of how scenarios are incorporated into the tool.

User parameterisation: Describes the data and information users need to enter to the model.

Detailed review of selected tools

**InVEST**

**Overview:** InVEST is a sophisticated GIS-based tool which incorporates models for an increasing range of ecosystem services, allows valuation of those services, and provides some measure of risk assessment or trade-offs. It can handle scenarios and has a wide range of applications in decision making. Development is ongoing. Information sources: Nelson et al. (2009), Tallis et al. (2011)

**Applications:** Its uses range from simple spatial mapping or quantification of ecosystem services to more complex assessments to inform decision-making such as spatial planning, sustainability impact assessment (SIA) or strategic environmental assessment (SEA), payment for ecosystem services (PES), designing mitigation and climate adaptation.

**Services modelled:** InVEST has models for both terrestrial ecosystem services and marine and coastal ecosystem services. At present, there is relatively little linkage between the two, but development work is addressing this issue. There are terrestrial/freshwater models available to quantify biodiversity: habitat quality and rarity, carbon storage and sequestration, reservoir hydropower production, water purification- nutrient retention, sediment retention model-avoided dredging and water quality regulation, managed timber production, crop pollination. Marine models can quantify wave energy, coastal vulnerability, coastal protection, marine fish aquaculture, marine aesthetic quality, with some spatial and risk assessment analyses: marine overlap analysis model- fisheries and recreation, marine habitat risk assessment.

**Model design:** Models to quantify ecosystem services include process-based components, land-use coefficients and spatial calculations, all linked to land-use in a climatic context. Coverage of flows of services within a landscape, and barriers to those flows is limited, other than water flows, and the use of viewsheds in calculating landscape aesthetics. The model for biodiversity uses habitat quality and rarity as proxies for biodiversity, with distance from threats dictating habitat quality. Some models are dynamic, capable of running at annual time-steps with annual average data, but development is aiming to improve dynamic modelling to daily, seasonal timesteps.

**Scenarios:** Scenarios are typically developed in dialogue with relevant stakeholders to the question of interest. They are developed externally to InVEST and are fed into the package as scenario-specific maps, GIS layers, or altered data-tables.

**User parameterisation:** In application to new regions, models have to be parameterised for local circumstances, therefore models can not be immediately applied in new situations or locations without significant parameterisation and, in some cases, adaptation of the models. However, development work is ongoing for a version applicable at global scale, which will have general applicability but at coarser resolution. At its simplest, users enter the data to run each model in the form of maps of land use or land cover (e.g. current, past, future, scenario-based) and data tables,
plus some additional input parameters for models (e.g. for valuation). Hydrological and some other calculations also require digital elevation models (DEM).

**Uncertainty:** The limitations and assumptions of each model are explained, the methodologies are presented and transparent. Data quality may be used to inform risk assessment – see the chapter on Habitat Risk Assessment in Tallis et al. (2011).

**Scales applied and examples:** In principle, InVEST can be applied at any scale, depending on data availability, although in practice there may be constraints for some of the models. InVEST has been applied in case studies in the Americas and Africa. Some examples include: policy and conservation planning in the Willamette Basin USA, private landowners in Hawaii USA, multi-stakeholder planning in Tanzania, permitting and licensing in Colombia, and priority setting for international aid in the Amazon Basin.

**ARIES**

**Overview:** ARIES (ARtificial Intelligence for Ecosystem Services) is a web-based decision support system that is used for Ecosystem Services assessment and valuation (ESAV). It differs from other packages in that it provides a modelling framework which can run external models via model-wrapping in addition to its internal Bayesian probabilistic models. It can be run remotely via web browsers and therefore does not need extensive computing power or data storage capacity to be held by the user. It incorporates a conceptual framework for mapping services comprising: source, users, sinks, flows, and includes positive and negative ‘carrier’ impacts. This means it can currently map potential ecosystem services, the beneficiaries, and the landscape routes which deliver those services. Valuation is currently lacking, but planned. The structure allows users to supply data and knowledge at fine-scales to develop locally relevant case studies. Information sources: Bagstad et al. (2011).

**Applications:** ARIES has been used for spatial mapping/quantification of services and valuation of services; PES; conservation; spatial planning; future change; land management decisions.

**Services modelled:** There are ten services modelled so far: carbon sequestration & storage, open space proximity, aesthetic viewsheds, flood regulation, sediment regulation, water supply, coastal flood regulation, subsistence fisheries, recreation, nutrient regulation. Eight of these services have been modelled in local situations, and models require adapting for new locations. There is a developing library of additional models written by other users for new situations. A global version is planned which can model major services across the globe using globally available datasets; this may be some way off. Linkages between terrestrial and aquatic systems are limited at present.

**Model design:** Internal models are primarily probabilistic Bayesian models (Figure 1), allowing greater flexibility to model semi-quantitative measures such as cultural services, or in areas which are data-sparse, and which can extract relationships using machine learning. ARIES can also run external models, including process-models which have been model-wrapped, and allows the flexibility to run different suites of models depending on the context. Some models are dynamic, running at annual time-steps. Improvement to seasonal or finer temporal resolution is planned.
Scenarios: ARIES can handle scenarios, as separate data and information layers which are fed in as inputs. Certain modules have built-in scenario editors.

Figure 1. Bayesian network model for aesthetic proximity sources for the San Pedro River watershed (Bagstad et al. 2011).

User parameterisation: Application to new case studies or situations requires consultation with the ARIES development team to discuss the fit to existing models, partnership opportunities and training are available for new development.

Uncertainty: Model assumptions and data sources are made explicitly. The Bayesian probabilistic modelling allows uncertainty to be calculated at each stage of the modelling process, and can be quantified or mapped as overlays.

Scales applied and examples: In principle, it can be applied at any scale. Figure 2 below shows where ARIES has been parameterised, and for which services. These models are assumed to be broadly transferable to areas with similar land use and climate elsewhere.

Figure 2. Case study applications of the ARIES model. From Bagstad et al. (2011).
**EcoMetrix**

**Overview:** EcoMetrix combines biophysical indicators of ecological function into a single habitat score, weighted to achieve balanced contribution of biotic and abiotic indicators. It can handle 'cultural services', and can be used with valuation. Spatial analysis appears to include area-weighted service delivery by land use/land cover, but not spatial context, i.e. position in landscape.

Information sources: Halsey et al. (2010; 2011).

**Applications:** Its uses include corporate sustainability planning, alternatives analysis, environmental impact assessments/statements, crediting basis for market systems.

**Services modelled:** These include water provisioning, water regulation, climate regulation and a range of cultural services.

**Model design:** Metrics are built up from maps and databases of land use, land cover and habitat attributes. Resulting habitat or biophysical units are scored for contribution to relevant functions (Figure 3), and these building blocks are combined in various ways, balanced through weighting procedures, into summary metrics of ecosystem service/function (Figure 4).

![Figure 3. Each ecological attribute converts to a standardised score of performance against relevant functions, with response functions based on literature and expert judgement.](image)

**Scenarios:** Data sets are created for a baseline condition and anticipated future condition. Ecosystem function scores are calculated using these as inputs.

**User parameterisation:** Major new applications are directed by Parametrix staff. Base data are collected and entered by the user, stratified by pre-set land-use types. Service provision is calculated from these according to in-built algorithms. An early web-based prototype is available on-line, and subsequent developments run as a desktop application which incorporates Microsoft Excel spreadsheets and ArcGIS. Other models can be run alongside.

**Uncertainty:** Uncertainty analysis has been run in some applications (Eurasia ESA pilot study), but it appears not to be included in the model.

**Scales applied and examples:** Applications so far have been at site scale, but it can be adapted for larger scales. Most examples are run for commercial clients, run by Parametrix. An example in
development involves EcoMetrix as a base with addition of a Bayesian spatial DST for Spatial Marine Planning (with US BOEMRE), but no further information is available.

Figure 4. Aggregating biophysical building blocks into ecosystem service functions. Halsey et al. (2010).

**LUCI/Polyscape**

*Overview:* LUCI/Polyscape is a GIS toolbox designed to explore spatially explicit synergies and trade-offs amongst ecosystem services to support landscape management (from individual fields through to catchments up to 10,000 km² scale). It quantifies and maps a variety of ecosystem services. It includes algorithms to calculate where trade-offs and/or synergies between services exist by combining GIS layers using simple rules (e.g. Figure 5). Information source: Jackson et al. (in press).

In its original guise it was called Polyscape, but now has a new version LUCI, incorporating additional service models.

*Applications:* Mapping of ecosystem services, decision support at farm and larger scales, identifying areas with maximum potential for change in land use, and also existing features or management regimes in the landscape that are worthy of protection.
**Services modelled:** Agriculture, water regulation, erosion and sediment control, carbon sequestration, habitat connectivity, N and P water quality (under development).

**Model design:** The water regulation and erosion/sediment delivery models are novel algorithms combining established physical relationships related to water holding capacity, infiltration capacity etc and spatially explicit topographic routing. The agricultural model uses a simple rule set based on slope, aspect, fertility, and hydraulic properties. The carbon layer follows IPCC Tier 1 guidelines, and considers both current carbon stocks and emission/sequestration, while the habitat connectivity is an automation of the Forestry Commission habitat connectivity model “BEETLE”.

**Scenarios:** Scenarios can be constructed by modifying input parameters and/or input land use data.

**User parameterisation:** Users can modify base data, parameters and define questions of interest using GIS toolboxes.

**Uncertainty:** Not quantified.

**Scales applied and examples:** Has been applied at farm-scale up to landscape/catchment scales (up to approximately 10,000 km² and with the capability to handle larger areas). Case studies have been applied within Wales, New Zealand, Ghana, Greece and England (the Bassenthwaite catchment and the Loweswater catchment).

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Figure 5. Example of flood mitigation / carbon trade-off layer in LUCI/Polyscape application for Bassenthwaite catchment.
**SIAT**

**Overview:** SIAT (Sustainability Impact Assessment Tool) was designed to aid decision making by policy makers at a European, and regional scale within the EU SENSOR project. Using pre-defined policy cases and scenarios, it assessed impact of policies on a wide range of indicators and land-use functions partly analogous to ecosystem services but explicitly incorporating social and economic indicators. The tool never reached final production, but incorporated many useful features. Information sources: Helming et al. (2011a,b).

**Applications:** SIAT was applied *ex ante* to assess impacts of European-scale policy decisions on e.g. subsidy of biofuels.

**Services modelled:** Around 60 environmental, social and economic indicators were modelled, aggregated to nine higher level Land Use Functions.

**Model design:** Indicator models ranged from simple land use or land cover metrics, to more complex decision trees and process models. Linkages between indicator models and changes in large-scale agricultural and economic drivers under different policy initiatives were established off-line, with these response functions used in the on-line tool.

**Scenarios:** Scenarios were pre-defined, and indicator model outputs calculated for all combinations of scenarios. Entirely new scenarios would be very costly to construct and parameterise.

**User parameterisation:** The policy user could alter a range of settings, e.g. subsidy level for biofuel within a series of set menus. No other changes were possible.

**Uncertainty:** Models and linkages were described in fact-sheets. Uncertainty in data and models was presented as traffic lights.

**Scales applied and examples:** Applicable at EU scale, down to regional (European NUTS2 regions). Policy cases looked at CAP reform, subsidy of biofuels, and strengthening Biodiversity protection.

**NatureServe Vista**

**Overview:** NatureServe Vista was developed by a non-profit conservation group. It is a GIS-based decision-support system that helps users integrate conservation values with other planning and assessment activities. Users can evaluate, create, implement, and monitor land use and resource management scenarios designed to achieve conservation goals within existing economic, social, and political contexts. Information source: [http://www.natureserve.org/index.jsp](http://www.natureserve.org/index.jsp).

**Applications:** Has been used for conservation, spatial planning, land-use decision making.

**Services modelled:** The primary role of NatureServe Vista is mapping of conservation, land-use and other information layers, with the aim of exploring synergies and conflicts. It does not aim to model ecosystem services. However it can calculate marginal values for land parcels based on how unique the parcel’s biodiversity, how threatened it is, and the cost to conserve it. These can be ranked and evaluated against other land-uses to inform conservation priorities. However, it can be linked to hydrology models to quantify water-related services.
Model design: See above.

Scenarios: Scenarios are built up as variations within a case study application. Scenarios of e.g. land use can be imported from other sources as GIS layers.

User parameterisation: Each case study is a unique application of a question/problem. It is an iterative process, building data and information layers with technical support. Internal weights, e.g. rarity weighting for a conservation element, can be modified by the user according to local priorities.

Uncertainty: Not presented to our knowledge.

Scales applied and examples: NatureServe Vista is freely downloadable. Technical support is available at a cost. Applications in the USA include sustainable forest management in Potlatch, Arkansas and sustainable agriculture assessment in the Napa Valley, California. A case study on conservation and land management is ongoing in Peru.

Biodiversity information tools.

In some of the tools reviewed above, biodiversity is not expressly considered or quantified. This is partly because a focus of many of these tools is ecosystem services which are often seen as deriving from biodiversity (i.e. biodiversity is not regarded as a service in itself), and partly due to the difficulties of quantifying biodiversity on a spatial basis.

However, a suite of tools are being developed worldwide which provide users with information about biodiversity, primarily for use as planning screening tools. These are often developed in conjunction with conservation organisations who hold or collate biodiversity data, and are used by large organisations at coarse spatial resolution as initial screening to identify areas where biodiversity may be a constraint to development of infrastructure, planned land acquisitions or planned changes in land use.

One example is the Integrated Biodiversity Assessment Tool (IBAT) which provides access to global biodiversity data including protected area boundaries, biological information about habitat and species diversity indices, and key areas for biodiversity. It was developed in partnership with conservation organisations including BirdLife International, Conservation International, International Union for Conservation of Nature and UNEP World Conservation Monitoring Centre. Data access is made possible by a diverse set of data providers in government, business and civil society from over 200 countries/territories. The tool has two main applications: IBAT for Business\(^2\) is designed to facilitate access to accurate and up-to-date biodiversity information to support critical business decisions; IBAT for Research and Conservation Planning\(^3\) is designed for use in research and for conservation planning purposes, in particular to inform the development or revision of National Biodiversity Strategies and Action Plans (NBSAPs), which outline actions for addressing threats to biodiversity. IBAT allows overlaying of information layers and export of layers or data to other software.

Other applications do not store biodiversity data directly, but aim to quantify or to classify biodiversity measures on the basis of land-cover. These have been developed primarily by the academic sector, but some have also been developed by businesses in conjunction with conservation organisations. The overall purposes are similar, to arrive at proxy measures of biodiversity (or relative biodiversity) as a function of land cover where detailed biodiversity information is not available. These approaches treat land cover as a proxy, with pristine land cover representing maximum or the reference biodiversity level, and have progressively lower biodiversity scores associated with land classes exposed to increasing human disturbance or alteration.

In the Globio model, five main land degradation categories are defined from pristine (e.g. primary forest) to fully degraded (e.g. degraded agricultural land) (Figure 6). Relative biodiversity scores for each category equate to an index of Mean Species Abundance (MSA), quantified via meta-analysis of species richness for a range of global biomes, and relevant to a range of drivers including land-use degradation and atmospheric pollution (Alkemade et al. 2009). Calculation of MSA scores is based on difference from the species composition of the reference pristine habitat, and not just on species richness (Alkemade et al. 2009; de Groot et al. 2010).

A simpler idea with ordinal classes of biodiversity is fleshed out in the Ecometrica Normative Biodiversity Metric (NBM) score (Jarrett 2011) where five land-classes ranging from pristine to degraded each have a biodiversity score, which can be increased by the presence of endemic mammal species on the IUCN endangered list. To apply this metric to a case study the available land-classes are categorised according to their status along the pristine-degraded gradient, the biodiversity score for each category is adjusted for presence of endemic species, the biodiversity score is then multiplied by the area of each and the score divided by the total area, giving a single metric. In the NBM approach there is no theoretical maximum score because biodiversity scores can be increased for each endemic species present before scaling by land class area. The NBM score can be used to evaluate policy options which alter land-area or biodiversity quality for conservation, or can be used simply for environmental accounting purposes. A disadvantage is that there is considerable subjectivity involved in assigning land cover to degradation classes, and interpreting how land management may alter this classification.
Tools and applications in the UK

Within the UK, a number of initiatives have been improving public and private access to existing data and information sources, using web-based systems. These provide some of the functionality of a spatial decision support tool. Here we review a selection of tools and applications which provide varying degrees of the functionality required by a spatial decision support tool.

The UK National Biodiversity Network (NBN) has been involved in developing some planning screening tools with other partners including Natural England. These include the Greenspace Information for Greater London (GiGL)\(^4\), initiated in 2005. This is a portal initially designed to provide planning professionals with species data through the NBN Gateway, but functionality has since been considerably extended for use by the wider public. Users can see locations and details of biodiversity records and other information layers including habitats, geodiversity, open space, and derived information such as quality of local area with respect to greenspace (e.g. “Areas of deficiency to sites of importance for nature conservation”, Figure 7). It also allows users to enter their own biodiversity records. Other tools making use of NBN data include the Environment Agency’s ‘EASIMAP’. This collates a range of data sources and conducts an automated rapid-screening of permit applications to identify those that require the most attention, based on proximity of biodiversity features to the...

\(^4\) [Accessed: 7 March, 2012]
proposed activity within a series of relevant buffer zones. Expert staff use the summarised information from the screening to come to a judgement on whether the activity should go ahead.

Figure 7. Quality of green space in London, from Greenspace Information for Greater London (GiGL)

Another web-based source of biodiversity information in the UK is the Biodiversity Planning Toolkit\(^5\), created by the Association of Local Government Ecologists (ALGE). This comprises a web site providing links to information on species, habitats, legislation etc. which are relevant to planning issues. It also provides an ‘Interactive Landscape’ which contains a number of animated scenarios showing how biodiversity issues can be addressed in various types of development and in different planning situations.

An off-line tool which is somewhat dated but is a useful example of collating and integrating data is the Countryside Information System (CIS) (Howard & Bunce 1996). It is a spatial information system covering the whole of the UK. It was developed in the 1980s following the 1984 Land Use Survey carried out by ITE to present results of the Countryside Surveys (CS - including Land Cover Map) to policy advisors. It operates on a simple 1 km raster base using the Ordnance Survey (OS) National Grid. As well as CS data, a wide variety of other datasets have been formatted for CIS, these include OS map data (areas of town, villages, roads, woodland, etc.), administrative areas (down to local authorities and NUTS regions), designated areas (National Parks, SSSI, AONB, NNR, etc.), climate data (old air ministry data and some modelled values), vegetation (CIS was bundled in the BSBI Plant Atlas and has all species in). WS Atkins carried out a project populating the system and producing a

catalogue that was updated by ADAS. CS2007 data (Field survey and LCM2007) have been added to the system. It is a relatively simple system to use, but has limited capability and most datasets require updating.

Other tools include the recently launched CEH wetlands and climate change tool. This provides three levels of assessment: Tier 1 (a web-based rapid screening tool), Tier 2 (site-based analysis requiring some model runs, and weeks of time), Tier 3 (detailed site-level assessment, requiring detailed hydrological modelling, taking months and requiring specialist consultant expertise).

Forest Research use a number of decision support models including The Ecological Site Classification (ESC) decision support system which relates spatial distribution patterns of productivity to related key climatic variables; the SPECIES model (Spatial Estimator of the Climate Impacts on the Envelope of Species), based on a neural network which uses processed climate data to simulate the natural distribution of species ‘trained’ on European species distribution data; the HaRPPS tool which is a combined information retrieval system and decision support tool to provide information and guidance for managing habitats and rare, priority, and protected species. HaRPPS is a web-based application, that will be accessible for use by forest managers and the general public. It currently holds information about 131 woodland species including animals, birds, insects and plants, and is currently being developed to assess the impacts of forest operations on species and habitat disturbance, and to assess opportunities for habitat improvement. Forest Research are developing a range of landscape GIS tools within an umbrella project called BEETLE (Biological and Environmental Evaluation Tools for Landscape Ecology) which include functionality for manipulating land cover data, measuring landscape structure, and assessing landscape function and connectivity. The BEETLE habitat connectivity uses similar principles to the European LARCH habitat connectivity model.

Platforms:
In addition to meta-models (e.g. InVEST, ARIES, LUCI/Polyscape) and data gateways (e.g. NBN) there are developing initiatives to improve access to data and information in the UK. One of these is the Environmental Virtual Observatory (EVO).

The Environmental Virtual Observatory is a Natural Environment Research Council-funded pilot project which is scoping how to use cloud computing technology to centralise access to environmental data, models and tools. It aims to provide a platform for a wide range of users from local to national, un-informed public through to scientists and policy makers to access the environmental information they need to make decisions. The vision of the Environmental Virtual Observatory is:

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To make environmental data, models, information and tools from public and private data assets more visible and accessible to a wide range of potential users including public good applications.

To develop new tools to facilitate the integration of data and models for hypothesis testing and gap analysis, tools for visualisation and interpretation of results, and links to added knowledge and expert analysis.

To provide a forum for testing and developing decision-support tools to help resource managers and policy makers to tackle environmental challenges, from local to global scales.

Work towards realising this challenging vision is being started through a two year £2 million pilot project. The Pilot Environmental Virtual Observatory (EVOp) seeks to develop a proof of concept to stimulate interest and engagement in the environmental community at all levels in these new technologies, to demonstrate effectiveness, to help to set international standards for exchanges of data and models and to explore how the technology can be used in environmental management. The initial focus is on the “Sustainable use of Soils and Water” component of NERC’s research.

**Box 3.1** An example of the EVO vision relevant to the localism agenda:

“A small rural market town has a flood problem, and the community is too small to be eligible for flood-protection investment. But several agencies are willing to make small changes to how they manage the catchment: the Forestry Commission will build debris dams; Natural England will block drainage ditches to slow water flowing off the hills; farmers will create some fenced overgrown buffer strips along streams; and the Environment Agency will create flood-storage ponds on the floodplain. But where should all this be done to make the most difference and exactly how much ‘action’ is required? Can we just add up the effects of these changes or do they interact? What will the overall effect be on flood risk, and how can you communicate these proposed actions to the community? The EVO will let you explore these different options and communicate them to a diverse audience.” (Planet Earth, 2011)

**Valuation:**

Valuation of biodiversity, the environment and ecosystem services is an emerging issue. In addition to government and scientific interest in being able to value externalities associated with, for example, impacts of policies or air pollution (e.g. Defra, 2007; Jones et al. 2012), it is developing momentum for corporate use in the USA where businesses seek to quantify the environmental impact of their operations, evaluate planned operations, and for purposes of environmental accounting. Valuation could be provided in a UK context by linking to databases for value transfer or to economic models. Consultation with environmental economists would be essential to explore how this would best be implemented, and would likely comprise a phase 3 or later development of any tool. At this stage it should be noted as a consideration of functionality required for future tool development.
**Assessment against users’ needs**

Those responding to the e-questionnaire had a wide range of expertise with a majority (61%) having used some form of decision tool. They also covered the spectrum of decision makers and potential users of a tool, from those making high-level decisions, those providing data to inform decisions and those making day-to-day decisions on the ground.

In general, the key functionalities identified as desirable within a tool were (in order of decreasing importance):

- Produce maps to visualise data/outputs spatially
- Present information at a range of spatial scales
- Simple and easy to understand with reference to a manual (doesn’t require training)
- Able to contribute own data to the tool
- Export outputs as data files or for use in other software

This suggests most users don’t actually want a decision-support tool, just improved access to data and information. However, responses differed among sectors, and some sectors (particularly National government, Statutory Advisory Bodies and Industry/Agriculture) ranked features of more complex tools very highly. These additional functionalities, ranked no lower than third by at least one sector, were:

- The ability to evaluate trade-offs between information layers and competing decision solutions
- The flexibility to incorporate user-defined rules for evaluating those trade-offs
- The ability to include scenarios of future impacts of drivers such as land-use and climate change

National government respondents were particularly interested in the functionality of being able to run scenarios, which requires a tool of intermediate complexity, and if this was to involve genuine modelling capability to model changes under different scenarios would require the most complex typology of tool able to run dynamic models. By analogy with the type of decisions that respondents currently use tools for, there is also the requirement for users to parameterise their own decision-cases in the form of scenarios. Industry/agriculture and Local Record Centres were also interested in the ability to evaluate trade-offs between information layers, including the flexibility for user-defined rules to explore these trade-offs.

These findings illustrate some basic tensions between the perceived needs of different user groups, primarily the conflict between the need for a tool that is easy and cheap to use with the requirement for flexibility, the ability to parameterise your own decision-making context, and
dynamic modelling which necessitate a complex tool and the technological and resource overheads that go with that. A second distinction is drawn out from the requirements for decision making (question 7). Industry and agriculture respondents were interested in a tool to provide them with ‘the answer’ while national and local government and statutory advisory bodies ranked this facility lowest of all and were interested in a tool that provided them with the information they needed in order to take an informed decision themselves.

**Draft recommendations/Conclusions**

The field of decision support tools, and particularly the ability to run these spatially is rapidly evolving, due to technological advances in data storage, data processing algorithms and software development. As a result, the approaches are generally so new that no stable, flexible and well-used set of tools exists. In many ways, the UK is slightly behind other European countries and the USA. There are few examples of application of major decision support tools in the UK, and none of the larger ecosystem service tools. There is therefore considerable groundwork to be done with respect to developing and applying some of these tools in case studies. On the other hand, the UK has some sophisticated biodiversity information tools and a number of different information gateways which provide access to biodiversity and other environmental data (e.g. GiGL, EASIMAP). Of particular importance are recording initiatives which rely on the public reporting biodiversity and environmental data, often using mobile phone applications. Examples include the OPAL biodiversity survey and iSPOT. Development and application of ecosystem service tools is making some progress, with a UK-developed tool LUCI (formerly Polyscape) being run as a new case study for the Bassenthwaite catchment (several case studies of the older version Polyscape have been run in Wales), and InVEST is being run as a UK case study within a NERC Biodiversity and Ecosystem Services (BESS) project. Large-scale modelling of proxies for some ecosystem services was conducted in the Countryside Survey Integrated Assessment. The functionality aimed to be supplied by the Environmental Virtual Observatory (EVO) has the potential to offer a powerful platform for providing access to a wide range of data and models.

The main findings are that:

- Most tools can in principle operate at any scale, but some are more suited to particular scales due to their data requirements and algorithms/models.
- For many tools, the biggest limitations to their use are data availability
- A secondary limitation is the algorithms/models required for new features e.g. mapping ecosystem services, but these are rapidly being developed.
- There are few or no applications of large complex tools exist in the UK context, with exception of current/imminent pilots on LUCI/Polyscape and InVEST. Therefore parameterisation of such models has to start from scratch.
- Tools vary in their complexity and user-friendliness. Increased functionality usually comes with increased complexity and the associated overheads of technical time and expertise required to run those tools.
- Different user groups have different sets of requirements from tools.
• It is therefore likely that no single tool is able to satisfy all possible elements of functionality.

Based on these findings we make a number of recommendations.

• An important next step is to scope the feasibility of implementing a range of tools within the hierarchy of functionality (see text below).
• Build on existing expertise and functionality for the simpler tools (e.g. Planning Screening Tools, or biodiversity information tools).
• Trial a selection of more complex tools in the same case-study area to identify issues and time constraints associated with implementing these tools. A similar approach applied in the USA is shown in Appendix 1, comparing ARIES, InVEST and other ecosystem service tools.

A simple hierarchical typology of tools is presented below. This could comprise a diverse range of tools, providing functionality within one level, or one or two tools with the flexibility to operate at different levels (a disadvantage of this approach may be overheads of understanding and using a comprehensive tool, even for simple operations).

Level 1. The simplest approach would be a one-stop shop for data and information layers. Simple routines could allow users to specify or explore rules for trade-offs between data layers and their outcomes. Predicted future land-use/climate impacts under different scenarios may be incorporated by addition of fixed data-layers, but there would be limited flexibility to explore these ideas without algorithms or algorithms to derive new data layers based on manipulating data from a variety of sources. It may be possible to add valuation functionality by linking to databases for value transfer. In principle it may be possible for users to add their own data layers, but the majority of technical users would be more likely to extract data-layers for use in their own software.

Level 2. A more functional approach would build on level 1 to add models or algorithms to quantify ecosystem services and other parameters of interest based on a wider array of input data. These may be based on complex tools like InVEST, ARIES, LUCI or NatureServe Vista, parameterised for the UK. This approach would require specialist expertise to parameterise and set them up, and be responsible for upgrades. It can be modular, with additional datasets and modules (e.g. mapping of new ecosystem services, improvement of existing models, new scenarios for climate, land-use etc., valuation all added at later stages.

Level 3. Most comprehensive would build on level 2, but with the capacity to run predictive or dynamic models to explore future states, impacts of climate change (incorporating changing processes, socio-economic drivers as well as future climate as static input), and changing land use under other policy scenarios etc. This functionality may best be provided by an independent service provider with the required expertise.
References


### Appendix 1

Comparison of ecosystem service modelling tools, from a corporate environmental accounting perspective, applied to a case study in the USA. From BSR (2011b).

<table>
<thead>
<tr>
<th>Tool</th>
<th>Ideal Scale</th>
<th>Application Approach</th>
<th>Time Required for Application</th>
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</table>
| ARIES    | Landscape to Watershed | » Computer modeling with a probabilistic basis, reporting uncertainty levels, as well as with artificial intelligence enabling work in areas with less data  
» Accounts for spatial flows of ecosystem services from provision to beneficiaries | 200–300 hours of senior technical expert with GIS capabilities  
*Note: Time noted is to develop and parameterise a new case study, which currently can only be done by working with the ARIES team. In the future, applications in areas where models have already been developed will require substantially less time.* |
| InVEST   | Landscape to Watershed | » Designed to run present and future scenarios of LULC’s changing conditions and their effects on the flow of ecosystem services  
» Computer modeling based on data sets, generally accepted process models, and (if desired) public input | 160–260 hours of senior technical expert with GIS capabilities  
*Note: The time it takes to use InVEST varies dramatically by site and according to the technician’s level of expertise. The bulk of the time needed to run InVEST is to review literature and parameterize the models. Time used can be substantially reduced if literature is assembled beforehand.* |
| ESValue  | Landscape to Site-Level | » Expert ecological input identifying and weighting project variables that determine the degree of ecosystem change  
» Stakeholder preferences associated with ecosystem services in an area  
» Ecological science and social preferences integrated to identify relative effect on ecosystem service values of different alternatives | Approximately 200 hours of a company’s staff time, including:  
» 60 hours gathering input from stakeholders (not including about eight hours of each stakeholder’s time individually)  
» 100 hours preparing the GIS data, meeting with scientists, and collecting expert opinion, as well as setting up the ecological relationships  
» 40 hours running the tool and analyzing the results |
| EcoAIM   | Watershed to Site-Level | » GIS optimization model analysis of rare species with a risk-analysis basis, including metric weightings of stakeholder preferences | 25 hours reviewing, identifying, downloading, converting, and uploading data, with administrative staff spending eight hours downloading and scientists’ work accounting for the remainder  
*Note: For an application limited to biodiversity* |
| ESR      | Watershed to Site-Level | » Priority setting | Fewer than 40 hours were needed to complete the ESR worksheet and document assumptions, strengths, and weaknesses of the approach.  
A "real-world" ESR application would require more time. It would bring together corporate representatives from different business units, inform them about ecosystem services, and seek their input and then have an analyst synthesize it. The time requirements may not be trivial, depending on the scope of the analysis and baseline knowledge about ecosystem services within the organization. |
| EcoMetrix| Parcel- and Site-Level | » Ecological field site data collection on presence and status of ecosystem services at a particular site | Field data collection, data entry, and data verification can range from 15 to 60 minutes per acre, depending on the site’s complexity. |