Operationalisation of Natural Capital and Ecosystem Services

Preliminary guidelines describing the set of methods for mapping and modelling ecosystem service supply and their application in the WP5 case studies

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Edited by
Paula A. Harrison and Robert W. Dunford

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Preface

This deliverable describes a range of methods and models for assessing the biophysical factors controlling ecosystem service (ES) supply that have been developed and refined within Work Package 3 (WP3) of the OpenNESS project. These methods and models are being applied within 27 real-world case studies within WP5. The current deliverable (D3.2) represents the 'preliminary' guidelines which have been developed specifically for the OpenNESS case studies. This will be refined over the next 12 months into the 'final' guidelines (D3.4) which will use the experience from the OpenNESS case studies to develop more generic guidance that can be integrated in the Oppla web platform (WP6) for users outside of the OpenNESS consortium.

These preliminary guidelines include some suggestions for integrating the biophysical methods used in WP3 with the guidance on monetary and non-monetary valuation developed in WP4 (described in preliminary form in D4.3 and in final form in D4.4). This integration will be considered more comprehensively within the final guidelines of both WPs 3 and 4 due in November 2016.

Summary

A range of methods are available for mapping and modelling the supply of ecosystem services (ES). A meeting of mapping and modelling experts identified 25 potential models or methods, from which six were selected for use in the OpenNESS project, on the grounds that they were flexible and applicable to a wide range of contexts. The 27 OpenNESS case study teams each selected one or more methods to meet their needs, and have been applying them to real-world situations with guidance from modelling experts.

This deliverable presents detailed guidelines on how to use the six methods, their data requirements, their advantages and limitations, and examples of how they are being applied by the OpenNESS case studies. We also describe seven further models or methods being used by the case studies to address specific needs, as well as a European model (CLIMSAVE) and a global model (GLOBIO-ES) that can provide a broader context for the case studies. Finally, we analyse the reasons why each case study selected particular methods, and present preliminary steps towards developing decision trees and guidance to help practitioners select the best models and methods to meet their needs in different situations. The six selected models and their key strengths and weaknesses are listed below.

Spreadsheet-type methods (e.g. GreenFrame)

A quick and simple way to get an overview of ES provision in an area is through linking a spreadsheet of ES supply/demand indicators by land cover category to a GIS map, to generate maps of ES supply, demand and balance (supply minus demand). The indicators can be derived from scientific data or can be scores based on local or expert knowledge; scoring encourages stakeholder participation and discussion, which is useful in itself, but can also lead to biased or subjective results. The indicators are normalised to a common scale (e.g. 0-1) so that different services can be added together, and can be weighted to reflect the priority attached to different ES. It is assumed that each land use class (e.g. forest) scores the same across the region, but it is possible to use more detailed spatial data (e.g. sub-divisions of forest types) if that is available.

ESTIMAP

ESTIMAP is a set of separate process-based models that assess the supply, demand and flow of different ES, for use within a GIS. Currently there are eight models for assessing air quality regulation, protection from soil erosion, coastal protection, water retention, pollination, habitat for breeding birds, recreation and cultural services, and bird richness of pest regulators. The models are linked to LUISA, the JRC's land use modelling platform, enabling analysis of land use change scenarios. Although developed at the European scale, the models can be downscaled to the local level, and the recreation, pollination and air quality models are being used by several of the OpenNESS case studies. Data preparation can be intensive, but only a moderate level of GIS expertise is required.

Bayesian Belief Networks (BBNs)

BBNs are based on simple diagrams consisting of nodes representing processes or factors, and links showing how the processes are connected, typically derived using expert knowledge. For ES assessment, the nodes may represent factors determining the supply or demand of ES, such as land cover or soil type, as well as outcomes such as water flow, and information on values and preferences. Each link is assigned a weight to indicate the probability that the link is true, or the strength of the causal relationship, so that uncertainty is explicitly taken into account. When the model is run, it will compute the expected outcomes of alternative decisions, which can be costs or benefits.

BBNs are flexible and can be incorporated within other modelling approaches including decision-support tools, multi-criteria analysis, state and transition models and agent-based modelling. Although they are not spatially-explicit, relying instead on summarised spatial information (e.g. mean values across a region), they can be used to represent the key inputs and outputs from more complex models such as hydrological models, or to link together a chain of models, e.g. representing the ES cascade, and they can be embedded in a GIS. They are also useful for 'live' exploration of scenarios with stakeholders, where they help to build a common understanding of a problem, and are also good for evaluating trade-offs. However, some detail may be lost when constructing the model; for example, continuous variables must be discretised. Although the model is quick to use, some experience is needed to set it up correctly.

State and Transition Models (STMs)

STMs are simple, diagrammatic, conceptual models of how ecosystems respond to disturbances. They are based on alternate state theory, which maintains that natural or man-made disturbances may trigger a potentially irreversible regime shift leading to a new state with different properties. The model acknowledges that ecosystems can respond to external pressures in a non-linear fashion, and that the resulting changes in ecological properties can be abrupt. The models are typically developed through consultation with experts, and are useful as a basis for discussion with stakeholders, especially for raising awareness of the impact of human activity. They are flexible and easy to use, and are increasingly being applied to guide the management of ecosystems, including for assessing the risk of ecosystem degradation and identifying proactive measures to avoid degradation and restore ecosystems. They are well suited to an adaptive management approach. Although they do not explicitly take uncertainty into account, this can be overcome by applying them within a BBN.

QUICKScan

QUICKScan is an interactive GIS-based modelling tool designed to be used in a facilitated workshop, to enable policy-makers, experts and stakeholders to jointly explore the impacts of different policy options. The model can be pre-loaded with any available data (maps or statistics) on current or past ecosystem condition and trends – it is easy to combine different types of data from different sources. In the workshop, run by a discussion facilitator and an experienced QUICKScan modeller, participants can explore this data to understand the key issues affecting the ecosystem and decide on key indicators. They then jointly define chains of linked *'if..then..else'* expert rules to describe the impacts of alternative policy options (e.g. setting up protected areas). The rules can consist of scripts or knowledge matrices, for example to define which species can exist in different habitat conditions, or which benefits derive from different land cover types. The software applies these rules to the ecosystem data to derive indicators describing the likely impact of different policy options, with results being displayed as maps or graphs, including spider diagrams to help assess trade-offs. The tool is transparent, with the ability to easily trace back from particular aspects of the results (e.g. hotspots or puzzling results) to the rules that created them, but it cannot incorporate dynamic effects such as feedback loops. The main aim is to support stakeholder dialogue and discussion.

InVEST

InVEST is a set of GIS models for mapping and valuing the ecological or economic value of multiple ES at a local to regional scale. There are currently 16 models, covering recreation, aesthetic quality (visibility of features), biodiversity (habitat quality), habitat risk assessment, carbon storage and sequestration, water purification, sediment retention, marine water quality, coastal protection/vulnerability, pollination, timber production, aquaculture (salmon farming), wave and offshore wind energy, hydropower production and overlap analysis to identify areas of conflict between uses.

The power of InVEST lies mainly in the capacity to map multiple ES which enable users to do a trade-off assessment of certain land use or management scenarios. Uncertainty analysis is also possible. GIS expertise is required and data preparation can be time consuming, but the tool is well-documented and has a wide community of users around the world. However, the model is not transparent – the intermediate steps are not visible.

Supplementary models

The seven supplementary models used by some of the case study teams were:

- Species distribution models – these predict species distributions over time, e.g. under climate change;
- ECOPLAN-QUICKScan – converts spatial datasets on ES supply (e.g. maps of carbon stored) into a set of average values per unit area (e.g. carbon per hectare);
- MapNat smartphone application – for citizen science, emphasis on cultural services, allows areas to be mapped and associated with particular ES;
- RUSLE (Revised universal soil loss equation) – GIS tool to estimate average long-term soil erosion risk in an area based on slope, rainfall, soil type, crops, etc;
- Blue-green factor scoring – smartphone app/spreadsheet to score blue/green features for a property based on flood regulation value, aesthetic value and biodiversity habitat;

- Photoseries analysis – analysis of photos uploaded to sites such as Flickr to reveal preferences for cultural ecosystem services (aesthetic value and recreation);
- Eco Chain participatory biodiversity management – an approach for working with stakeholders to implement ecosystem management in indigenous forest communities.

Selecting the right method

A survey of the reasons why case study teams selected particular methods revealed that 'novelty' of approach was the most common consideration – this covered advances in knowledge, addressing new areas and meeting particular research needs. Practical considerations came next, including the level of expertise needed, the data requirements and the spatial scale. Stakeholder participation was also high in the list of priorities.

It was interesting to find that certain features of the methods could be viewed either as advantages or disadvantages. For example, spreadsheet approaches are easy to use and can readily incorporate expert knowledge and stakeholder views, but they are also seen as being too simplistic and depending too heavily on this expert knowledge. Similarly, the use of probabilities in BBNs enables them to model uncertainty, but also makes them difficult to explain to stakeholders in a participatory workshop. ESTIMAP and QUICKScan were seen as being powerful tools, but the requirement for specific modelling or GIS expertise could be a barrier. However, the availability of expert support encouraged a strong uptake of ESTIMAP by the OpenNESS case studies.

Preliminary decision trees have been developed, with the aim of helping to guide future practitioners in choosing ES methods appropriate for their context. These are being refined through consultation with the case study teams. The next phase of work will focus on developing more detailed guidance and decision-support tools, which will eventually be made available to the wider practitioner community through the OPPLA web platform.

1 Introduction

Paula A. Harrison & Robert W. Dunford

A range of methods have been developed and refined that can be used to further understanding of the biophysical control of ecosystem services (ES). By matching appropriate methods with the WP5 case studies, we demonstrate how this knowledge can be used to inform sustainable land, water and urban management in practice. Linking of the methods to the OpenNESS case studies and providing guidance and training to implement the methods has been an iterative process following several broad steps:

1. A meeting of mapping and modelling experts was held to collect information on all models/methods that were considered to be appropriate for mapping/modelling ES supply. This list of 25 models/methods was refined into a short-list of six key models/methods that were considered to be the most flexible and applicable to a wide range of contexts.
2. A questionnaire was circulated to the OpenNESS case studies to collate information on: (i) what biophysical components are of interest (ES, habitat/land use, species-related and abiotic); (ii) the level of experience they have with modelling; (iii) what data they have available; and (iv) if they already have a model or method which they wish to use.
3. A workshop was held in which case study leaders and mapping/modelling experts discussed the six proposed methods/models and how they fitted with the case study objectives and workplans. This led to a first matching of methods to case studies as written up in Milestone 6 'Preliminary list of methods linked to specific case studies'.
4. A set of detailed guidelines on all six methods/models explaining the types of problem the method can be used to study, its data requirements, its constraints and limitations, the steps required to apply the method within a case study, worked examples of the practical application of the method/model, and further reading was created for use by the case studies in implementing their selected method(s). This was supported by various training sessions in the OpenNESS Annual Meetings, a specific 2-day training workshop (organised with WP4) and one-to-one contact between WP3 method experts and case studies to progress application of methods/models.

The six method/models cover a diversity of approaches which require varying levels of expert knowledge and data availability to ensure that methods can be operationalised in all case study contexts. It is also important to note that the majority of case studies are using more than one method to make the most of the varying opportunities that different approaches provide. Figure 1.1 shows which methods are being used by each of the case studies.

This deliverable first presents the guidelines for the six main methods/models, providing examples of their application within the OpenNESS case studies (Section 2). It then provides a brief overview of other biophysical methods that have been used by individual case studies (Section 3) and methods/models for assessing ES supply at the European and global scale which provide a broad context for the local/regional OpenNESS case studies (Section 4). Finally, Section 5 presents an evaluation of the different methods based on feedback from the case studies, and describes preliminary decision trees which are being designed to help choose the most appropriate biophysical and valuation method/model in different contexts. These decision trees will be further refined for D3.4 (the final guidelines) and for implementation into the Oppla web platform.

	Spreadsheet/GIS	Quickscan	BBN	STM	ESTIMAP	INVEST	Other methods
1. Sibbesborg, Finland	1	0	2	0	2	0	N
2. Trnava, Slovakia	2	2	2	0	1	0	N
3. Oslo, Norway	2	2	2	0	2	0	Y
4. Vitoria-Gasteiz (5 areas, Spain)	2	1	2	1	0	0	N
5. Forestry in French Alps	2	0	2	0	0	1	Y
6. Forestry in Finland	1	0	2	0	0	2	N
7. Forestry in Carpathian Mountains	2	0	2	2	1	2	N
8. Bioenergy in central Germany	2	0	2	0	2	0	Y
9. Cairngorms National Park, Scotland	2	2	2	0	2	0	N
10. Sierra Nevada National Park, Spain	2	0	0	0	0	2	N
11. Warwickshire, UK	2	0	0	0	0	0	Y
12. Kiskunság, Central Hungary	1	2	1	0	2	0	N
13. Belgium	0	1	2	0	0	0	Y
14. GI linked cases	0	0	0	0	0	0	N
15. Gorla Maggiore in northern Italy	1	0	0	0	0	0	N
16. Loch Leven, Scotland	0	0	2	1	2	0	N
17. Lower Danube, Romania	2	2	2	0	1	0	N
18. Demer basin, Belgium	2	1	2	0	0	0	Y
19. Doñana National Park, Spain	0	0	0	0	0	2	N
20. Wadden Sea, Netherlands	2	1	0	0	0	0	N
21. Costa Vicentina, Portugal	2	0	0	0	2	1	N
22. Essex, UK	2	0	0	0	0	0	Y
23. Andhra Pradesh, India	1	0	0	0	0	0	Y
24. Kakamega Forest, Kenya	0	0	2	0	1	1	N
25. Retention forestry, Patagonia	0	0	2	2	0	0	N
26. São Paulo, Brazil	1	0	0	0	0	1	Y
27. Barcelona, Spain	1	2	0	0	2	1	N

Urban
Forestry
Mixed rural
National Parks
Water-focused
Export-focused

2	Working on the method
1	Expressed interest
Y	Using broader methods

Figure 1.1: Current uptake by the case studies of the methods presented in this deliverable.
'2' = self-reported in deliverable D5.2 as, at least, currently working on the method in question or have been confirmed by a method leader to be underway.
'1' = did not self report as currently working on the method but expressed an interest in the method in the D5.2 questionnaires.
'Y' = currently working on at least one of the broader methods presented in Section 3 of this deliverable.

2 Guidelines for the six selected WP3 methods

2.1 Spreadsheet-type methods

Leena Köpperoinen & Laura Mononen

2.1.1 Introduction to method/model

Spreadsheet-type methods (also known as matrix methods) are a quick and simple way to get an overall spatially-explicit picture of the ES in case study areas. The method is based on the idea of linking tabular spreadsheet data and spatial data together, i.e. joining external datasets to spatial units to create maps. The spreadsheet format data can be collected, for example, as expert evaluation or constructed from indicators or statistics. Simple application of the approach typically involves land use or land cover (LULC) datasets, although other datasets can be used.

An extended version of the matrix method has been suggested to improve representation of the transdisciplinary issues that are often related with ES studies (Jacobs et al. 2015). A modified, transdisciplinary version of the spreadsheet-type method is GreenFrame, which utilises an extensive set of spatial datasets grouped into themes (instead of using solely LULC data) combined with both scientific experts' and local actors' scorings (Kopperoinen et al. 2014). The method was developed to assess spatial variation in ES provision potential of green infrastructure in spatial planning.

Keywords: GIS, ecosystem services, spreadsheets, matrix, expert scoring, stakeholder engagement, semi-quantitative methods.

2.1.2 Why would I use this method/model?

1) To get a quick overview of the potential supply of, demand for and budgets of ecosystem services.
Burkhard et al. (2012) used spreadsheets for creating a scored ES reclassification table (also often called an expert knowledge table) which was coupled with the CORINE Land cover (CLC) database to produce ES supply, demand and budgets maps. By linking expert evaluation of the ability of each LULC class to supply ES as well as the demand for various ES within the same LULC classes, overview maps of both supply and demand were quickly derived. When supply and demand were calculated together, budgets were created.

2) To detect possible areas of conflict where multiple land use interests or needs for biodiversity conservation exist.
A spatially-explicit ES mapping exercise can be used for detecting possible areas of conflict where multiple land use interests or needs for biodiversity conservation exist (e.g. Vihervaara et al. 2010; 2012). In addition, optimising multiple ES and conservation needs is possible. Potentially relevant biodiversity datasets include for example EUNIS (e.g. Natura 2000 habitats), agricultural parcels (e.g. grasslands, pastures) and multi-source forest inventories. In general, ES assessments can be extended by using additional datasets related to land cover types, such as statistics (e.g. Kandziora et al. 2013), modelled data (e.g. Nedkov & Burkhard 2012) or monitoring data (Baral et al. 2013).

3) To help spatial planning in assessing green infrastructure based on ES supply and demand.

By using GreenFrame it is possible to get a more comprehensive map of the spatial variation in ES provision potential of green infrastructure. This helps to identify the key areas of green infrastructure in spatial planning (see procedure in Itkonen et al. 2015). Coupled with spatial assessment of potential and actual ES demand, as well as the connectivity of green infrastructure, spatial planners obtain valuable information on what type of ecological and social values are attached to different areas and are better informed for making decisions of land allocation for different purposes.

4) To engage stakeholders and local and regional actors in decision-making, to enhance joint understanding and to raise awareness of the various benefits that nature provides to us.

GreenFrame, which involves focus groups and the active involvement of local and regional stakeholders, raises awareness of the benefits of the ES approach. To enable the scoring of different data themes based on whether they are likely to positively or negatively affect ES provision potential, the concept of ES, content of the spatial datasets and the principles of scoring must be presented and explained in detail. In addition, by bringing stakeholders (local and regional actors) around the same table for discussion, different viewpoints are shared and common understanding is usually enhanced. The process itself can be as important as the maps resulting from the analyses when applying GreenFrame.

2.1.3 Requirements

Requirements		Comments
Data	☑ Data is available ☑ Need to collect some new data ☑ Need to collect lots of new data	The need to collect new data depends on: (i) the objectives of the case study; (ii) the matrix-type method selected (based solely on LULC or based on a wide variety of spatial datasets as in GreenFrame method); and (iii) on the availability of data from the case study area.
Type of data	☑ Qualitative ☑ Quantitative	Spatially-explicit datasets (vector or raster) and additional information are needed.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	Basic knowledge in spreadsheets and GIS are needed to conduct the assessment successfully. Facilitating expert evaluations and focus groups needs social and stakeholder engagement skills as well as the ability to clarify the ES concept, ES categories, the content and quality of various spatial datasets, and the scoring task in an understandable and uniform way.
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	Any general spreadsheet software (e.g. Excel, Lotus123, Google Spreadsheets) is suitable to collect data in tabular form. Before the data is imported into a GIS programme, the data must be saved to a database IV file (*.dbf) or Excel format (*.xls). The method can be applied using any type of GIS software, licensed (ArcGIS) or open source (GRASS, QGIS, R, etc). The LULC data should be in Shapefile format (*.shp) or a raster image (e.g. *.tiff, *.img), with LULC coding. The GIS software is needed to join the tabular data to the spatial data for the spatial analysis and creating output maps.

Requirements		Comments
Time resources	☑ Short-term (< 1 year) ☑ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Time and economic resources depend on the availability and accessibility of spatial datasets, on the need for pre-preparing the datasets for analysis, and on the expertise of the researchers and GIS specialists.
Economic resources	☑ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	Similar to time resources.
Other requirements	When using GreenFrame, expertise is needed in carrying out focus groups and working together with researchers from other fields as well as with local and regional actors. Basic knowledge of statistics is also needed (understanding variation, mean, median, etc.).	

2.1.4 Advantages

- Relatively easy and fast to perform;
- Draws on existing data, can handle missing data, and expert knowledge can be included;
- Basic knowledge of spreadsheets and GIS is usually enough;
- Takes also into account features that reduce the provision potential;
- Open source software can be used;
- Simultaneous assessment of multiple ES;
- Applicable at different scales: best possible datasets of appropriate resolution need to be used accordingly;
- Naturally an integrative / holistic approach;
- Suitable for transdisciplinary research problems;
- Useful in a participatory approach with stakeholders;
- Easily adoptable, transparent and flexible.

2.1.5 Constraints and limitations

- Availability of the background data might be a restraint;
- If a matrix using LULC data is applied, the data might be too coarse to study small case study areas;
- Data preparation can be quite a long and demanding task when a wide array of spatial datasets is used (GreenFrame);
- Possibly biased answers by the experts;
- Reliability of the results should always be evaluated;
- Wide matrices can be quite exhausting to fill in with scores and loss of concentration can result in errors in scores.

2.1.6 Does the method address uncertainty?

Spreadsheet-type methods do not address uncertainty, i.e. they do not produce probabilities of ES supply or demand. Spreadsheet-type methods can be applied to scenarios if the GIS data can be projected to represent the future situation.

Spreadsheet-related methodological uncertainties have been examined by Hou et al. (2013). Uncertainties relate to case study area selection, LULC class selection, data acquisition, ES selection (matrix columns), quantification, evaluation scale, mapping and interpretation of the results. Depending on the case study area and its size (scale), data with the right resolution (pixel size) and precision must be used. For example, CORINE Land Cover data might be too vague for assessing small areas as some special characteristics might get lost because the classification is too coarse. It is important to use consistent data throughout the study area.

Other uncertainty issues relate to expert evaluation and the tabular data. The ES which are assessed must be chosen carefully, ideally with stakeholder input to capture those considered most important in the case study region. The principles for filling the matrix with scores should be clear to all respondents to avoid ambiguity. All respondents should understand each ES and the scoring system the same way to reduce confusion. Jacobs et al. (2015) have listed guidelines on how to conduct a good quality expert survey.

Uncertainties associated with most spreadsheet methods relate to the basic assumption that one class (e.g. LULC class) uses the same score all over the region and, hence, does not take into account possible regional or place-specific differences. This problem is reduced in the GreenFrame method in which more accurate place-based detail is derived by using all available, good quality spatial datasets from the study area giving insight into ES provision potential. Finally, results must be interpreted carefully. Testing the score sheet beforehand can help in detecting errors that might occur, leading to results that more closely reflect the desired outcome.

2.1.7 Spreadsheet methods using LULC data: Steps required to apply the method within a case study

The following steps need to be undertaken to apply the spreadsheet-type method within a case study:

Step 1: Gather relevant spatial datasets on land use, land cover type, habitats, biodiversity, etc. in GIS format. The most commonly used GIS data on LULC for Europe is CORINE which is readily available. However, other relevant spatial datasets can also be used, but it is important to evaluate their accuracy. It is also important to ensure that spatial datasets of an appropriate resolution are used for the spatial scale of the case study (Figure 2.1.1). The LULC or other classes in these datasets form the basis for the spatial interpolation of the spreadsheet data.

Step 2: Create a fit for purpose spreadsheet arrangement following the LULC classes and the selected ES (see Figures 2.1.2 and 2.1.3 where the first column contains the names of the CORINE land cover classes). The ES to be assessed are usually listed in the columns and the LULC classes in rows. A column with identical numbers for LULC classes helps to link the matrix information to the GIS data.

Step 3: Test your matrix with expert colleagues to find out any possible errors that might occur.

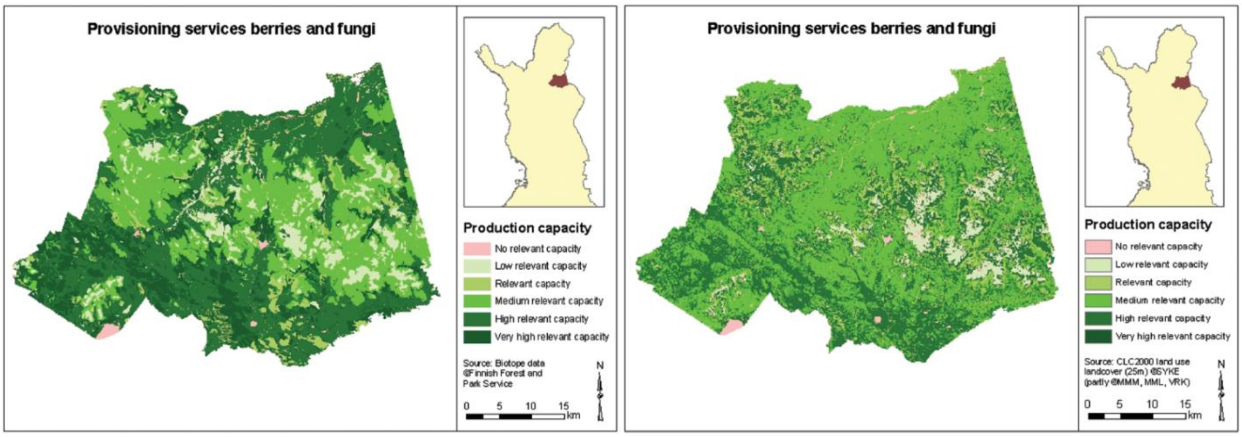


Figure 2.1.1: Illustration of how the use of datasets of different spatial resolution affect the resulting ES maps. A detailed biotope habitat data is used in the left-hand map and CORINE land cover in the right-hand map (Vihervaara et al. 2012).

CORINE land cover type:	Ecological Integrity Σ	Abiotic heterogeneity	Biodiversity	Biotic waterflows	Metabolic efficiency	Exergy Capture (Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	Regulating services Σ	Local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	Provisioning services Σ	Crops	Livestock	Fodder	Capture Fisheries	Acquaculture	Wild Foods	Timber	Wood Fuel	Energy	Biochemicals and Medicine	Freshwater	Cultural services Σ	Recreation& Aesthetic Values	Intrinsic Value of Biodiversity
Continuous urban fabric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Discontinuous urban fabric	7	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	3	1	0	1	0	0	1	0	0	1	0	0	0	0	0
Industrial or commercial units	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Road and rail networks	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Port areas	2	1	1	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Airports	7	1	1	1	1	1	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Mineral extraction sites	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
Dump sites	8	2	1	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Construction sites	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green urban areas	18	3	3	2	1	4	3	2	11	2	1	0	2	1	2	1	1	1	2	0	0	0	0	0	1	0	1	0	0	0	3	3	0
Sport and leasure facilities	16	2	2	2	1	4	3	2	9	1	1	0	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	5	5	0
Non-irrigated arable land	22	3	2	3	4	5	1	4	5	2	1	1	1	0	0	0	0	0	21	5	5	5	0	0	0	0	0	2	1	0	1	1	0
Permanently irrigated land	21	3	2	5	2	5	1	3	5	3	1	1	0	0	0	0	0	0	18	5	5	2	0	0	0	0	0	1	1	0	1	1	0
Ricefields	20	3	2	5	1	5	1	3	4	2	0	0	2	0	0	0	0	0	7	5	0	2	0	0	0	0	0	0	0	0	1	1	0
Vineyards	14	3	2	3	1	3	0	2	3	1	1	0	1	0	0	0	0	0	5	4	0	0	0	0	0	0	1	1	0	0	5	5	0
Fruit trees and berries	21	4	3	4	2	3	2	3	19	2	2	2	2	2	2	1	1	5	13	5	0	0	0	0	0	4	4	1	0	0	5	5	0
Olive groves	17	3	2	3	2	3	1	3	7	1	1	0	1	1	1	1	1	0	12	4	0	0	0	0	0	4	4	1	0	0	5	5	0
Pastures	24	2	2	4	5	5	2	4	8	1	1	1	1	0	4	0	0	0	10	0	5	5	0	0	0	0	0	1	0	0	3	3	0

scale for assessing capacities:
0 = no relevant capacity
1 = low relevant capacity
2 = relevant capacity
3 = medium relevant capacity
4 = high relevant capacity
5 = very high relevant capacity

Figure 2.1.2: Overview of the spreadsheet matrix where experts have assessed the capacity of all CORINE land cover classes to supply ES using a scale of 0-5 (Burkhard et al. 2012).

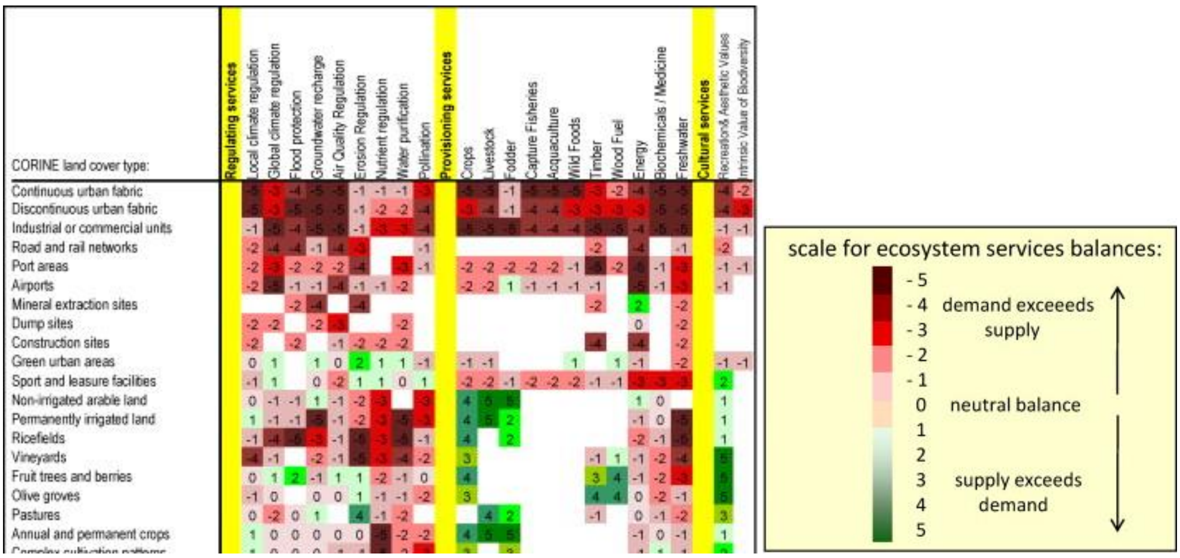


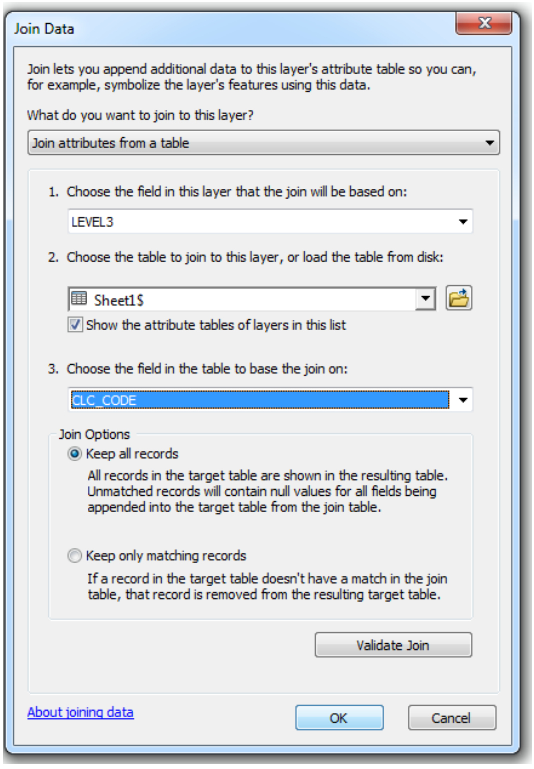
Figure 2.1.3: Example of where two separate matrices have been combined (supply – demand) to derive information on the balance (or budget) between ES supply and demand (Burkhard et al. 2012).

Step 4: Collect expert evaluation scores within spreadsheet tables based on questionnaire surveys, interviews or workshops. Whatever method is used to collect the evaluation score, it is crucial that the respondents are carefully selected to represent the case study area and issue. Unambiguous definitions for each ES and other unclear terminology should be provided to all the experts to ensure they have the same understanding of how to fill the table. Scores are derived from an expert evaluation based on the expected ability of all LULC classes to supply ES and in a separate sheet the demand for such services within current LULC classes. Simple calculation rules are applied between the columns.

Step 5: Collect all the scores from different respondents in one file and derive the median or mean value per LULC class and ES. Save the scores to a database file (*.dbf) or Excel format (.xls).

Step 6: Import the data from the spreadsheet to a GIS programme to illustrate the results in a map. Joining the imported table to the spatial datasets enables a spatial representation of ES provision to be generated (see Figure 2.1.4). It is possible to open Excel tables directly in common GIS software, such as ArcGIS, and work with them in the same way as other tabular data sources. For example, you can add them to ArcMap, preview them in ArcCatalog, and use them as inputs to Geoprocessing tools. Simple assessments can be undertaken with basic overlaying techniques (e.g. Geoprocessing Tools, Raster Calculator, Overlay Tools in ArcGIS). Maps can be finalized in Layout View.

Figure 2.1.4: Joining datasets in ArcGIS. Once the map layer and spreadsheet data are in ArcGIS, click on the spatial dataset and choose Joins and Relates → Join. (1) Choose the field name that has the information, (2) choose the tabular dataset and (3) define the column name that has the matching classes → OK.



Step 7: Evaluate the relevance and uncertainties of the results. It is also useful to elaborate them with the experts in a second workshop. Comparisons can also be made with similar case studies.

Figure 2.1.5 illustrates the principles involved in applying the spreadsheet method.

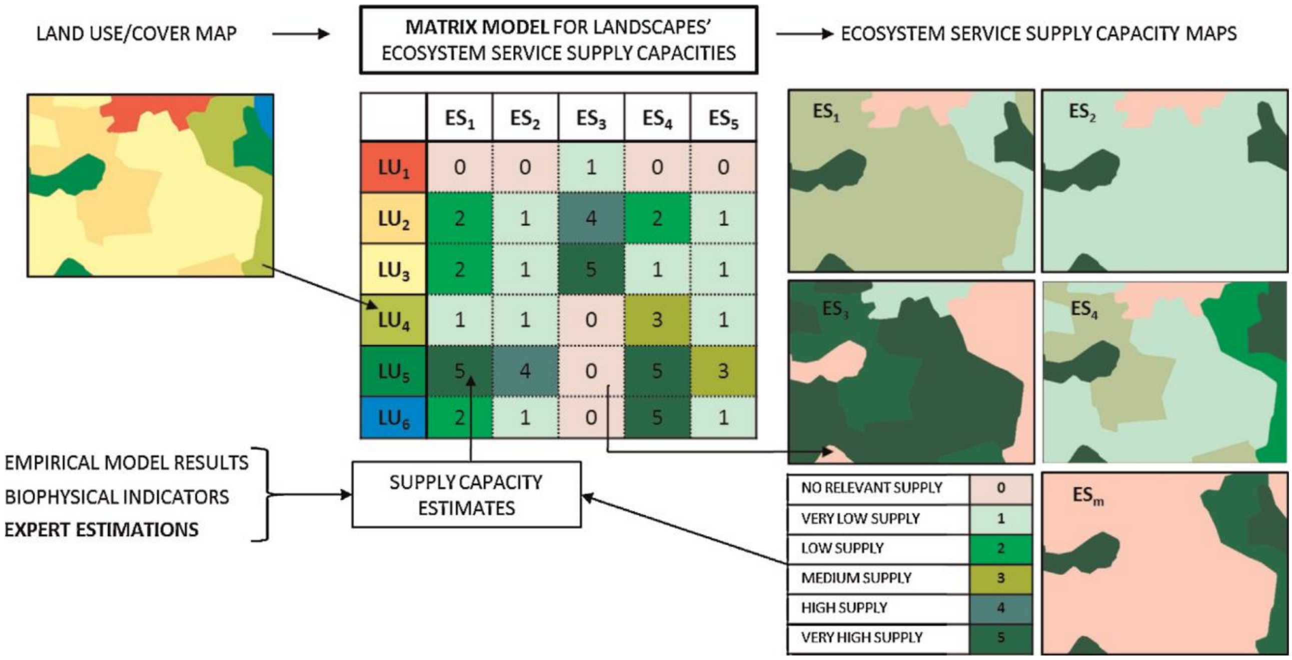


Figure 2.1.5: The principles of using the spreadsheet method to produce ES supply capacity maps: (i) a LULC map is sourced; (ii) a spreadsheet is created by linking the ES groups with the corresponding LULC classes; (iii) selected experts fill in the matrix using a scale of 0-5 according to the assessed supply capacity of each ES; (iv) ES supply capacity maps are generated using GIS software (Image: Jacobs et al. 2015).

2.1.8 GreenFrame method: Steps required to apply the method within a case study

GreenFrame is a place-based method developed at the Finnish Environment Institute for combining green infrastructure and ES in land use planning (Kopperoinen et al. 2014). It aims to provide an operational and transparent tool that supports land use planning at different scales and recognises key areas of green infrastructure based on their potential to provide various ES.

The method focuses on identifying spatial differences in the provision potential of ES based on expert and layman assessments and spatial datasets; not on quantifying the actual stocks and flows of ES. It is possible to combine various types of spatial data in the analysis to ensure adequate coverage of regulating and maintenance, provisioning and cultural services. Quantitative data is often available for provisioning services, such as timber volume. However, quantitative spatial data for regulation and maintenance services and cultural ES is often lacking. GreenFrame provides an approach to qualitatively infer this information from related thematic data based on assessments from experts and local and regional actors.

The outcomes of the analysis are maps showing the potential provision of individual ES or a synthesis across all ES. The provision potential of each individual ES is scaled to a common range, i.e. normalized, between 0-1. This makes different ES equally important in the synthesis. A weight can also be given to selected ES, or some services can be excluded completely from the output. Weights and the inclusion or exclusion of ES in the final maps are subject to the decision-making and values involved in the planning process. A workflow chart of the GreenFrame method is given in Figure 2.1.6.

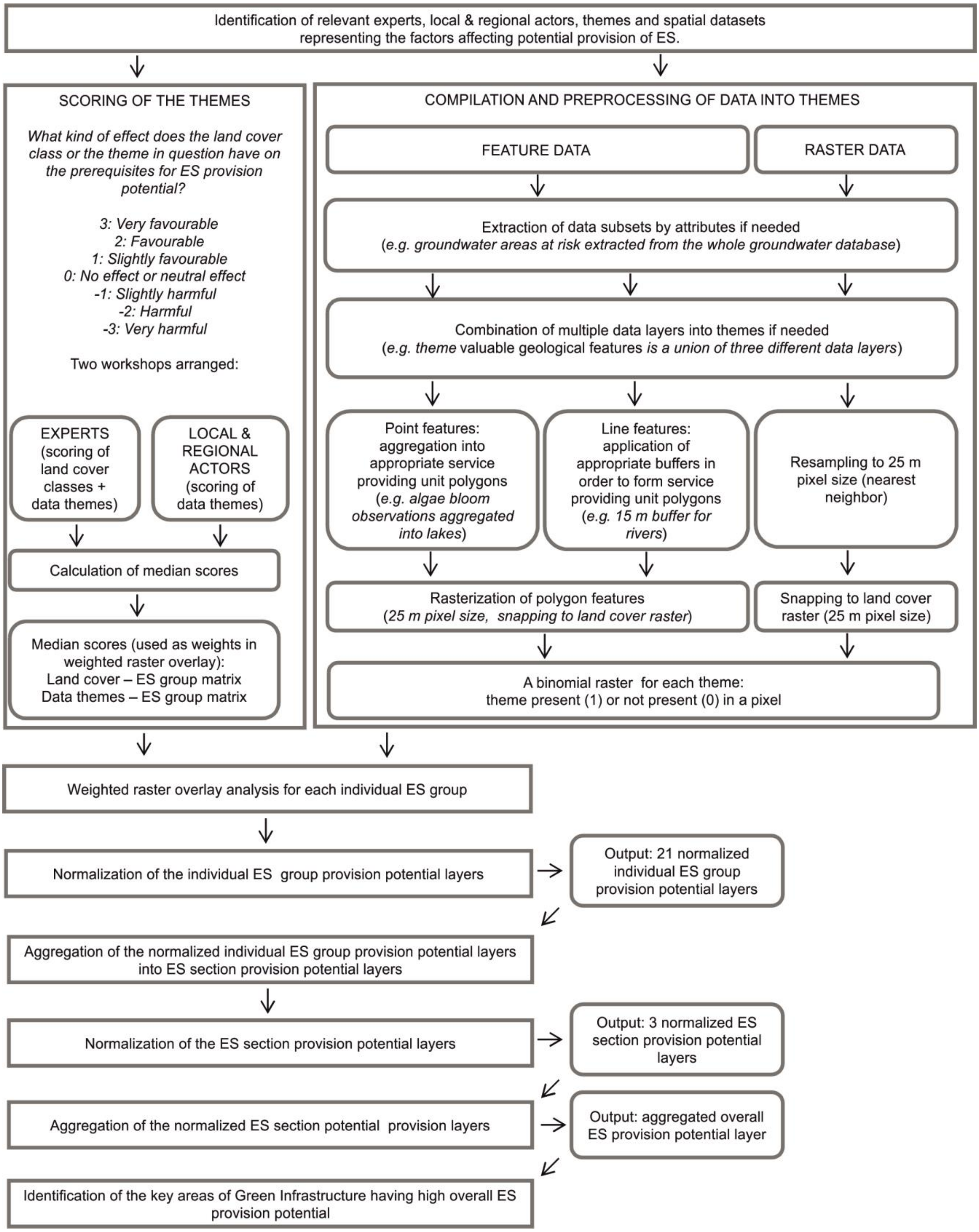


Figure 2.1.6: The workflow for applying the GreenFrame method (Kopperoinen et al. 2014).

The following steps need to be undertaken to apply the GreenFrame method within a case study:

Step 1: What is your problem?

- To identify and spatially locate different elements and key areas of green infrastructure based on the provision potential of ES?
- To aid a land use planning process by identifying the most important areas from the ES point of view?
- To get an overall picture of the ES supply of an area?
- To assess supply of, demand for and flows of ES?
- For detecting possible areas of conflict where multiple land use interests or needs for biodiversity conservation exist?

Step 2: Define the limits / borders of the study area

- The extent of the study area defines what should be taken into account in the analysis.
- If you work with, for example, a land use planning area, that defines what type of spatial datasets are needed.
- To avoid border effects, create a wide enough buffer around the study area and do the analysis using a union of the area and the buffer.

Step 3: Based on your problem

- Identify the set of ES you are targeting in the analysis.
- Decide on the ES classification you want to use. Modify it to fit your case by leaving out non-relevant classes or groups, and leaving out other ES classes or groups that you do not want to examine (but do not forget them).

Step 4: Identify the participants of the first focus group

- People who can help you identify the relevant scientific experts and key local stakeholders or actors to be invited to the scoring focus groups.
- People who can help you identify and locate the best available spatial datasets with regard to the set of ES in focus:
    - The level of detail of spatial datasets depends on the scale of the study area. -> The bigger the area examined, the coarser the scale.
    - Scale and resolution of spatial data matters when choosing datasets for evaluation:
        - National level analysis: a very general overview which should not be zoomed in;
        - Regional level analysis: local details cannot be taken into account;
        - Local level analysis: need for more detailed data;
        - Block / plot level analysis: data on small features, such as individual trees, bushes, green walls, etc., is needed.

Step 5: Arrange the first focus group

- Explain the context of your research and the key concepts carefully and objectively, including green infrastructure and ES with the help of a (simplified) ES classification. It can also be helpful to use the ES cascade to present the ES concept to land use planners, governance and management staff and other actors in an understandable way.
- Facilitate a discussion on:

- Identification of relevant scientific experts (people attending the focus group can belong to them!).
- Identification of local and regional experts if applicable.
- The best existing spatial datasets (type, content, collected by whom, spatial extent, quality, update period, consistency, availability, administrator).

Step 6a: Compilation and preprocessing of data

- Collect the spatial datasets taking into account costs, individual researcher's 'property', privacy questions (e.g. socio-economic data) and dataset sensitivity (e.g. threatened species, valuable natural features in private land).
- Examine the extent and quality of the spatial data (does it cover the whole study area, is it available at reasonable cost for research purposes, is it up-to-date, is it of good quality, does the resolution of the data match the scale of the case study). Note any shortcomings of the data for later use and understanding. If the quality is good enough, proceed to preprocessing.
- Preprocess the datasets into comparable formats by extracting data subsets (e.g. groundwater areas of good quality) and combining different data layers into themes (seeTable 2.1.1). Data may need to be converted from feature to raster format and the raster layers resampled to a common pixel size to ensure that the raster layers align with each other spatially. Thematic layers are assigned a binary value of 0 or 1 indicating the presence or absence of the theme in a pixel.

Table 2.1.1: Example of a data table with names of spatial datasets and their combinations into themes.

	THEME	DATASET	TYPE	YEAR
1.	Conservation areas	1.1 Natura 2000 areas	Polygon vector	2012 [1]
		1.2 Nature reserves on public and private land, founded based on Nature Conservation Act	Polygon vector	2012 [1]
		1.3 Nature conservation program areas	Polygon vector	2010
		1.4 Forest Service's property reserved for conservation purposes	Polygon vector	2012 [1]
		1.5 Conservation areas of regional plans	Polygon vector	2012 [1]
2.	Observed sites of endangered species	2. TAXON database on endangered species	Point vector	2012 [1]
3.	Important bird areas (IBA)	3. Important bird areas (IBA)	Polygon vector	2010
4.	Valuable landscapes	4.1 Nationally significant landscapes	Polygon vector	2010
		4.2 Regionally significant landscapes: National database on regional plans	Polygon vector	2012 [1]
5.	Valuable geological features	5.1 Nationally significant bedrock outcrops	Polygon vector	2012
		5.2 Nationally significant moraine landforms	Polygon vector	2008
		5.3 Nationally significant windblown and shore deposits	Polygon vector	2012
6.	Old forests (age ≥ 120 years)	6. Multi-source National Forest Inventory	Raster	2012
7.	Important forest habitats	7. Habitats of special importance according to Forest Act	Polygon vector	2012 [1]
8.	Undrained peatlands	8. Draining status of peatlands	Raster	2011

	THEME	DATASET	TYPE	YEAR
9.	National hiking areas	9. VIRGIS database on outdoor recreation opportunities	Polygon vector	2009
10.	Regional recreation areas	10. National database on regional plans	Polygon vector	2012 [1]
11.	National urban parks	11. National urban parks	Polygon vector	2012 [1]
12.	Urban green areas	12. Corine Land Cover 2006 (Finnish National Raster)	Raster	2008
13.	Discontinuous urban fabric	13. Corine Land Cover 2006 (Finnish National Raster)	Raster	2008
14.	High Nature Value farmlands	14. High Nature Value farmlands	Point vector	2008
15.	Traditional agricultural biotopes	15. Traditional agricultural biotopes	Polygon vector	2005 - 2012
16.	Surface waters of high or good ecological status	16. Surface water formations of the Water Framework Directive, first planning term (2010 - 2015)	Polygon vector	2010
17.	Groundwater areas	17. Groundwater areas	Polygon vector	2012 [1]
18.	Fish passages	18. Database on hydraulic engineering	Point vector	2012 [1]
19.	Peat extraction sites	19. Draining status of peatlands	Raster	2011
20.	Sealed surfaces	20. Urban Layer	Raster	2007
21.	Surface waters of moderate, poor or bad ecological status	21. Surface water formations of the Water Framework Directive, first planning term (2010 - 2015)	Polygon vector	2010
22.	Sites of frequent algae bloom observations	22. National algal bloom monitoring database	Table	2012 [1]
23.	Groundwater areas at risk	23. Groundwater areas	Polygon vector	2012 [1]
	[1] Data is updated regularly			

- Preprocessing of quantitative datasets:
  - The data layers are converted into continuous raster layers, where the quantities of the original data are rescaled between 0 and 1 (Figure 2.1.7).
  - As in the case of qualitative data, pixel value 0 represents the lowest, and pixel value 1 represents the highest provision potential within the study area.
  - Therefore, when quantitative datasets are available it is useful to denote pixels outside 'service providing units' as 0 and rescale the quantities of the service providing areas between e.g. 0.5 and 1 (the lowest value depends on how low the quantity is in regard to the highest value).

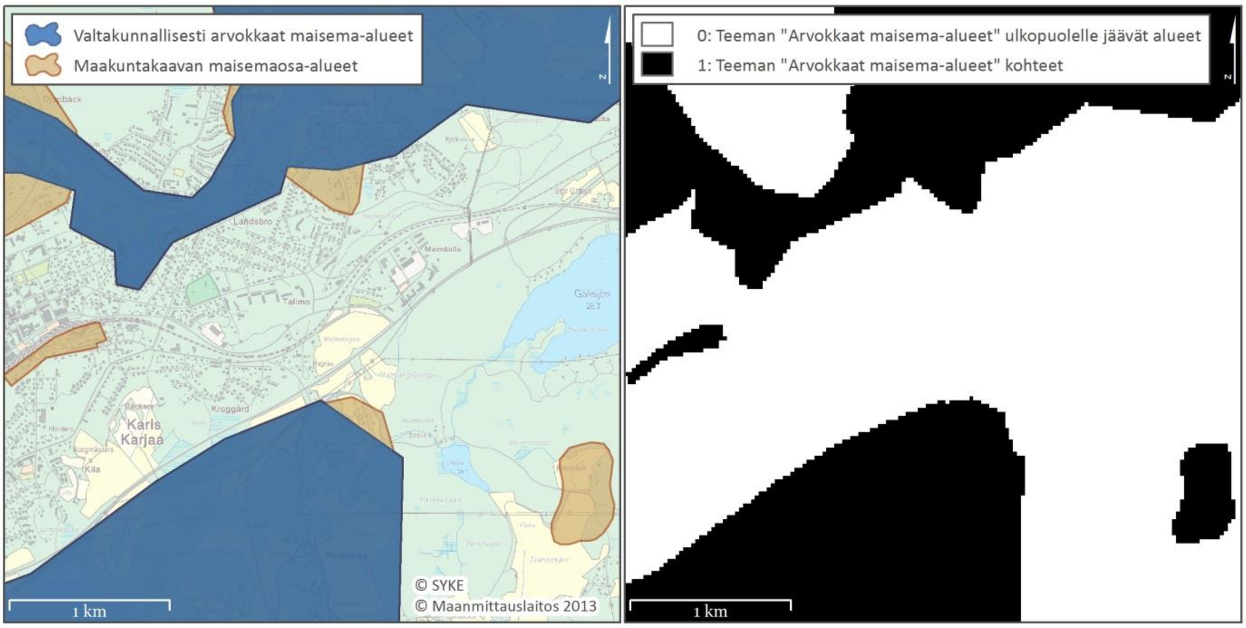


Figure 2.1.7: An example of the pre-processing of the data themes: two separate datasets describing the same theme are combined using the Union tool in GIS software. The resulting union layer is then converted into a binary raster, where the areas belonging to the theme obtain pixel value 1 and areas outside the theme obtain pixel value 0. All resulting raster layers need to have same pixel size (pixel size here is 25 metres) and the pixels of different layers need to coincide with each other.

Step 6b: Scoring of the themes affecting ES provision potential

- The data themes are assessed in focus groups where participants assess the effect of each theme on the provision potential of each ES group and score the themes accordingly. The relevance of the themes to the provision potential of ES is summarized as median scores. Each theme has to be considered in relation to each ES group, because all themes are not equally relevant for all ES.
- This done by asking 'what effect does the theme in question have on the prerequisites of ES provision potential? For example, does the presence of a conservation area have a favourable or harmful effect on the ES 'Habitat and gene pool protection'? If the effect is favourable, the effect is scored as: very favourable (3); favourable (2); or slightly favourable (1). If the effect is neutral or the theme is irrelevant for the specific ES, a score of zero (0) is given. If the effect is harmful, the effect is scored as: slightly harmful (-1); harmful (-2); or very harmful (-3). Respondents are also allowed to respond as 'I don't know'. An example scoring is given in Table 2.1.2.

Step 6c: Criteria for summarising the scores

- Unanimous answers: The median value of the answers is used in the summary if all respondents agree upon the direction of the causal relationship between the theme and the ES in question, for example, if all respondents give either a positive value [or zero] or all respondents give a negative value [or zero].
- Slight disagreements: Differing answers are excluded from the summary if less than 20% of the respondents disagree with the majority's opinion of the favourableness or harmfulness of the effect. Slight disagreements might result from misinterpreting the question and concepts involved.

- Clear disagreements: Value zero is used, if over 20% of the respondents disagree with the majority's opinion of the favourableness or harmfulness of the effect. This way the theme in question is interpreted not to have a clear effect on the provisioning potential of the specific ES in the analysis. Clear disagreements might result from a lack of unambiguous understanding of the causal effect between the theme and the ES or from significant complexities / uncertainties related to them.

Table 2.1.2: An example of a matrix used in the GreenFrame method (Itkonen et al. 2015).

DATA THEME	ES GROUP CODE																				
	P1	P2	P3	P4	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	C1	C2	C3	C4	C5
1. Conservation areas	0	2	2	2	0	1	2	3	2	2	3	2	2	2.5	2	2.5	3	3	2	3	3
2. Valuable landscapes	3	1.5	1	1	1	2	1	1	1	2	2	1	1	1	0	1	2	2	3	2	2
3. Valuable cultural heritage environments	2	1	0	1	0	1	1	1	0	2	1	1	1	1	0	1	3	1.5	3	2	2
4. Traditional agricultural biotopes	2	2	0	1	0	1	1	1	1	3	3	1	2	1	0	1	2	2	3	2	3
5. Important forest habitats	0	2	1.5	1.5	1	1	1	2	1	2	3	1	2	2	1	1	2	3	2	2	3
6. Undrained peatlands	0	2	2	2	1	0	1	3	1	1	3	1	2	2.5	1	2	2	3	2	3	3
7. Important bird areas	0	1	0	1	1	1	1	1	0	1	3	1	1	1	0	1	2	3	2	2	3
8. Valuable geological features	0	1	3	2	1	2	1.5	2	1	1	1	1	2	3	0	1	2	2	2	2	3
9. Groundwater areas	0	1	3	3	0	1	1	3	1	1	1	0	2	3	0	1	1	1	1	1	2
10. High Nature Value farmlands	3	1	0	0	0	1	1	1	0	2	2	1	1	1	0	1	2	2	2	2	2
11. Good and continuous agricultural areas	3	2	0	0	1	1	0	0	0	1	0	0	1	0	0	1	0	1	2	0	0
12. Surface waters of high or good ecological status	0	2	3	3	0	0	0	2	0	0	3	2	0	3	0	0	3	3	2	2	3
13. Surface waters with low or very low level of human-induced alterations	0	2	2	3	0	0	0	2	0	0	2	1	0	3	0	0	2	2	2	2	3
14. Regional recreation areas	1	2	1	1	0	2	1	1	1	1	1	1	1	1	0	1	3	2	2	2	2
15. Groundwater areas at risk	-2	-1	-3	-2	-3	0	0	-1	0	0	0	0	0	-3	0	0	0	0	0	0	-1
16. Sealed surfaces	-3	-3	-3	-3	-2	-1	-2	-3	-2	-2	-3	-1	-3	-2	-1	-2	-3	-3	-3	-3	-3
17. Land extraction sites	-2	-3	-2	-2	-2	-3	-2	-2	-1	-2	-2	-1	-3	-2	-1	-1	-3	-2	-2	-3	-3
18. Peat extraction sites	-2	-3	-2	-2	-2	-2	-2	-2	-1	-1	-2	-1	-3	-3	-2	-1	-3	-3	-3	-3	-3
19. Surface waters of moderate, poor or bad ecological status	-1	-1	-2	-2	-1	0	0	0	0	0	-1	-1	0	-2	0	0	-2	-1	-2	-2	-2
20. Sites of frequent algal bloom observations	-2	-2	-2	-2	-1	0	0	0	0	0	-1	-1	0	-2	0	0	-2	-1	-2	-2	-2
21. Surface waters with moderate or high level of human-induced alterations	0	-2	-2	-2	-1	0	0	-1	0	0	-1	-1	0	-2	0	0	-2	-2	-2	-2	-2

3: *Very favourable effect*, 2: *Favourable effect*, 1: *Slightly favourable effect*, 0: *No effect / neutral effect*, -1: *Slightly harmful effect*, -2: *Harmful effect*, -3: *Very harmful effect.*

Step 7: Analysing the spatial variation in ES provision potential using a GIS

- The pre-processed and rescaled quantitative data layers already represent the spatial variation in the provision potential of certain ES within the study area (e.g. groundwater supply, timber volumes of forests). Therefore, using the expert scores and overlaying qualitative data themes is not required to assess these ES.

- For other ES, the spatial variation in the provision potential is assessed using the pre-processed data themes and median scores (weights) obtained from the expert assessments in GIS software. First, each ES group is assessed individually by calculating a weighted sum of the preprocessed binary raster layers. The median scores for each data theme for the given ES are used as weights. Thus, a median score of 0 omits a data theme from the assessment of the ES group in question. The weighting can be implemented for example with the Weighted Sum tool in the Spatial Analyst extention of ArcGIS (version 10.1). The tool allows weights to be assigned to each layer and sums overlaying pixels into an output layer.
- The resulting layers for each ES are rescaled to a range of 0 – 1. In the output, the pixel value 1 represents the area with the highest provision potential for the ES in question, and pixel value 0 represents the lowest provision potential within the study area. A value of 0 does not necessarily indicate that the location has no provision potential for the given ES, but it indicates that within the study region, other locations have greater potential for the provision of this particular service.
- The spatial patterns of each ES section (provisioning, regulating and maintenance, and cultural) can be analysed by summing the results of related ES groups according to the section they belong to, and normalising the results to a common range of 0 – 1. All ES can be included as equally important in the synthesis, or weights can be assigned according to the importance of different layers.
- A full synthesis of the analysed ES can be created by summing up the layers for each ES section and rescaling the resulting values to a range of 0 – 1. An example of such an ES synthesis map is shown in Figure 2.1.7).

Step 8: Visualisation of the results

- Once all desired ES groups are assessed individually and syntheses of different ES sections and all ES are made, the results are ready for visualisation. An intuitive way to present the results is to use a sequential monochromatic color scheme, where areas with highest potential are visualised with darker tones and areas with lower potential are visualized with lighter tones (Figure 2.1.8). Depending on the distribution of the pixel values, different classifications of the pixel values can be used. Often, but not necessarily always, the pixel values are somewhat normally distributed. In this case, it is good to apply standard deviations stretch or quantile classification of the pixel values.

Step 9: Validation of the results

- After carrying out the analyses, it is recommended to validate the results with stakeholders and/or scientific experts who have expertise on the study area. Among possible methods for obtaining feedback on the results are individual fill-forms, focus group discussions, interviews, and interactive workshops.
- It is advisable to collect the feedback in such a way, that the comments can be attached to specific locations. This enables a more detailed analysis on the factors that affect the results in these locations. An easy way to collect this information is to use hard-copy paper maps and ask the respondents to pinpoint locations where they find the results either plausible or unconvincing / inconsistent etc. The targets can be marked with numbers, and justifications for each pinpointed target can be written down. These paper maps can then be scanned and georeferenced. In order to avoid digitizing paper copy maps, also online map surveys, or for example Google Earth can be used to get the feedback directly in GIS format.

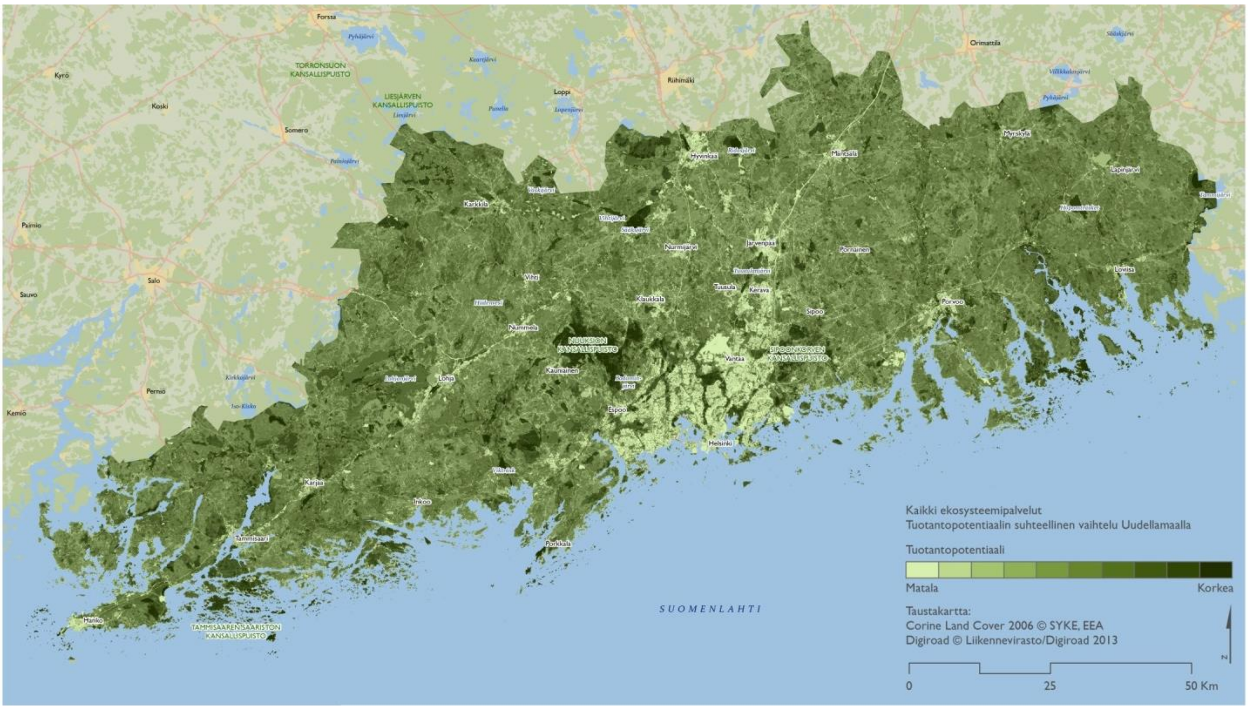


Figure 2.1.8: Illustration of relative provision potential of all ES over the landscape for the Uusimaa Region of Finland (Kopperoinen et al. 2015).

2.1.9 Illustration of practical applications of the method using the OpenNESS case studies

Illustrations of the practical application of both the simple spreadsheet method and the GreenFrame method are included within the previous sections. Several OpenNESS case studies have applied the simple spreadsheet method based on LULC datasets (Table 2.1.3). Only one case study applied the GreenFrame method: Trnava urban case study (Slovakia). Other case studies considered applying GreenFrame, but ended up implementing the simpler matrix-method due to spatial dataset limitations.

Table 2.1.3: An overview of OpenNESS case studies applying spreadsheet-type methods.

	Case study	Country	Issue being assessed
2	Trnava	Slovakia	Landscape-ecological planning in urban and peri-urban areas
3	Oslo	Norway	Urban green space plans
4	Vitoria-Gasteiz	Spain	Urban planning
5	French Alps	France	Regional and national forest management planning
7	Carpathian Mountains	Romania	Forest management
8	Central Germany	Germany	Bioenergy production in forest and farmland
9	Cairngorms National Park	UK	National Park management
10	Sierra Nevada National Park	Spain	National Park management
11	Warwickshire	UK	Biodiversity offsetting
17	Lower Danube River	Romania	Adaptive management plan
18	Demer Basin	Belgium	Integration of ES in the planning of a flood control area
20	Wadden Sea	Netherlands	Coastal management
21	Costa Vicentina	Portugal	Coastal management

2.1.10 Further reading

Burkhard, B., Kandziora, M., Hou, Y. and F. Müller (2014), 'Ecosystem service potentials, flows and demands–concepts for spatial localization, indication and quantification'. Landscape Online, 34, 1-32.

Burkhard, B., Kroll, F., Nedkov, S. and F. Müller (2012), 'Mapping ecosystem service supply, demand and budgets', Ecological Indicators, 21, 17-29.

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Vihervaara, P., Kumpula, T., Ruokolainen, A., Tanskanen, A. & B. Burkhard (2012), 'The use of detailed biotope data for linking biodiversity with ecosystem services in Finland', International Journal of Biodiversity Science, Ecosystem Services & Management, 8 (1-2), 169-185.

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2.1.11 References (not included in further reading)

Burkhard, B., Kroll, F., Müller, F. and W. Windhorst (2009), 'Landscapes' capacities to provide ecosystem services–a concept for land-cover based assessments', Landscape online, 15 (1), 22.

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2.2 ESTIMAP

Grazia Zulian

2.2.1 Introduction to method/model

ESTIMAP is a consistent and flexible set of spatially-explicit models each of which can be run separately for the assessment of different ES at the European scale. They are all developed following the CICES classification (Haines-Young & Potschin 2013) and framed in the ES cascade model which connects ecosystem structure and functioning to human well-being through the flow of ES. The models are dynamically linked to LUISA, the JRC land use modeling platform (Lavalle et al. 2011). This provides the opportunity to evaluate the impact of different scenarios of land use changes on ES provision.

At present eight modules are operational at the European scale:

1. Capacity of ecosystems to remove air pollutants;
2. Capacity of land cover to prevent soil erosion;
3. Capacity of coastal ecosystems to protect against inundation and erosion from waves, storm or sea level rise;
4. Capacity for retention of water in the landscape;
5. Capacity of ecosystems to sustain pollination activity;
6. Habitat quality for breeding common birds;
7. Recreational and cultural services;
8. Bird richness of pest-control providers.

ESTIMAP was originally developed to support policies at a continental scale. Nevertheless the approaches are flexible and can be easily downscaled in order to fit the specific local scale needs and local planning demands of the OpenNESS case studies. This section focuses on the downscaled ESTIMAP-Recreation and ESTIMAP-Pollination models which have been extensively applied in the OpenNESS case studies (Table 2.2.1 provides a list of ESTIMAP models applied in different OpenNESS case studies).

Table 2.2.1: An overview of OpenNESS case studies currently applying downscaled ESTIMAP models.

<table>
<tr><th>Cluster</th><th>Case</th><th>Case name</th><th>Country</th><th>Model</th></tr>
<tr><td rowspan="3">Urban</td><td>03</td><td>Valuation of urban ES in Oslo: developing a spatially representative blue-green area factor</td><td>Norway</td><td>Recreation
Pollination</td></tr>
<tr><td>27</td><td>Sustainable urban planning in the metropolitan region of Barcelona</td><td>Spain</td><td>Recreation
Air Quality Regulation</td></tr>
<tr><td>01</td><td>ES in urban land use planning: Sibbesborg</td><td>Finland</td><td>Recreation</td></tr>
<tr><td rowspan="3">Mixed rural landscapes</td><td>09</td><td>Cairngorms National Park management</td><td>UK</td><td>Recreation</td></tr>
<tr><td>12</td><td>Living on the edge in a drying region: Kiskunság</td><td>Hungary</td><td>Recreation</td></tr>
<tr><td>08</td><td>Bioenergy-related synergies and trade-offs in ES provision</td><td>Germany</td><td>Pollination</td></tr>
<tr><td>River basin management</td><td>16</td><td>Consequences of EU Water Policy (Water Framework Directive) for the delivery of ES: Loch Leven, Scotland</td><td>UK</td><td>Recreation</td></tr>
<tr><td>Coastal area management</td><td>21</td><td>Natural capital and ES for sustainable livelihoods in Costa Vicentina, Portugal</td><td>Portugal</td><td>Pollination</td></tr>
</table>

Keywords: spatially explicit models, ecosystem services, mapping.

2.2.2 Why would I use this method/model?

ESTIMAP provides a framework for an exhaustive and consistent spatially-explicit assessment of ES. Each model is framed in three parts: (i) an indicator of the potential capacity of the ecosystems to provide the service; (ii) an indicator of the flow of the service; and (iii) an indicator of the demand of the service. It represents an integrated but data-intensive approach, based on the application of dynamic process-based models or data models which estimate ecological production functions which are subsequently used to map potential or actual ES.

2.2.3 Requirements

Requirements		Comments
Data	☐ Data is available ☑ Need to collect some new data ☑ Need to collect lots of new data	
Type of data	☑ Qualitative ☑ Quantitative	Spatially-explicit datasets (vector or raster) and additional information are needed.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	The models can be computed using any types of GIS software, licensed (ArcGIS) or open source (GRASS, QGIS, R, etc)
Time resources	☑ Short-term (< 1 year) ☑ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Time and economic resources strictly depend on the expertise of the researchers and GIS specialists
Economic resources	☐ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	
Other requirements		

2.2.4 Advantages

- The GIS models and processes are relatively easy to implement, requiring only a medium level of GIS expertise, especially for the data preparation;
- Mapping and visualisation facilitate dialogue among scientists, policy-makers and the general public;
- The models allow simulation of different scenarios and evaluation of different policy options;
- The models are flexible; they can be downscaled and modified in order to fit the local needs and conditions.

2.2.5 Constraints and limitations

- Data preparation can be quite a long and demanding task;
- The utility of the results depend on identifying a clear set of questions to be addressed.

2.2.6 Does the method address uncertainty?

The method doesn't address uncertainty.

2.2.7 ESTIMAP-recreation: steps required to apply the method within a case study

Cultural ES are recognised as 'physical and intellectual or spiritual, symbolic and other interactions with biota, ecosystems, and land- /seascapes [environmental settings' (Haines-Young & Potschin 2013). Examples of cultural ES are: appreciation of natural scenery; opportunities for tourism and recreational activities; inspiration for culture, art and design; sense of place and belonging; spiritual and religious inspiration; education and science. Outdoor recreation and tourism represent an important service that interests millions of people and contributes to connecting them with nature. While tourism is an occasional activity, local outdoor recreation affects the daily life of people.

ESTIMAP-recreation provides models for mapping and assessing the potential provision of nature-based outdoor recreational opportunities (Paracchini et al. 2014). An overview of the model is provided in Table 2.2.2.

Table 2.2.2: Overview of the ESTIMAP-recreation method.

General meaning of the indicator	Potential opportunities provided by ecosystems for a nature-based recreation activity
Method	Composite mapping
Components at the European scale	Degree of naturalness Natural protected areas Water-related data
Components at the local scale	The three components and their elements can be adapted to fit specific needs
Outputs	1. RP raster map (dimensionless) 2. ROS raster map (categories) 3. Demand (statistics)

It is framed in three parts:

- Recreation potential [RP] – capacity
  - The potential opportunities provided by the ecosystem for recreational activities (RP Map, D, Figure 2.2.1)
- Recreation Opportunity Spectrum [ROS] – flow
  - The flow of service, which combines the potential provision map (RP) with proximity map (P) (ROS Map, L, in Figure 2.2.1). Proximity to roads and built areas is considered to be one of the main drivers of the service being used; people have to reach recreational sites and opportunities by transportation infrastructures. The Recreation Opportunity Spectrum (ROS), originally developed as a tool for inventorying, planning and managing recreation

opportunities (*Recreation Opportunity Spectrum Procedures and Standards Manual 3.0*, 1998) is used to provide an indicator of recreation opportunities available.

- Estimate of potential trips – demand
    - The assessment of potential benefits: evaluates the percentage of potential trips for each ROS category (% PPB, N, in Figure 2.2.1).

Figure 2.2.1 shows a flow chart of the steps within the model. Firstly, it assesses the potential capacity of a group of identified ecosystems and other elements to provide opportunities for local outdoor recreation (D). This varies according to the presence of three key aspects: the degree of naturalness (A), the presence of natural areas (B) and the presence of water (C). In a second step, it computes Euclidean distances from urban (E) areas and from roads (F). The two maps are then combined to derive a proximity map (H), which depends on specific proximity parameters (G). A final map of recreation opportunities (ROS) (L) is then computed by a cross tabulation between the RP (D), the Proximity Map (H) using a second set of parameters (I) with thresholds for the degree of recreation opportunities provided by nature and the degree of proximity and remoteness. Parameters (G and I) can be derived from a literature review.

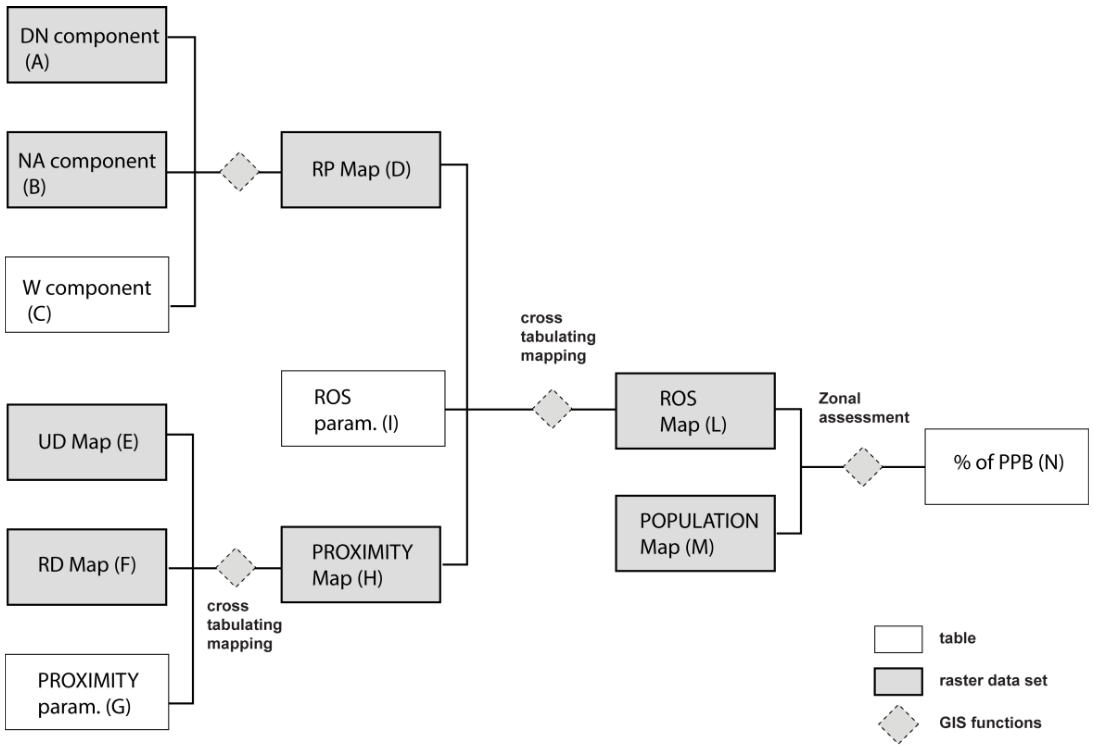


Figure 2.2.1: Flow chart of the ESTIMAP-recreation model.

This model configuration represents the original model developed to fit the continental scale. To downscale the model to the local context, the first step is to determine the main questions to be addressed (see examples in Table 2.2.3).

Table 2.2.3: Examples of different problems addressed in the OpenNESS case studies.

OpenNESS cluster	Example questions
Sustainable urban management	• What is the relative amount of recreational opportunities available per capita? • Is the local provision equally distributed? • Does the local management of urban parks and play grounds, and the local transportation network, fit citizens needs?
Management of mixed rural landscapes	• How are the opportunities for nature-based recreation spatially distributed inside the park? In terms of quality and accessibility? • Where are the most important conflict areas between nature conservation and recreation?
Integrated river basin management	• What is the value of the lake to local tourism and recreation? • Is this value affected by the water quality of the lake (link to the Water Framework Directive)?

2.2.8 Illustration of practical applications of the method using the OpenNESS case studies: Cairngorms National Park, Scotland

The first step in applying the ESTIMAP-recreation model within the Cairngorms National Park was to define the main research/policy questions to be addressed (see 'Management of mixed rural landscapes' in **Error! Reference source not found.Error! Reference source not found.**). The second step was to collect the relevant data and define the different components of the model as shown in Figure 2.2.1. Recreational Potential (RP) was defined in terms of four components: (i) suitability of land to support recreational activities; (ii) features influencing the potential provision, e.g. infrastructure; (iii) natural features; and (iv) presence of water. Table 2.2.4 lists the inputs used for the application of ESTIMAP-recreation in the Cairngorms National Park. These data are then prepared by scoring each input according to its suitability to support recreation activities. The scores for each input layer are then combined between components and the components summed and normalised. The resulting map of recreational potential is shown in Figure 2.2.2.

We considered all types of outdoor recreation across nine activity categories (Bicycling, Camping, Fishing, Hunting, Off Roading, Snow Sports, Trail Sports, Water Sports and Wildlife Viewing). We asked a group of experts to score all the spatial datasets according to their capacity to provide opportunities for two types of recreationists: '*hard recreationist*' and '*soft recreationist*'. The first group is interested in more extreme experiences (trekking, mountain biking, canyoning, long open water swimming), whilst the second group is attracted to low impact activities, such as walking and cycling. An illustration of output from the model is given in Figure 2.2.2.

Table 2.2.4: Inputs used for ESTIMAP-recreation in the Cairngorms National Park. At a local level the number of components and inputs increase and depend on the local setting.

A. Recreation potential		
SLSRA (Suitability of land to support recreational activities) (A)	Land cover	Morton et al. (2014)
	Historic land use assessment	http://www.historic-scotland.gov.uk/index/heritage/valuingourheritage/historiclandscapes.htm
	HNV farmland	Paracchini & Capitani (2011)
Features influencing the potential provision INFRASTRUCTURE (B)	National Forest Estate Scotland Recreation points – routes and areas	http://www.forestry.gov.uk/datadownload
	Nature paths (walk highlands)	http://www.walkhighlands.co.uk/
	Distilleries	Data gathered on site
	Ski centres	
Features influencing the potential provision (C)	Geological formations	https://gateway.snh.gov.uk/natural-spaces/index.jsp
	Slope (DEM)**	Morris & Flavin (1990)
	Native Woodland Survey of Scotland	http://scotland.forestry.gov.uk/supporting/strategy-policy-guidance/native-woodland-survey-of-scotland-nwss
	National Forest Inventory	http://www.forestry.gov.uk/datadownload
	National Vegetation Classification	http://jncc.defra.gov.uk/page-4259
Features influencing the potential provision CULTURAL (D)	Archaeology / cultural heritage data	Royal commision for the Ancient and Historical Monuments of Scotland http://www.rcahms.gov.uk/
Water (D)	Streams	Morris & Flavin (1994)
	Lakes	http://www.geofabrik.de/data/download.html
B. Recreation opportunity spectrum		
Proximity	Residential buildings and settlements	Morton et al. (2014)
	Main and local roads and bike paths	http://www.geofabrik.de/data/download.html
Wildlife data		
Wildlife data	Site of Special Scientific Interest (*SSSI*)	http://www.snh.gov.uk/protecting-scotlands-nature/protected-areas/national-designations/sssis/
	RSPB reserves	http://www.rspb.org.uk/forprofessionals/gis/
Species data		Data received from North East Scotland Biological Records Centre (NESBReC)

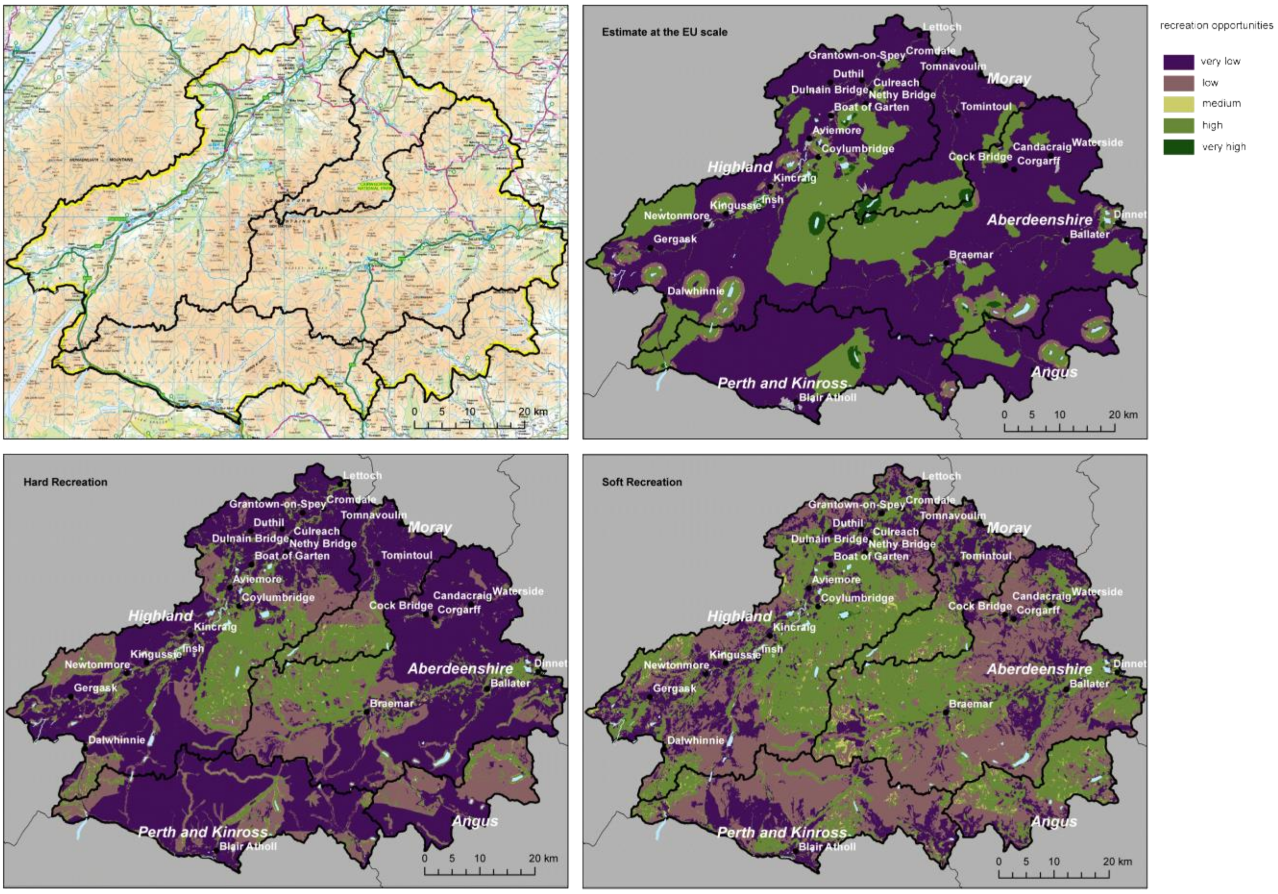


Figure 2.2.2: Map of recreation potential for different user groups in the Cairngorms National Park: Upper left: map of the case study area; Upper right: map of recreation potential extracted directly from the European model; Lower left: map of hard recreational potential from the downscaled model; and Lower right: map of soft recreational potential from the downscaled model.

The third step is to map the Recreation Opportunity Spectrum (ROS). To derive the ROS it is first necessary to compute a proximity map. The proximity map shows five degrees of proximity and depends on the distance from local roads (excluding motorways and primary roads) and walking paths and the distance from the built areas (Table 2.2.5). The ROS map is derived by overlaying the recreation potential (RP) map (reclassified into four levels of service provision using the natural breaks (Jenks classification)) with the proximity map. The ROS is then classified into nine categories of service consisting of three levels of provision (low, medium and high provision) and three degrees of proximity (from near to far) as shown in Table 2.2.6. The classes represent proxies of how a recreational opportunity may be reached, preferably by walking or short distances (Marquet & Miralles-Guasch 2014). The assumption is that the more an opportunity is reachable the more people potentially will visit the area. Illustrative output for ROS for the hard recreationist group is shown in Figure 2.2.3.

Figure 2.2.4 shows the final output from applying the model in a small area within the Cairngorms National Park (the RSPB nature reserve Insh Marshes).

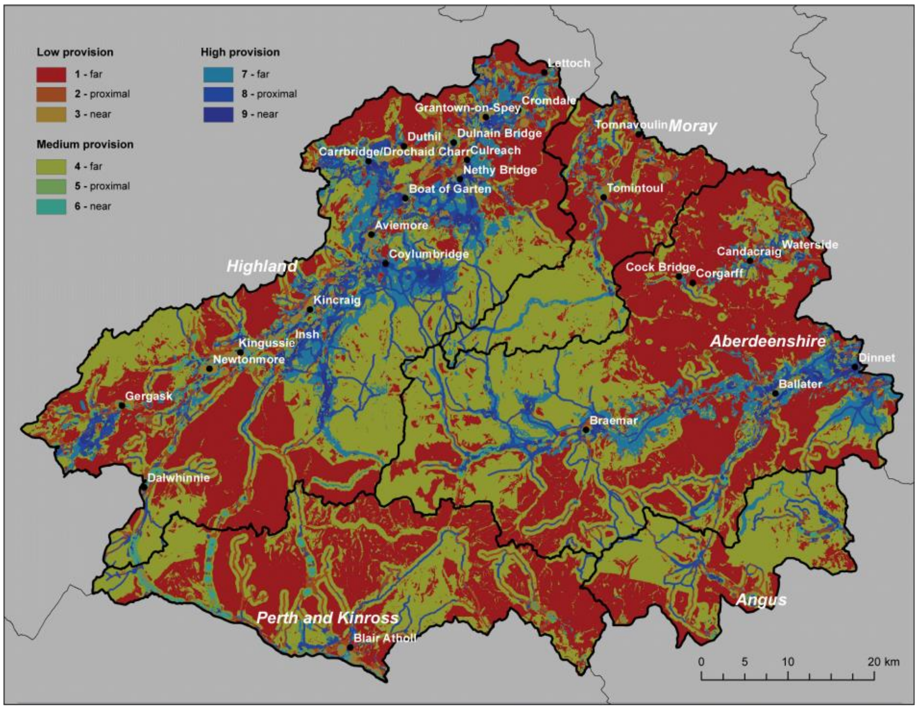
Table 2.2.5: Conditions and thresholds applied for the computation of the proximity map. The same methodology was used as proposed in Paracchini et al. (2014). The distances thresholds vary according to different classes of common walking distances (Prins et al. 2014).

Thresholds		Distance from roads (m)					Proximity categories	
		<100	100-300	300-500	500-1000	>1000		
Distance from urban (m)	<100	1	1	2	3	4	1	near
	100-300	1	1	2	3	4	2	
	300-500	2	2	2	4	5	3	proximal
	500-1000	3	3	4	5	5	4	far
	1000'	3	4	4	5	5	5	

Table 2.2.6: Conditions and thresholds applied for the computation of the Recreation Opportunity Spectrum (ROS) map. The same methodology was used as proposed in Paracchini et al. (2014), but different thresholds were set.

		Recreation potential (classes)						Proximity	Code
		<0.24	0.14-0.35	0.23-0.46	>0.46	Degree of service provision	low	far	1
Proximity	5	1	1	4	7			proximal	2
	4	1	4	4	7			near	3
	3	2	2	8	8		medium	far	4
	2	3	5	5	9			proximal	5
	1	3	6	6	9			near	6
							high	far	7
								proximal	8
								near	9

Figure 2.2.3: Map of the Recreation Opportunity Spectrum for the Cairngorms National Park.



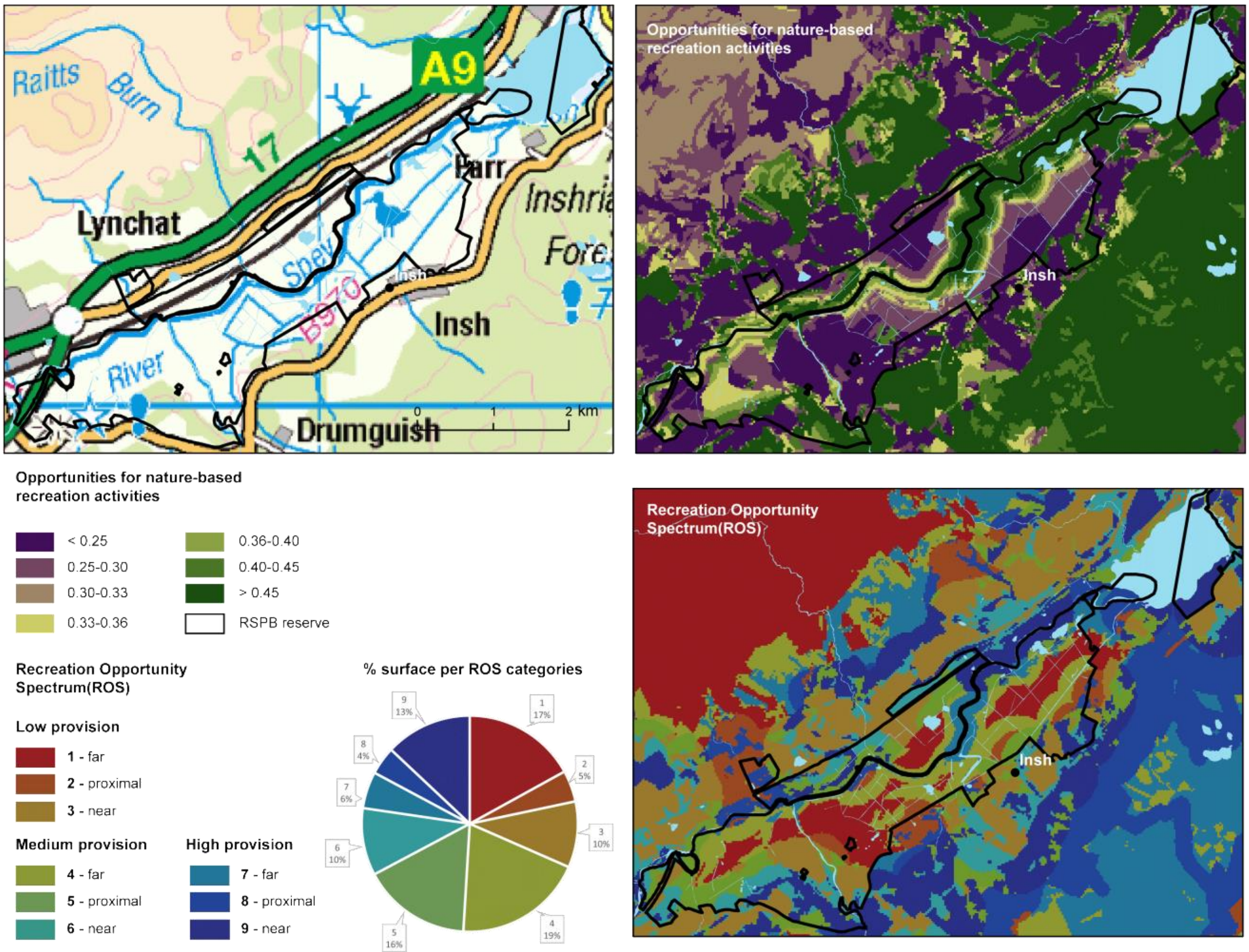


Figure 2.2.4: Final output from applying the ESTIMAP-recreation model to the the RSPB area Insh Marshes within the Cairngorms National Park: Upper right: recreation potential map; Lower right: recreational opportunity spectrum (ROS) map; Lower left: percentage of the area divided per ROS categories.

2.2.9 ESTIMAP-pollination: steps required to apply the method within a case study

Different habitats, but in particular forest edges, grasslands rich in flowers and riparian areas, offer suitable sites for wild pollinator insects such as solitary or honey bees, bumblebees or butterflies (Garibaldi et al. 2011; Kells & Goulson 2003; Svensson et al. 2000). Ecosystems that host their populations have the potential to increase the yield of adjacent crops (such as important fruit, vegetable, nut, spice and oil crops; Klein et al., 2007) that are dependent on insect-mediated pollination. The demand for the pollination service is thus generated by the decision of a farmer to plant crops which depend on, or profit from, pollination (Lautenbach et al. 2012). In meeting this demand, wild pollinators deliver economic value which can be measured by assessing the contribution of pollination to total crop yield or by estimating the costs that are saved from replacing wild pollination with a managed form (Aizen et al. 2008).

The ESTIMAP-pollination model is derived from InVEST[1] (Lonsdorf et al. n.d.; see Section 2.6), but has been adapted to fit a continental-scale mapping approach in four essential ways (Zulian et al. 2013):

1. Different input data were used to model composite indicators for floral availability and nesting suitability;
2. A specific land parcel system based on the CAPRI model (Common Agricultural Policy Regionalised Impact; Britz & Witzke, 2008) was used to estimate the contribution of crops to floral availability and nesting suitability and to estimate the relative benefits derived from pollination;
3. An extra module was added to calculate the activity of bee pollinators;
4. Areas where pollinators cannot occur due to physical barriers were excluded.

An overview of the ESTIMAP-pollination model is given in Table 2.2.7 and a flow chart showing the steps for implementation of the model in Figure 2.2.5. The model uses an expert-based assessment of various types of land cover information to estimate the availability of floral resources (A) and foraging ranges (B) to map possible foraging sites (C). This data is combined with an estimate of available nesting sites (D) to derive an index of relative pollinator abundance (E) for each cell of a land cover map. Map E is corrected for differences in activity (F) as a result of climatic variation in temperature and solar irradiance. Bees become inactive when a combination of temperature and irradiance falls below a certain threshold (Corbet et al. 1993), which affects their abundance outside the nest. Including temperature-dependent activity results in an updated relative pollinator abundance map (G). Flight range information (B) is used a second time to estimate relative pollination potential (H). A final map of relative pollination potential (L) is then obtained by masking out areas where insect pollinators cannot find nesting sites such as open water and high altitudes (I).

Table 2.2.7: Overview of the ESTIMAP-pollination model.

General meaning of the indicator	Estimates the relative capacity of land cover to sustain pollinators; according to (i) the capacity of land cover parcels to host and feed wild pollinators, (ii) an activity index [climatic data), and (iii) a foraging distance
Method	Composite mapping
Components at the European scale	Three main components based on land cover, road network, crop data, climatic data, foraging distance
Components at the local scale	Depends on the local conditions and species
Outputs	Pollination potential map, raster, dimensionless

[1] Integrated Valuation of Environmental Services and Tradeoffs (http://www.naturalcapitalproject.org/InVEST.html)

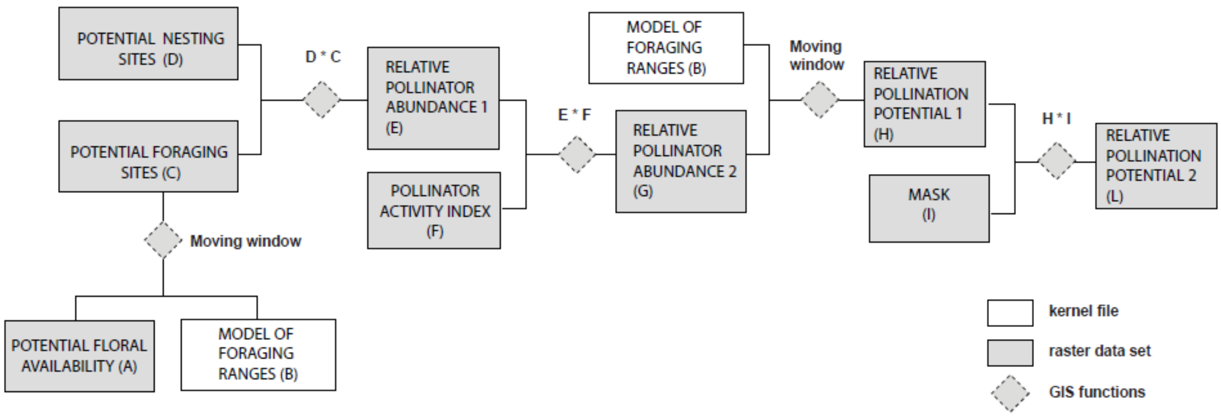


Figure 2.2.5: Flowchart showing the steps of the ESTIMAP-pollination model for calculating relative pollination potential.

Maps of relative pollination potential can be produced for each pollinator species provided that parameters for flight distance and activity are available (Lonsdorf et al. n.d.). Nesting suitability and floral availability (Maps D and A, Figure 2.2.Figure 2.2.) are derived from a set of composite models that estimate the capacity of different landscapes to provide food and shelter to insects; both maps are constructed using similar spatial datasets and models but different weights are given to each spatial attribute with respect to their capacity to host nests or their availability of floral resources.

2.2.10 Illustration of practical applications of the method using the OpenNESS case studies: Oslo, Norway

The steps which were undertaken to apply the ESTIMAP-pollination model to the Oslo case study are listed below (see Zulian et al. (2013) for further details):

1. Choose the pollinator species to be modelled
    a. Collect information on foraging distances (Table 2.2.8), preferred nesting sites and floral resources.
2. Collect and prepare the relevant datasets (see Table 2.2.9 for an example of data used in Oslo).
    a. Define a floral availability and nesting suitability score for each data set.
3. Prepare the kernel to compute the moving window (the kernel depends on the data resolution and the foraging distance)- B in Figure 2.2..
4. Compute the Potential Floral Availability map (A in Figure 2.2.)
    a. Sum all components and sub-components of the floral availability.
5. Compute the Foraging Map (C in Figure 2.2.)
    a. Moving window: inputs are Floral availability and Kernel (B).
6. Compute the nesting suitability map (D in Figure 2.2.)
7. Compute the relative pollination potential
    a. Multiply map D by Map C.

Figure 2.2.6 shows the final output from applying the model in the Oslo case study.

For the Oslo local case study it was decided not to compute the activity index. Full details of implementing this part of the ESTIMAP-pollination model are given in Zulian et al. (2013).

Table 2.2.8: Pollinator species addressed in the Oslo case study and information on their relative foraging distance.

Pollinator species group	Foraging distance
Bumblebees	400m
Honeybees	400m
Solitary bees	100m - 1km

Table 2.2.9: Datasets used in the ESTIMAP-pollination model for Oslo. At the local level the number of components and inputs increases and depends on the local setting.

Data		Source
Nesting suitability and floral availability	Land use	Norwegian Map Service - Kartverket: http://kartverket.no/Kart/Kartdata/Vektorkart/N50/ NIBIO: http://www.skogoglandskap.no/kart/ar5/map_view
	Forest	
	Vegetation types	
	Trees	
	Old big trees in green urban areas	‘Bymiljøetaten(BYM), Oslo Kommune’.
	Ponds in green urban areas	
	Flowers in green urban areas	
	Fruit trees in green urban areas	
	Grass in green urban areas	
	Shrubs in green urban areas	
	Parks	

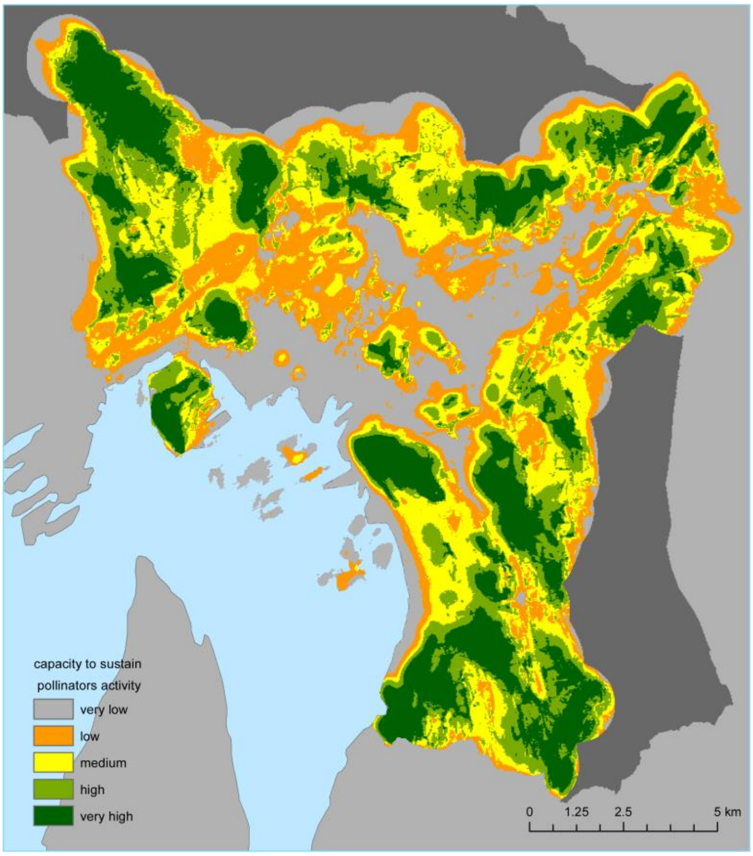


Figure 2.2.6: Final outputs from the ESTIMAP-pollination model showing pollination potential in Oslo.

2.2.11 Further reading

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2.3 Bayesian Belief Networks

Ron Smith, Anders L. Madsen & David N. Barton

2.3.1 Introduction to method/model

A Bayesian Belief Network (BBN) starts from a diagrammatic representation of the system that is being studied, developed by pulling together the knowledge of scientists and practitioners (both are stakeholders) about the processes leading to the supply and demand of ES. As a knowledge representation tool, this initial development of a BBN generates a framework of nodes and links, similar to many other representations of an ecological system or a human decision process (Figure 2.3.1). Its purpose is to formalise the flows of information through the system (from ecology to economics) and leads to a transparency about what is being represented.

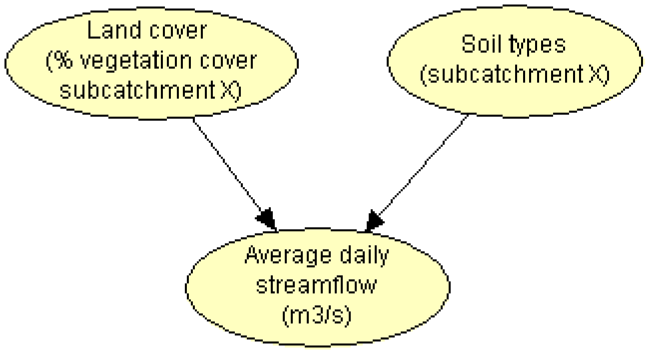

Figure 2.3.1: Simplistic representation of a BBN as nodes and linkages.

The next stage is populating the knowledge framework with information, which can include expert opinion, model outputs and empirical measurements (both quantitative and qualitative). If a statement based on that information, for example 'the colour of a leaf is green' compared to alternatives that the leaf could be yellow or brown, is an assertion, then the uncertainty can be seen as the weight of evidence that supports each assertion. Within a BBN there will be values that measure the weight of evidence for each possible assertion being true. Well-known probability theory is then used to provide inferences, i.e. conclusions based on evidence, in the form of the information and uncertainties within the outcome nodes.

The ES and natural capital (NC) concepts are by definition inter-disciplinary and logically fit into the framework of a decision process. The idea of value is only relevant when it is comparable to another value, rather than as an abstract concept, and the BBN can be extended to include decision-relevant information such as preferences and costs[2]. Therefore the BBN is an appropriate decision support tool that can be applied to many of the challenges of ES and NC assessment.

The BBN is very flexible and can also be used to model other methods, such as state and transition models (STM; see Section 2.4) and multi-criteria decision analysis (MCDA; see deliverable 4.3), and can be

[2] Technically this becomes an influence diagram (ID).

combined with other model frameworks, such as agent-based models, to improve realism in modelling socio-ecological systems.

Keywords: Object-oriented bayesian networks, influence diagrams, cost-effectiveness, cost-benefit, multi-criteria analysis, decision-support.

2.3.2 Why would I use this method/model?

Types of problem

The BBN is a flexible tool that can be used in a number of ways. Particular features of the tool are relevant to its use in ES studies:

- **Compact model knowledge representation -** The BBN can be used directly for simple modelling tasks or represent the simulation output from a more complex model in the form of key input and output variables in a network with conditional probabilities. For example, the detail of a complex hydrological model may not be necessary when assessing the costs of flooding over a 10 year period. The simulated effect, e.g. of land cover and soil type, on run-off over a given area and time span can be summarised in the form of a conditional probability table within a BBN with two conditioning variables.
- **Linking knowledge domains -** The BBN can link diverse types of information, and be used as a meta-modelling tool to link together different models in a causal model chain. Through the use of object oriented BBNs (in a simple case these are hierarchies of nested BBNs) and dynamic BBNs (using time slices to model temporal dependences, feedbacks, etc.), the BBN can be extended and adapted to modelling very complex applications. This is relevant to ES studies, especially implementing the ES cascade or other types of driver-pressure-state-impact-response (DPSIR) model chains. This makes it a good methodological framework for a multi-disciplinary project, as it easily transitions from ecological delivery to social assessment to economic cost, if that is what is required.
- **Knowledge updating -** BBNs can be readily updated with new information, so it is not a static representation of the issues. Existing knowledge on the strength of causal relationships is updated according to how much the new evidence 'weighs' in relation to the old (e.g. how many new observations there are relative to the prior data).

Decision support

- **Constructing a shared causal model -** A BBN is readily adaptable to accommodate stakeholders' belief about the structure of causality and the amount of knowledge/uncertainty about each outcome. BBNs are easily used 'live' for exploring scenarios with stakeholders because model run time is instantaneous once compiled. Here, BBNs are used to construct a common understanding of the problem.
- **Expected utility of decisions -** No decisions are taken with true certainty. The BBN can be used as a decision support tool with a consistent treatment of uncertainty. Decision alternatives can be associated with costs and multiple end-points can be associated with benefits. BBNs will compute the expected utility (net benefits) of decision alternatives. BBNs with multiple outcomes can also

be set up as a multi-criteria analysis, using multi-attribute value functions with utility weights on each outcome (instead of monetary utility).

- **Value of information -** BBNs include diagnostics such as the value of information of each variable in the network in relation to a specified outcome. With information on the cost of additional observations, BBNs can help decision-makers determine whether the cost of information is justified by the net benefits of making a better decision.
- See also 'Object-Oriented Bayesian Networks for Decision Support' (in OpenNESS Deliverable D4.3).

Scale relevance

The BBN is developed at the temporal and spatial scales chosen by the knowledge engineer (person responsible for constructing the BBN), and these must be defined clearly at an early stage in each study. Explicit choices on temporal and spatial scale follow automatically once the ES under study have been properly defined with geographical boundaries and time frames. There is also a scale of complexity so the BBN delivers sufficient detail without overloading the model with irrelevant information; this has to be appropriate to the individual study and can be tested through formal analysis and stakeholder interactions. The BBN is specific to the scales chosen, so any change of scale will often lead to a change in BBN structure or quantification.

The inputs and outputs are also linked to the scales of the BBN, and there is a significant challenge to upscale and downscale data from a variety of sources to make the information appropriate at the correct scales for the BBN.

Spatially-explicit

The BBN operates on the domain that is specified by the knowledge engineer using the scales of space and time, and these should identify the unit that is appropriate to make the decision. For a regional government looking at the decision of whether or not to increase the area of forestry, the BBN would model one regional decision process, which will often rely on summaries of supplementary spatially-referenced data such as maps to inform the process. The decision is not to plant a specific tree at a particular location; it is to provide a policy of increasing forestry by a certain amount across the region. The decision process itself is not spatial, and neither is the BBN.

A BBN can be embedded within a GIS where it does become spatially-explicit, but it also inherits the constraints of a GIS system in terms of representing spatial dependence. Here, the BBN models the functional relationships between the states of nature represented by the GIS layers, and these are generally based on a raster or polygon with uniform information across the geographical unit. There is a possibility of capturing local spatial dependence by using information from neighbouring geographical units, but it is more difficult to include correlations or dependences that occur across longer distances.

2.3.3 Requirements

Requirements		Comments
Data	☑ Data is available ☐ Need to collect some new data ☐ Need to collect lots of new data	Data are always available through the use of expert knowledge, so there is never a need to wait for new data before exploring possibilities. BBNs are excellent at integrating knowledge by providing a framework to combine expert opinion and data within a single model.
Type of data	☑ Qualitative ☑ Quantitative	Handles all types of input information, but internally the software holds it as qualitative data.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	Very useful in an inter-disciplinary study and where working with stakeholders (of all backgrounds) is important.
Software	☑ Freely available ☑ Software licence required ☐ Advanced software knowledge required	Software is available either free or on licence.
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Short-term to get models working, explore potential frameworks, and get the most out of available data.
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	<6 person-months, longer time will be required if there is a lot of stakeholder interaction and/or there is no initially agreed model structure.
Other requirements		

2.3.4 Advantages

- Easy to use once some experience has been gained;
- Quick to use;
- Recognised and established approach;
- Advanced state-of-the-art method;
- Draws on existing data, can handle missing data, and expert knowledge can be included;
- Useful in a participatory approach with stakeholders;
- Naturally an integrative/holistic approach;
- Spatially-explicit where required;
- Covers a wide range of ES;
- Trade-offs can be evaluated in terms of expected utilities of alternative decisions;
- Temporal capability through dynamic BBNs;
- Naturally set up for use in scenario analysis;
- Uncertainty can be managed;
- Can be constructed incrementally;
- Easily updated with new data as it becomes available;

- Easy to deploy a model on a website to enable stakeholder interactions with the model, also useful during model construction.

2.3.5 Constraints and limitations

- The detail within a BBN is restricted by the use of classes or states to record information;
- Continuous variables must be discretised when BBNs are used with utility nodes for decision support; this discretisation may lead to some information loss / loss of resolution;
- Uncertainty is defined by the chosen spatial and temporal scale, the complexity of the causal structure of the network and the resolution/discretisation in the model; experience is required in finding the right balance between these sources of uncertainty, given the purpose of the BBN.

2.3.6 Does the method address uncertainty?

All inputs and outputs in a BBN have an associated uncertainty which is propagated throughout the network using Bayesian conditional probabilities.

2.3.7 Steps required to apply the method within a case study

There are three generic steps in setting up a BBN: (i) identify the structure (nodes and links); (ii) parameterise the structure (using conditional probability tables (CPTs), equations, and/or learning from data cases); and (iii) run options and scenarios including tests on the structure, sensitivity analyses, etc. These three steps are interspersed with a number of stakeholder consultations, as illustrated by the flow diagram shown in Figure 2.3.2. One advantage of using a BBN is that it can be set up to allow stakeholder consultations to interact with the program, so options suggested at these meetings can be explored in real time and stakeholders can engage fully with the development of the structure. The BBN could be embedded within a GIS but the process of construction and testing remains the same.

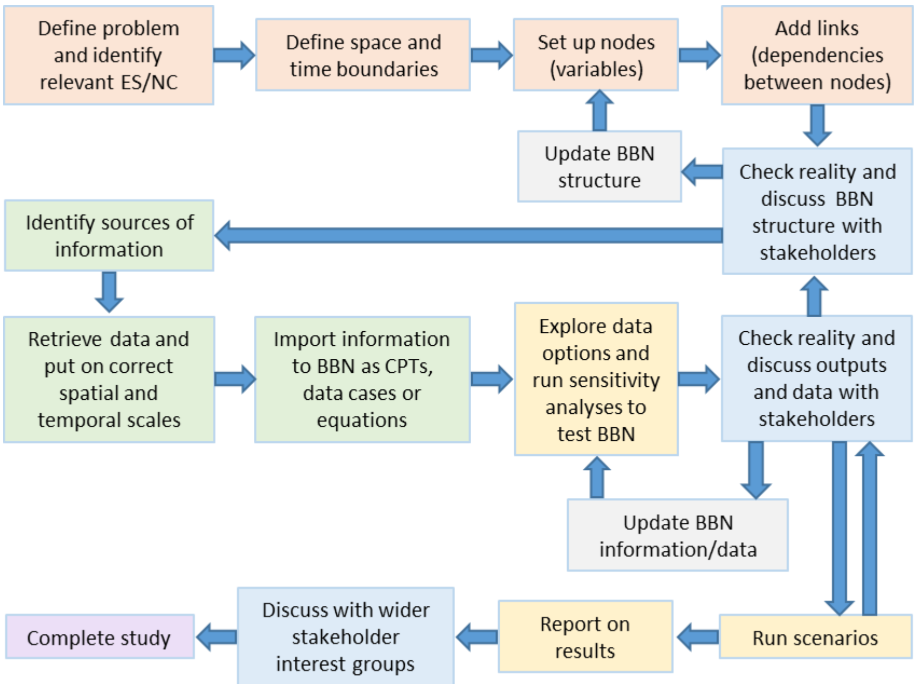

Figure 2.3.2: Flow diagram showing the steps required to develop and apply a BBN.

2.3.8 Illustration of practical applications of the method using the OpenNESS case studies

There are 15 OpenNESS case studies which chose to use a BBN (Table 2.3.1). Of these, most are still in progress at the time of writing.

Table 2.3.1: An overview of OpenNESS case studies applying BBNs.

	Case study		Status	Spatial extent
1	Sustainable urban planning	FI	+	City
2	Landscape-ecological planning in urban and peri-urban areas	SK	*	City and surrounding area
3	Urban green space plans in and around Oslo	NO	+	City focusing on individual trees
4	Urban planning in Vitoria-Gasteiz	ES	*	Wetland restoration and their contribution to flood risk reduction
5	Regional and national forest management planning	F	+	Region (GIS polygon)
6	Regional and national forest management planning	FI	+	National
7	Forest management in Carpathian Mountains	RO	*	Region
8	Bioenergy production in forest and farmland	D	+	Region
9	Cairngorm National Park management	UK	+	Catchment
13	Landscape and nature management in an intensively-farmed area in Belgium (De Cirkel)	BE	+	Region
16	Restoration of water resources in Loch Leven	UK	+	Water body (Loch)
17	Adaptive management plan for Lower Danube River	RO	*	Region
18	Integration of ES in the planning of a flood control area in Belgium (Stevoort)	BE	+	Region
24	Sustainable land management in Mau Region	KE	*	Region
25	Sustainable forestry in Tierra del Fuego, southern Patagonia	AR/CL	+	Distribution range of ñire forest (stand/paddock level)

+ Work ongoing. * Work completed.

One of the case studies has combined BBNs with STMs (Tierra del Fuego) and the two Romanian case studies are also developing the use of STMs alongside BBNs. The forest example from Patagonia is described in the STM section of this deliverable (Section 2.4). Illustrations of different BBNs from three other OpenNESS case studies are given in this section.

Loch Leven, Scotland (case study 16)

From the BBN perspective, the Loch Leven case study illustrates a simple development of a dynamic BBN with a good example of including a functioning BBN on a website and displaying outputs as a map (see http://openness.hugin.com/caseStudies/LochLeven_Habitat). The static BBN (Figure 2.3.3) links the driver

(Habitat Quality) to the delivery of a recreational ES, measured by the proxy Boat Effort, during a single year. This is changed to a dynamic BBN, with an annual time step running from 1987 to 2027, by introducing transition probabilities specifying how these drivers change from one time step to the next (Figure 2.3.4). The assumptions are made that (i) these transition probabilities do not change over the time span of the study, and that (ii) throughout the series the next time step will always depend on the current one but there is no extra information needed from previous time steps.

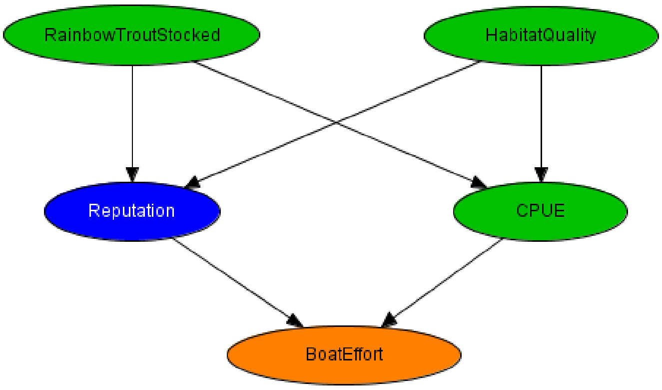

Figure 2.3.3: Static BBN developed for the Loch Leven case study for recreational ES.

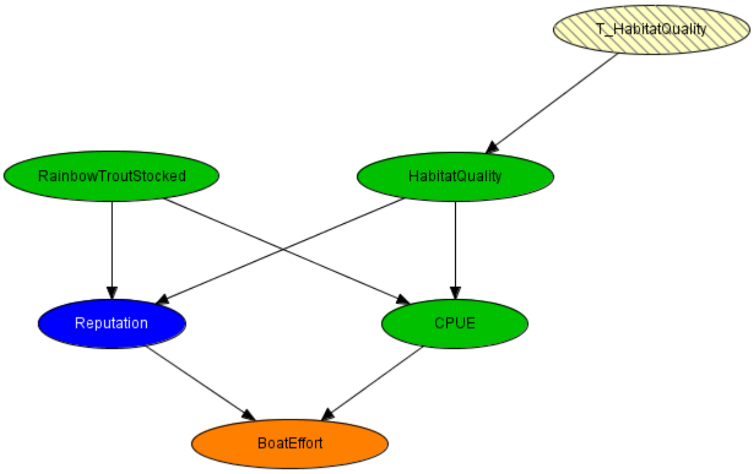

Figure 2.3.4: Dynamic BBN developed for the Loch Leven case study for recreational ES.

Using the website (see partial screenshot in Figure 2.3.5), the user can select specific states of variables on the screen and see the effect of their choice in current and subsequent years. The map display uses a combination of colour and intensity to display the most probable state for the selected node at different times. The current website example is only a demonstration of the potential use of dynamic Bayesian Networks for modelling ES.

The structure of the static BBN was established based on the availability of historical data and expert knowledge. The historical data used to construct the model covered the period 1972 to 2014. The data contained observations (with missing values) on Habitat quality, CPUE, Boat effort and whether or not Rainbow trout was stocked. There was no historical data on reputation. Based on an analysis of the data a correlation between Habitat quality in one year and Habitat quality in the previous year was identified as significant. Therefore, the static BBN was translated into a dynamic Bayesian network by creating a temporal clone of the Habitat quality variable and adding a link from the temporal clone to Habitat quality. For the parameterisation of the dynamic Bayesian network, the conditional probability distribution of Reputation was assessed based on expert knowledge and the parameters of the remaining conditional probability distributions were subsequently estimated from the historical data.

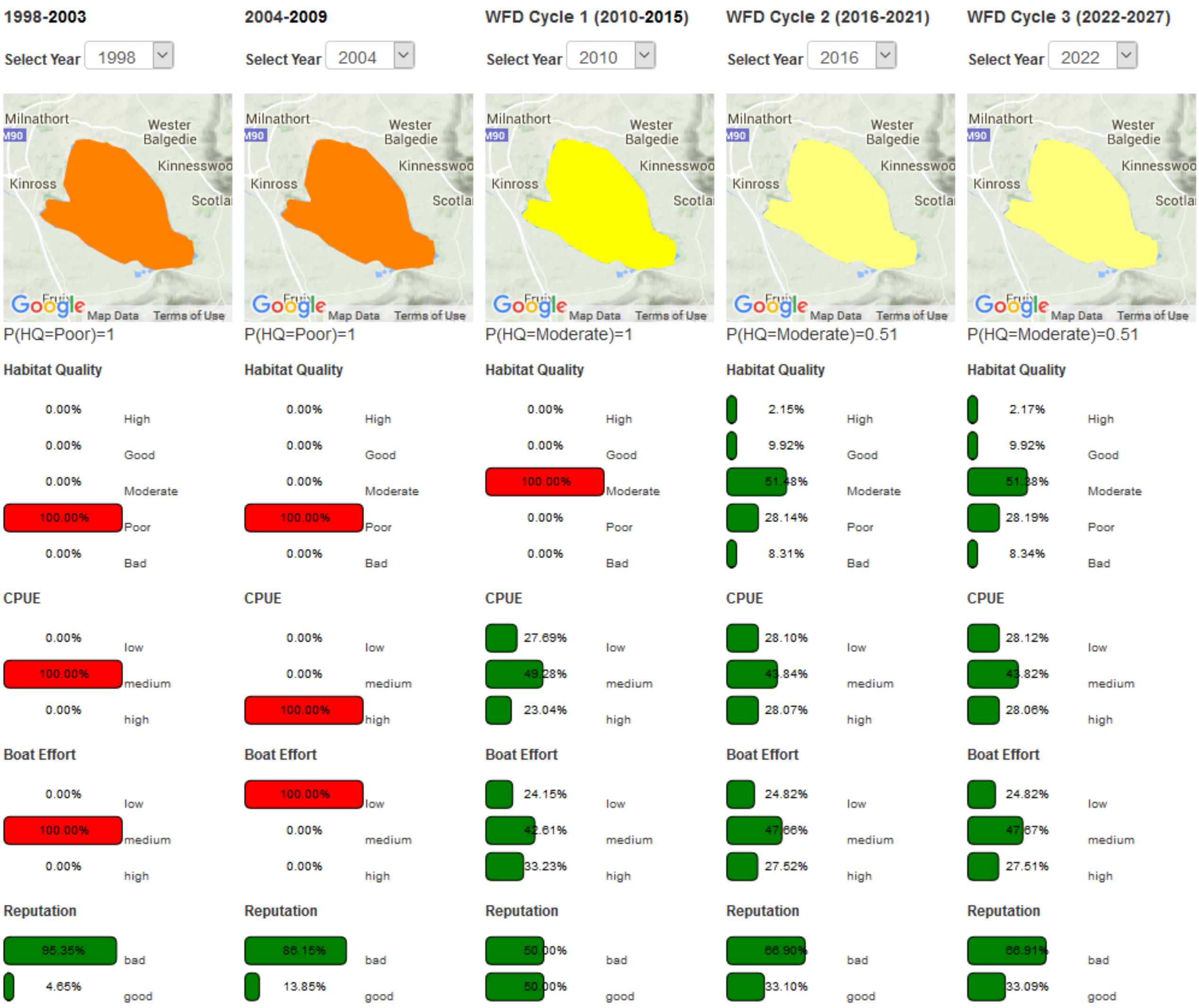

Figure2.3.5: Screenshot of the website interface to the Loch Leven BBN.

Vercors Mountain Range, France (case study 5)

Within the French site in the Vercors Mountain Range (case study 5), sub-project 4 looks at the trade-offs between forest productivity and biodiversity protection. Different land use planning strategies are investigated to identify which one provides the best compromise between biodiversity conservation and development activities, such as timber production. Data on the current situation is combined within a BBN to generate suitability indices for production and conservation on a particular parcel of land, and these are combined into an overall index to identify the management options. The input information is spatially referenced, so the BBN is embedded with a GIS system, and it could be developed as a dynamic BBN if future interest is in mapping the effect of policy scenarios on the changing landscape structure over time.

Oslo, Norway (case study 3)

The work on the urban green space plans in and around Oslo (case study 3) includes the development of a BBN to establish the ES liability value of city trees. Liability value is assessed by municipalities in cases where city trees are damaged or killed, for example during construction works. Oslo Municipality's Urban Environment Agency has adopted the approach and used it in a number of cases of tree damage to assess the fine to be paid by responsible parties. With the current state of knowledge in Oslo and in a rapid assessment, the assignment of the relative importance of trees for individual ES has to be based on expert judgement. An alternative is to calculate the compensation value of city trees based on assessing the relative importance of individual city trees with the so-called 'VAT03' procedure, developed for Denmark by Randrup et al. (2003) as a 'model for plant appraisal'.

The BBN is used to assess the probability distribution of environmental value summed over all registered individual city trees in Oslo. It is built in stages, with an initial implementation based on equations from the Danish model (nodes in green) to arrive at a compensation value for an individual tree, and then with the addition of data from a tree register to estimate the total expected compensation value across the city. The next stage addressed legal issues and added nodes to include amenity value, leading to the BBN shown in Figure 2.3.6.

Further work will include adjustments for property rights, differential values for individual trees in stands, and inclusion of regulating services (e.g. run-off regulation and habitat support) delivered by the urban trees.

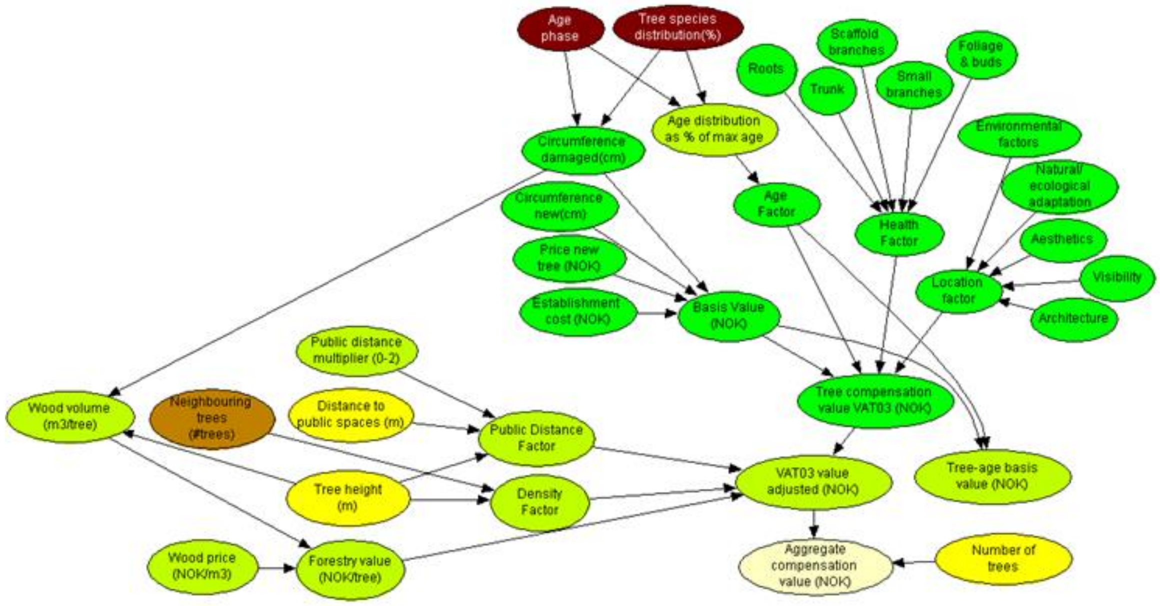

Figure 2.3.6: BBN to estimate the ES liability value of trees in Oslo.

2.3.9 Further reading

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2.4 State and Transition Models

Graciela M. Rusch, Dardo López, Verónica Rusch, Pablo Peri, Andrea Goijman, Laurence Carvalho & Anders L. Madsen

2.4.1 Introduction to method/model

State-and-transition models (STMs) are conceptual models of ecosystem dynamics after disturbances based on alternate state theory (Kachergis et al. 2011). In contrast to succession theory, which predicts that ecosystems recover from disturbances and return to a reference (undisturbed) state, alternate state theory maintains that disturbances may trigger a regime shift in critical processes (e.g. population recruitment, nutrient cycling) (Westoby et al. 1989) that will maintain the ecosystem in a state that differs from the reference state. The new state has different structural properties (e.g. functional diversity, species composition and dominance) from the reference state. The disturbances that trigger these changes are natural factors (e.g. droughts, windfalls, fire), management (e.g. clear-cutting, grazing by domestic animals), and the interactions among them; and the shifts in ecosystem condition that they trigger are irreversible in the absence of specific interventions. STMs acknowledge non-linear responses of ecosystem properties to human interventions; alternate states represent abrupt changes in ecological properties (Appendix STM A).

Given the magnitude of human disturbances on ecosystems (http://www.anthropocene.info/en/anthropocene) and how these are linked to ecosystem condition, a model of ecosystem responses to these factors can be very useful to guide the management of ecosystems and of the goods and services that they provide. STMs are used in this context: they have been increasingly adopted to represent ecosystem changes that result from management in interaction with natural biotic and abiotic drivers (see recommended reading). In OpenNESS, we use the framework as a tool to operationalise, gain a common understanding of, and communicate the importance of ecological functions and processes that underpin the provision of ES in a particular ecosystem.

STMs combine the representation of alternate states and the factors that drive the transitions among states with tables of qualitative descriptions of the states (e.g. Tables B1 and B2, Appendix STM B). The benefits of STMs are that they are diagrammatic, low cost, flexible and suit participatory modelling (Nicholson & Flores 2011). Participatory modelling can bring together diverse knowledge holders, build shared understanding about complex systems and create useful models to understand the system of interest (Knapp et al. 2011). When implemented as Bayesian Belief Networks (Section 2.3), they can be a powerful tool to communicate uncertainty about state categorisation and of the factors that trigger transitions between states.

Keywords: Ecological function, ecosystem condition, ecosystem dynamics, ecosystem management, thresholds, non-linear response, sustainability.

2.4.2 Why would I use this method/model?

STMs provide the opportunity to represent ecosystems and the provision of ES as process-based and dynamic models, making explicit the critical ecological functions underpinning the provision of ES, and the drivers that affect them. Hence, they complement frequently used models of ES provision that are based on spreadsheet/GIS approaches of spatial indicators (i.e. scoring of land cover/land use typologies and landscape elements; Section 2.1), by offering a mechanistic model of ecosystem condition as a function of ecosystem management. However, STMs can be spatially-explicit (Bestelmeyer et al. 2009) and be used for land and territorial planning, through mapping of ecosystem states.

Scale of the model

The ecosystems that are modelled with STMs occur under specific physical conditions (i.e. a forest under certain soil and climate characteristics). Alternate states are the result of management (i.e. grazing, wood extraction, tree species planted), of natural factors (droughts, floods, wind) and of their interactions. Hence, STMs are suitable to model ES at the local scale (e.g. farm level) and at regional scales, covering areas with the same soil and climatic conditions. For example, one of the STM applications in OpenNESS modelled the *Nothofagus antarctica* (Ñire) forest occurring in northern Patagonia.

STMs are also applicable to other systems that present threshold responses (see Section 2.4.8). In particular, the diagrammatic visualisation in STMs helps to further the understanding of land managers and supports their participation in the development of the model (Nicholson & Flores 2011).

Decision objectives

STMs are models of ecosystem dynamics, and therefore appropriate to model the consequences of management decisions and other actions on ecosystem condition and on the level of ES provision. By modelling the biophysical components of the cascade model, STMs are suitable for operationalising the 'cascade model cycle', making explicit the consequences of decisions about ES delivery on the capacity to sustain multiple ES provision. STMs can be used in the context of adaptive management (Rumpff et al. 2011), to maintain the provision of ES within sustainable ranges (avoiding degradation thresholds), and to evaluate the consequences of actions (management and policy) on multiple ES, including the analysis of trade-offs among ES and cost-benefit analysis. In OpenNESS we explicitly use STMs to address decision-making questions related to forest and freshwater system dynamics and the impacts of these decisions on levels of ES provision.

2.4.3 Requirements

Requirements		Comments
Data	☑ Data is available ☐ Need to collect some new data ☐ Need to collect lots of new data	STMs are built using different kinds of knowledge sources, i.e. historical maps and remote sensing data, time series/monitoring data, field measurements and ground-truthing, experiments, expert and practitioner's knowledge (Bestelmeyer et al. 2010).
Type of data	☑ Qualitative ☑ Quantitative	Both
Expertise and production of knowledge	☑ Work with researchers within your own field ☐ Work with researchers from other fields ☑ Work with non-academic stakeholders	STMs are used to capture all kinds and sources of knowledge that can help understand ecosystem dynamics.

Requirements		Comments
Software	☑ Freely available ☑ Software licence required ☐ Advanced software knowledge required	There is no need for any software to build an STM. But, if implemented as a Bayesian Belief Network (BBN), the model will require the corresponding licence.
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	STMs are generally built with the intention of putting together all existing knowledge about a system one is familiar with. In this sense, time resources required can be < 1 year, but this assumes that most of the data and information are assembled in advance. Modelling of ES in STMs (linked to state variables) requires additional data such as primary productivity, tree growth, meat production, recreational value, and information about other cultural services.
Economic resources	☐ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	Between 6-12 months depending on the level of information available and the kind of analysis to be performed.
Other requirements	If implemented as a BBN (as has been the case in the OpenNESS studies), it requires knowledge about BBN modelling, software, and licences.	

2.4.4 Advantages

- Easy to use: The graphical approach, the independence from any pre-defined functional relationships and the possibility of including different sources of knowledge makes STMs a very flexible and easy to use approach.
- STMs are increasingly being applied as an approach to guide the management of ecosystems and their ES, including to assess the risk of degradation of ecosystem condition; to take proactive measures to avoid degradation; to identify specific intervention strategies and promote desirable transitions based on ecological knowledge; and to set restoration targets (Bestelmeyer et al. 2010).
- In the context of ES assessments and modelling, STMs provide a new way of describing the underlying functions that support ES provision. It is a process-based approach to the management of ES, in which management interventions are drivers of ecosystem condition and ES provision levels.
- STMs draw on existing data from various sources and are suitable for both participatory knowledge integration and communication.
- States can be mapped, if suitable spatial data are available.
- STMs can be used in scenario analysis and are especially useful to inform adaptive management (Rumpff et al. 2011).
- STMs have an integrative approach of ecosystem functioning in response to management.
- STMs are very suited for implementation as a BBN. In these cases, ecosystem processes and management factors are modelled in a decision-support context, taking into consideration uncertainty (Bashari et al. 2009, Nicholson & Flores 2011).

2.4.5 Constraints and limitations

- They are specific to an ecological site, so extrapolation to other conditions is limited, but knowledge on similar or comparable sites may be used to complete missing information (Bestelmeyer et al. 2010).
- The identification of thresholds and alternative states is sometimes management driven, with limited correspondence with ecological processes and real ecological thresholds. The thresholds may then be misleading. However, the models must not be understood as static, but rather as representing the best ecological knowledge about a system at a particular time, which should be tested and updated as more knowledge is generated.
- Ecological thresholds can be triggered by interacting drivers at various spatial scales (Peters et al. 2004). These may be difficult to capture without appropriate data and analysis, and/or with other knowledge based on long-term experience (Knapp et al. 2011). Also in this case, STMs must be seen as a representation of the existing knowledge about the system that needs to be open to updates as new knowledge is available.
- The degree of uncertainty about states and thresholds is often not made explicit, although this is very much recommended. Recent implementation of STMs with BBNs provides a promising alternative to overcome this problem.
- STMs may be more demanding than other forms of ES mapping, but the level of demand depends on the ecological knowledge and long-term experience about the case study.
- If implemented as a BBN, the level of model complexity needs to be evaluated prior to building the model (Nicholson & Flores 2011). There are different options to overcome a potential model complexity challenge.

2.4.6 Does the method address uncertainty?

STMs can be implemented as BBNs to explicitly model uncertainty. This refers specifically to the probability of the system being in a particular state as a function of the initial condition and the different levels of the factors (natural and management) that drive change (Rumpff et al. 2011). BBNs provide a powerful combination of predictive, diagnostic and explanatory reasoning (Nicholson & Flores 2011). STMs can be the basis for an ES cascade model if implemented as a BBN.

BBN - STMs have been modelled in different ways. For instance, based on participatory modelling, Bashari et al. (2009) characterised the states of a rangeland in Queensland, Australia, derived from grazing pressure, fire and climate using the BBN framework in Figure 2.4.1. The catalogue of states, transitions and the factors affecting the transitions are shown in Tables 2.4.1 and 2.4.2.

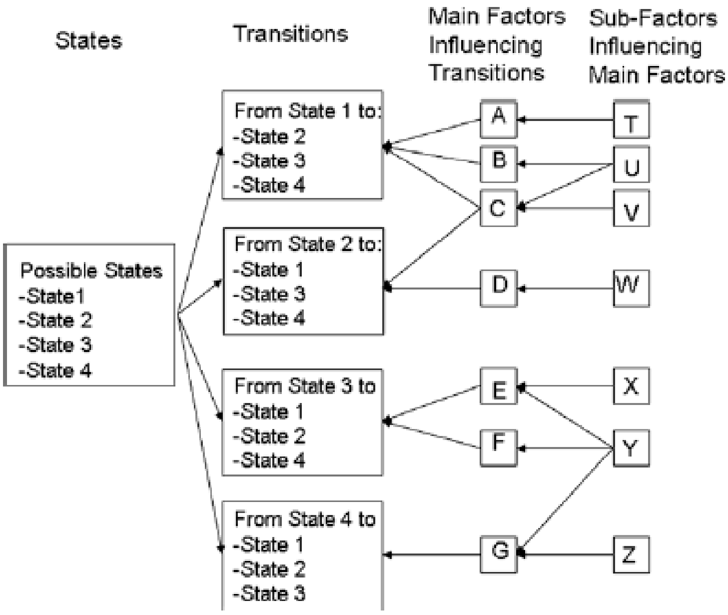


Figure 2.4.1: Framework used to construct a directed acyclic graph from a state and transition model. Source: Bashari et al. (2009).

Table 2.4.1: Catalogue of vegetation states for cleared Ironbark-spotted gum woodland in southeast Queensland, Australia. Source Bashari et al. (2009).

State number	State description	Dominant species composition
I	Palatable tall tussock grasses	*Heteropogon contortus* *Cymbopogon refractus* *Chloris gayana* *Panicum maximum* *Themeda triandra*
II	Unpalatable tall tussock grasses	*Aristida* sp. *Bothriochloa decipiens* *Melinis repens* *Sporobolus creber*
III	Short sward and sparse tall grasses	*Eragrostis sororia* *Eremochloa bimaculata* Tall tussock grasses
IV	Short sward	*Eragrostis sororia* *Fimbristylis dichotoma* *Eremochloa bimaculata*
V	Lawn	*Cynodon dactylon* *Digitaria* sp.

Table 2.4.2: Catalogue of vegetation transitions for cleared Ironbark-spotted gum woodland in south-east Queensland, Australia. Source: Bashari et al. (2009).

Transition name	Main causes	Probability	Time frame (years)
I, II	Selective grazing (high), grazing pressure (low)	High	2–5
I, III	Selective grazing (high), grazing pressure (moderate)	High	2–5
I, IV	Grazing pressure (high)	High	2–5
I, V	Grazing pressure (high), soil nutrient content (above average)	High	2–5
II, I	Grazing pressure(none), selective grazing (none), fire in time period (frequent)	High	2–10
II, III	Grazing pressure(high), selective grazing (low), fire in time period (infrequent)	High	2–5
II, IV	Grazing pressure (high), fire in time period (frequent)	High	2–5
II, V	Grazing pressure (high), soil nutrient content (above average)	High	2–5
III, I	Grazing pressure (none), selective grazing (none), good season (frequent)	High	2–5
III, II	Selective grazing (moderate), grazing pressure (moderate), good seasons (frequent)	High	2–5
III, IV	Grazing pressure (high), selective grazing (none), good season (infrequent)	High	2–5
IV, I	Grazing pressure (none), good seasons (frequent)	Low	1–10
IV, II	Grazing pressure (low), good seasons (frequent)	Low	1–10
IV, III	Good season (frequent), grazing pressure (none)	Moderate	>5
IV, V	Soil nutrient content (above average), grazing pressure (high)	High	2–5
V, I	Grazing pressure (none), soil nutrition (average), good season (frequent)	Low	>5
V, II	Grazing pressure (none), soil nutrition (average), good season (frequent)	Low	>5

Nicholson & Flores (2011) provide two different BBN models to represent the STM in Bashari et al. (2009). First, they show the implementation in a variant of Bayesian networks – so-called dynamic Bayesian networks (DBNs) – that allow explicit modelling of changes over time. In a second model, they propose a combination of STMs and DBNs. They compare the different BBN implementations of STMs, with a focus on model complexity analysis. They show that the complexity of each model depends on the inherent structure in the problem being modelled, and conclude that for the models to be tractable, the number of transitions from each state needs to be limited, and only influenced by a small number of causal factors. They recommend an assessment of model complexity prior to any detailed modelling.

2.4.7 Steps required to apply the method within a case study

Building of a STM requires the identification of a reference state for a particular ecological site or ecosystem, and of the alternative states that result as a response to human interventions in interaction with the physical environment (climate, soil, nutrient contents, etc). The reference and alternative states need to be described in terms of a series of state variables that characterise the state's ecological structures and functions (e.g. tree cover, species diversity, species composition, primary productivity, nutrient cycling). Then the drivers, natural factors and management interventions that affect state variables and that trigger change (i.e. transitions between states) have to be identified. A next step is to link the drivers of change with the states (as in Bashari et al. 2009) or with state variables (as in Rumpff et al. 2011) and to produce a catalogue of transitions. The model is revised and refined through literature searches and consultations. If the STM is implemented as a BBN, the conditional probability tables in the model have to be elicited.

In OpenNESS, we aimed to link state variables, a representation of ecosystem condition, with levels of ES provision. In this situation, two further steps are required once the STM is built: (i) to identify the important ES provided by the system, and (ii) to link levels of ES provision to levels in the state variables. In this way, the biophysical structures and functions that support ES provision are made explicit. The steps are summarised in Figure 2.4.2 and described below:

- Step 1: Identify reference and alternate system states. This is based on specific structural characteristics, that can be recognised in the field or from data and that derive from use.

Information can be derived from historical maps, field experience, scientific data, and/or local knowledge.

- Step 2: Prepare a catalogue of state variables. This step consists of identifying the structural and functional variables that characterise the states. The list is built from literature reviews, data from monitoring programs, and general knowledge about the system.
- Step 3: Build a graphical model of the states and transitions among them, including the levels of the variables associated with the transition. More than one model can be built if there are different beliefs about state transitions and underlying drivers of change.
- Step 4: Prepare a catalogue of factors that determine transitions, and describe them. In Rumpff et al. (2011), for instance, the factors are classified as 'independent environmental variables', 'processes' and (short time scope) 'management actions'. Identify time periods in which responses are expected to manifest.
- Step 5: Incorporate transition factors. Link transition factors to changes in states or state variables.
- Step 6: Refine the model iteratively.
- Step 7: Identify important ES provided by the system. Prepare a catalogue of ES and ES benefits.
- Step 8: Incorporate ES and benefits. Link levels of ES provision and benefits to states or state variables.
- Step 9: If implemented as a BBN, establish conditional probability tables.

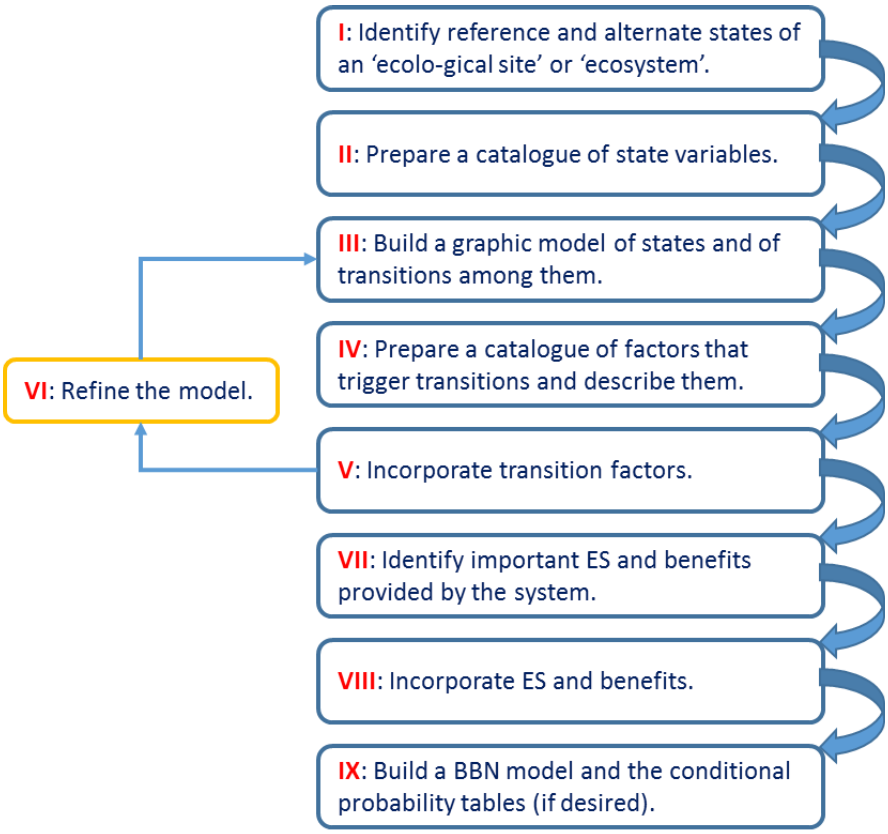


Figure 2.4.2: Steps required to build a STM, linked to ES and implemented as a BBN. Based on Rumpff et al. (2011).

2.4.8 Illustration of practical applications of the method using the OpenNESS case studies

There are three OpenNESS case studies which selected to use STMs (Table 2.4.3). Of these, only case study 7 in the Carpathians is still in progress at the time of writing.

Table 2.4.3: An overview of OpenNESS case studies applying STMs.

Case #	Case name	Spatial resolution	Spatial extent
07	Forest Management in the Carpathians, Romania.	Stand level	In progress
25	Agroforestry on native ñire forest in northern Patagonia	Stand /paddock level	Distribution range of ñire forest in northern Patagonia
25	Agroforestry on native ñire forest in southern Patagonia	Stand /paddock level	Distribution range of ñire forest in southern Patagonia

STMs have been developed for two agroforestry systems based on native forest of *Nothofagus antarctica (Ñire)*, in southern and northern Patagonia, Argentina, respectively (Case study 25). The ecological conditions of the southern and northern regions differ, as does the management, the kind of exploitation and the history of use. The knowledge base in each case relies on different sources. The reference states in each case are stands of native Ñire forest that occur in protected areas and in other areas with low human impact. The models are valid for the distribution ranges of Ñire in Patagonia, along the Andes mountain range in the provinces of Santa Cruz and southern Chubut (southern Ñire forest) and of northern Chubut, Río Negro and Neuquén (northern Ñire forest). The aim of the models is to guide management decisions based on the best ecological knowledge about the impact of management practices on these forest systems, and to maintain a use level that avoids thresholds that lead to the degradation of the system. ES are incorporated in the model to reveal how provisioning, regulating and cultural services are linked to ecosystem condition, and how they change when thresholds are exceeded.

Further information on the STM developed for the northern native Ñire forest in Patagonia is given in this section to illustrate the application of the method.

Agroforestry management of native Nothofagus antarctica forest in northern Patagonia (case study 25)

<u>Problem statement</u>

Management decisions that affect ecological functions underpinning ES provision in forests are often unsupported by knowledge about their long-term consequences. In 2007, a new law was enacted with the aim of protecting the environmental services provided by native forest in Argentina (Ley 26331 de Presupuestos Mínimos de Protección Ambiental de los Bosques Nativos). Tied to the Act, a fund for payments for environmental services (PES) exists. At present, there are no instruments that have been effective in implementing the Act.

The STM for this case study was proposed as a methodology that can guide decision-making on the conservation and sustainable use of Ñire forests, taking into account the value of ES. The approach makes explicit the ecological processes of importance for ES supply and the different valuations of ES benefits by the private and public sectors. Hence, it allows analysis and visualisation of the main factors that sustain ES, and is a first step towards implementing adaptive management practices.

Methods

The global model is based on three methodological tools: (i) STMs and determination of transition probabilities between states; (ii) the definition of ES that are linked to the STM, and a quantitative assessment of their value; and (iii) a BBN (with corresponding conditional probability tables) to model the system as a decision support tool, taking into account uncertainty (Barton et al. 2008; 2012). The STM was developed based on empirical data, literature review, local experience, and an expert workshop. The CICES classification (Haines-Young et al. 2013) was used to identify the main ES provided by the Ñire forest, and the benefits were quantified based on published data and models (Table 2.4.4). The main private benefits were considered to be income from agroforestry production, professional identity of being a 'cattle rancher', and sense of place. The most important public benefits were derived from national legislation and other documentation in the public conservation debate. They included biodiversity conservation (habitat for native species and forest species gene pool), maintenance of water quality (Act 26331 that regulates forest management - Ministry of Environment), and livestock production (based on 'Principles and guidelines for the management of forest for integrated livestock production'- Ministry of Agriculture).

Table 2.4.4: Final ES and benefits derived from the northern Ñire forest and an agroforestry system based on native forest in Patagonia. 'Monetary value' indicates whether ES are sources of income. 'State variables in the STM' indicates the variables included in the STM model that characterise the states. Levels of state variables are indicators of ecosystem condition.

ES type	Final ES	Benefits	Monetary value	State variables in the STM
PROVISIONING SERVICES				
Nutrition	Grass production (ANPP) (kgDM $ha^{-1}yr^{-1}$)	Income from meat production	yes	Herbaceous cover Cover bamboo cane
	Medicinal plants (nr species with medicinal properties)	Health	no	Species composition
	Edible species (fungi)	Income from edible species - food	yes	Species composition
Materials	Production of poles ($m^3 ha^{-1}yr^{-1}$)	Income from material for fences	yes	Tree basal area (BA)
	Production of fuel wood ($m^3 ha^{-1} yr^{-1}$)	Income from fuel wood - energy	yes	Tree basal area (BA)
	Grass production (ANPP) (kgDM $ha^{-1}yr^{-1}$)	Income from wool production	yes	Herbaceous cover
REGULATION & MAINTENANCE SERVICES				
Mediation of waste, toxics and other nuisances	Mediation by ecosystems. Retention of sediments along water courses	Water free from sediments	no	Shrub cover Tree cover
Mediation of flows	Mass flows. Soil erosion control.	Control of productive capacity	no	Shrub cover Herbaceous cover Tree basal area
Maintenance of physical, chemical, biological conditions.	Habitat provision for ñire forest species	Ecosystem conservation	no	Habitat quality for indicator species
	Maintenance of the gentic pool of native species	Future use of local/specific adaptions	no	(% native species)

CULTURAL SERVICES				
Physical and intellectual interactions with ecosystems and land-/seascapes [environmental settings]	Fodder and fuel wood production – self-sufficiency	Sense of belonging	no	Herbaceous cover Bamboo cane cover Tree basal area
	Grass production (ANPP) (kgDM $ha^{-1}yr^{-1}$)	Identity /livelihood ('to be a rancher')	no	Herbaceous cover Bamboo cane cover
	Landscape (slopes with forest cover, contrasting shapes and colours)	Landscapes valued for their beauty/pristine nature	no	Tree cover
	Space suitable for recreation	Space used for recreation	yes	Tree cover Herbaceous cover

The final STM (Figure 2.4.3) considered private and public benefits, and the alternatives of use were focused on management decisions made by the farmer (private decisions). Knowledge about the decisions taken by the farmer, based on benefits perceived from different ES, are useful to guide suitable instruments to promote the adoption of practices of sustainable forest management.

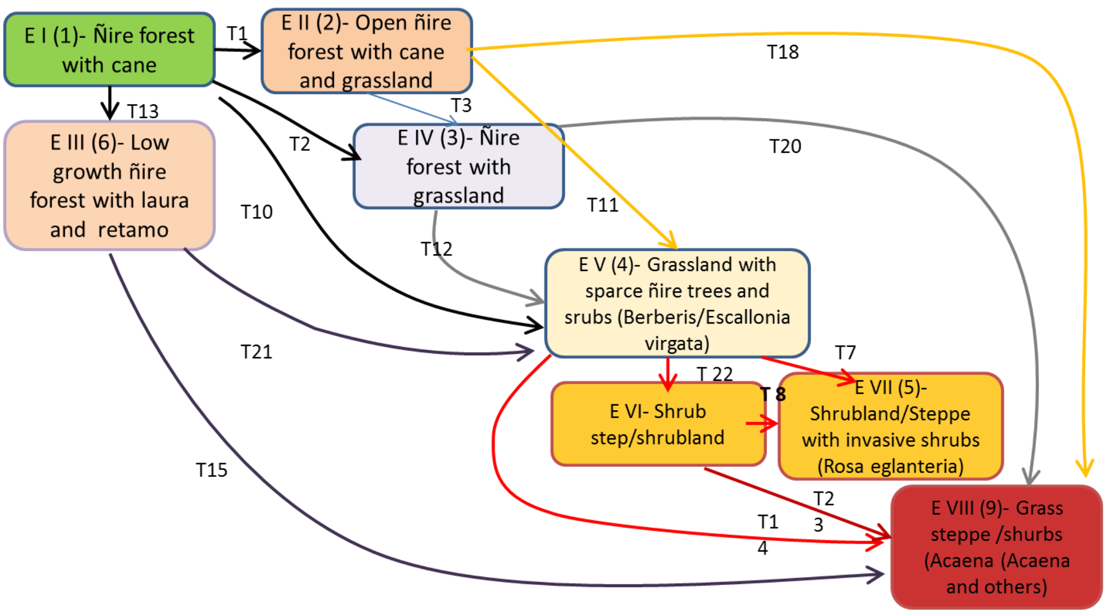
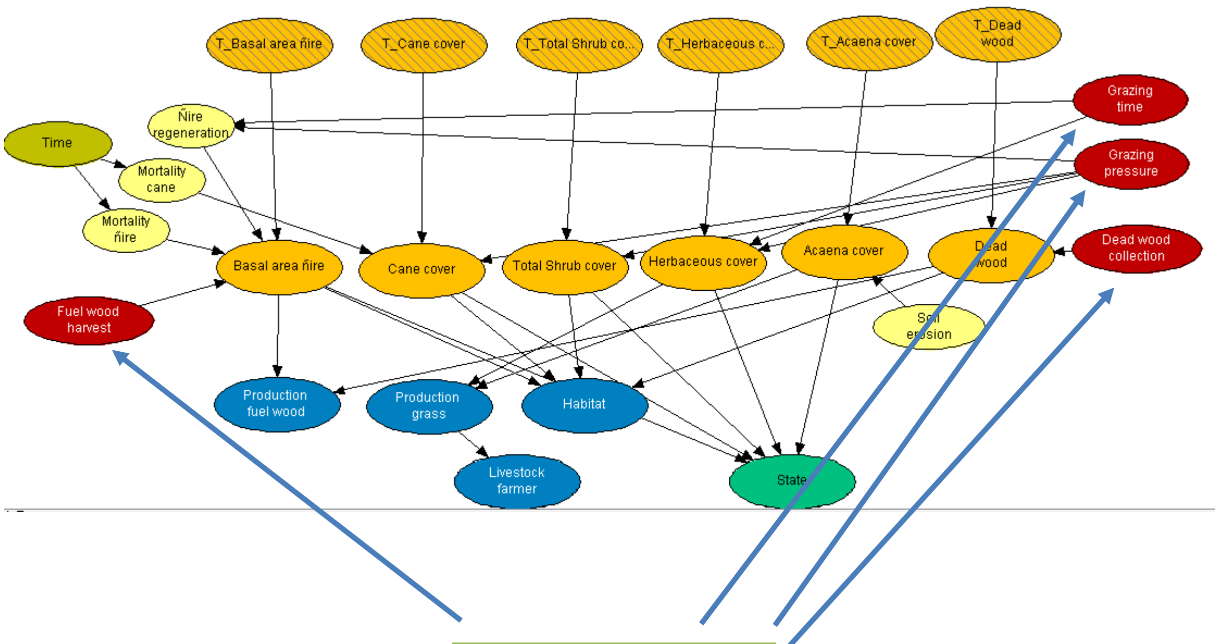


Figure 2.4.3: STM of the northern Ñire forest: E I – E VIII are the states; T 1 – T 22 are the transitions triggered by a combination of factors such as different levels of grazing and logging.

Preliminary results

In the global model (Figure 2.4.4), the STM is linked to ES through the state variables that characterise the different states. These variables are affected by the drivers of change that include management variables (grazing intensity and grazing time, fuelwood extraction, gathering of fallen wood) and natural processes (bamboo cane mortality, tree mortality, tree regeneration), that are in turn modulated by time. The main ES identified for the northern Ñire forest, their association with the state variables in the STM states, and the corresponding benefits (monetary and non-monetary) perceived, are presented in Table 2.4.4. These benefits define the alternatives that a farmer evaluates in his/her decision. The model enables visualisation of the balance between private and public benefits as a function of the farmer's decision and can be revised iteratively, enabling an adjustment of probability tables and/or the inclusion of new variables. Some ES from the Ñire forest that were considered important are not covered by public policies or private agents (e.g. scenic beauty, and the value of recreation and tourism). The approach also enables highlighting of private non-monetary benefits that are generally not considered in the design of PES and that can have impacts on the adoption of practices.

The methodology allows prediction of changes in the provision of important ES as a result of different management and practice decisions taken at the farmer level based on existing knowledge and beliefs. At the same time, it allows assumptions about factors and ecosystem responses to be iteratively revised when new knowledge is gained through, for instance, adaptive management. The tool can contribute to improved communication among actors, since it explicitly takes into account the functioning of the socio-ecological system through representing the relationship between decision-making and the provision of ES.



Private decisions
Logging
Apply to PES scheme
Livestock type
Grazing time
Grazing intensity
Gather fallen wood

Figure 2.4.4: Draft STM of northern Ñire forest/agroforestry implemented as a BBN using HUGIN software. Decisions at the farm level affect state variables and the provision of ES (only some of the ES in Table 2.4.4 are presented in the draft STM). Nodes in orange: state variables; blue: final ES linked to state variables; red: management factors affecting state variables; yellow: ecological processes.

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2.5 QUICKScan

Peter Verweij, Michiel van Eupen, Anouk Cormont, Marta Perez-Soba & Manuel Winograd

2.5.1 Introduction to method/model

QUICKScan is an approach and a toolbox that allows policy and decision-makers to explore options and transparently assess spatial impacts with stakeholders and experts. The easiest way to implement the approach is within a facilitated workshop where the participants obtain a common understanding by jointly building alternative options and linking their collective knowledge to available spatial data to determine the impacts and iterate results.

Conceptual framework

The QUICKScan software and QUICKScan tool (http://QUICKScan.pro) encompasses a modelling environment with functionalities to assess societal and environmental conditions, diagnose patterns and interactions, implement alternative responses and evaluate the impacts of those responses. The QUICKScan modelling environment enables the linkage of GIS data to qualitative and/or quantitative rules and allows the user to identify not only the direct, but also the indirect, impacts of spatial strategies. It enables analyses of causes; the user can dynamically and interactively adapt the strategies and/or rules to reach a desired state. The QUICKScan framework addresses five questions (after Winograd 2007):

1. What aspects are relevant with respect to ecosystems and human well-being?
2. What typical 'pictures' of the past and current condition exist and what are the trends?
3. What elements and interactions are relevant for the persistence of these patterns, trends and impacts?
4. Which strategies and options can be devised to preserve, restore, use, improve, mitigate, or adapt?
5. Which hotspot areas, services or land covers could be identified as targets for policy actions?

General application of QUICKScan

QUICKScan is an empty modelling shell which needs to be filled on a case by case basis with GIS data, qualitative and/or quantitative rules, and map algebra. The tool is not restricted to a specific geographic location or spatial resolution; similar to word processing software (e.g. Microsoft Word) which is not restricted to a specific document (type). The system enables the definition of *'if..then..else'* rules and links those to available data to create derived data. Typically the rules use quantitative classifications or qualitative typologies to help define the situation and options for change (Verweij et al. 2012). Rules may also be linked together to form a chain of rules. Alternative (chains of) rules are used to capture different options. Derived data from alternatives can be aggregated (e.g. by administrative units, or biophysical units such as catchments or climatic zones) to be displayed in tables and charts for overviews (see Figure 2.5.1 and http://quickscan.pro/features.html).

Figure 2.5.1: Collection of screenshots of the QUICKScan tool, showing its project library (1), rule definition (2), combinational workflow (3), and resulting maps and graphs (4).

2.5.2 Why would I use this method/model

The QUICKScan methodology is based on the use of an approach and a software tool that is applied in group processes with policy-makers and experts to develop and explore potential policy options and assess likely impacts of those options (Figure 2.5.2). A typical QUICKScan application is developed in three main steps:

1. Explore data related to the (policy) context: The system is populated with maps and statistics that the participants in a decision meeting find relevant to the policy question. The toolbox enables the data to be stored and described in an organised way, so that it can be viewed and compared in a clear way with users. This is usually done by the facilitators before a group session starts. During the workshop the maps and statistics are viewed and explained.
2. Design options and build workflows: Assess the impact of (jointly) defined policy options by defining *'if… then… else'* expert rules. Expert rules can be quantitative and/or qualitative and are linked together to form a chain of rules. The tool will apply these rules to the maps and statistics creating indicators that show the likely impacts of the policy options.
3. Evaluate and iterate results: The derived data/indicators can be aggregated (e.g. by administrative or biophysical units) and displayed in tables, charts (including spider diagrams to show trade-offs) and maps. The aim is to help the decision-makers and experts compare the impacts of different options, identify hotspots areas or issues and assess the trade-offs or alternatives. Often certain locations in the generated maps represent unexpected or puzzling results. The QUICKScan trace-feature lets the user trace back from the output maps to the applied rules. This is visualised by

displaying the causal relationships between all used rules and GIS data resulting in the map and highlighting the decision path in each of the rules as applied for the location of interest. This helps to either explain the result or allows iterative fine-tuning of the rules. If needed iterations with new rules or for new options and alternatives can then be implemented.

2.5.3 Requirements

Requirements		Comments
Data	☑ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data	The QUICKScan software encompasses a modelling environment that needs to be filled with spatial and/or statistical data during the preparation phase. Depending on the topic case study data is either already available in the QUICKScan tool (e.g. EU level, ES) or it needs to be prepared spcifically for the workshop. The tool is not restricted to a specific geographic location or spatial resolution.
Type of data	☑ Qualitative ☑ Quantitative	Both can be used. Typically the rules use classifications to describe quantitative data and typologies to give qualitative data meaning. Derived data can be aggregated to be displayed in tables and charts for overviews.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	QUICKSCan is (and thus can be) used in all three different mentioned settings, depending on the focus of the workshop. QuickScan is appropriate for targeted users: Multilateral, regional, national and local decision-makers; Multilateral, regional, national and local policy desk officers and project managers; Scientific experts and thematic researchers; NGOs staff, corporates staff, government officers. QuickScan can be targeted for: Participatory settings/workshops; Policy settings/explorations/assessments; Scientific baselines/iterations/validations; Ex-ante/ex-post impact assessments.
Software	☑ Freely available ☑ Software licence required ☐ Advanced software knowledge required	Two versions exist: 1. Community-edition: Light-weight latest version with up to 10 user defined rules. No support provided. 2. Ultimate edition: Full featured, latest stable version with an installation set, a user manual, support and free upgrades for a year. Software licence is required.
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	QUICKScan usually requires some days of data preparation and one or two days for the workshop itself. Usually from start to finish it requires less than a month of lead time.
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	Usually two or three persons are involved in both the preparation phase and the workshop itself, requiring less than one person month in total.
Other requirements		

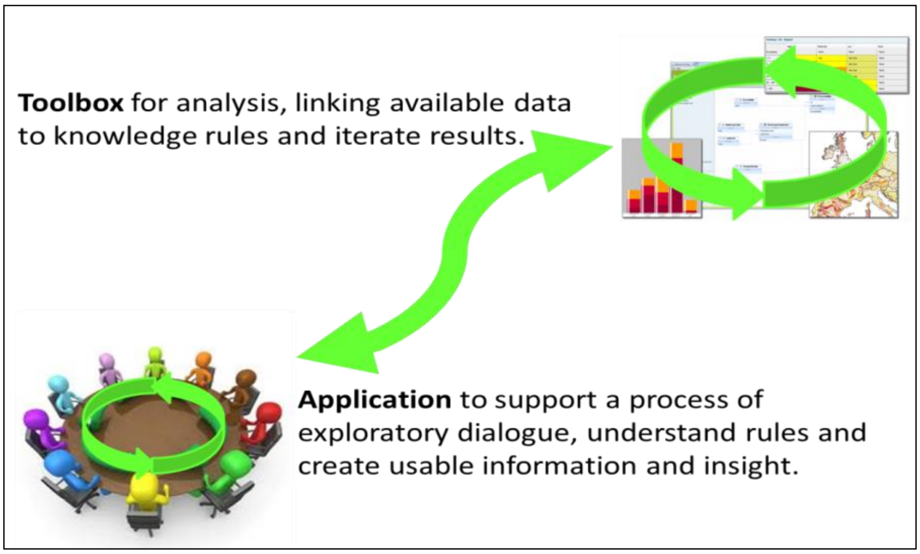

Figure 2.5.2: The use of the QUICKScan toolbox in a participatory impact assessment setting. QUICKScan can be applied to a selected area, to identify which options would be applicable and what would be the costs and benefits, using knowledge rules and calculations in Python[3].

2.5.4 Advantages

- QUICKScan is spatially-explicit.
- It can easily combine and handle a wide variety of different spatial data and knowledge rules.
- It has an open model structure with a direct response to all the implemented expert knowledge rules. This is often highly valued and seen as a possible future advance for more in-depth modelling approaches, e.g. the ease to test and trace back expert knowledge could not be replicated with current known standard GIS software without a lot of extra effort. The transparency of QUICKScan enables the easy transformation of the captured knowledge into other systems if/once this is judged feasible and desirable.
- It allows for the explicit and transparent implementation of all the calculation steps and knowledge rules required for addressing the impact of measures on ES and costs.
- It supports the use of Python for map algebra if this is required. The Python code can potentially be re-used in other programs or modules, if desirable at a later stage.

2.5.5 Constraints and limitations

- Limited to spatially-explicit issues.
- No system dynamics, no feedback loops.
- Currently restricted to use with ArcGIS 10.0.
- It is developed for, and mainly used in, (relatively) short and participatory workshops. However, the tool can be deployed as an additional desktop tool alongside existing GIS software programs.

[3] Python is a, cross-platform, open-source programming language. It is widely used and supported. To learn more about Python, visit python.org. Python is the scripting language of choice for geoprocessing in ArcGIS. http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//002z00000001000000

For many basic GIS functionalities, QUICKScan cannot be compared with the performances of commercially available GIS packages. It is questionable if a (pure) desktop application of QUICKScan is therefore of much added value.

- Defining solid causal relations to express final output indicators, related to the available spatial and temporal data, can be a complex and quite difficult task. Since the focus is often more on developing a proof of concept than to approximate the absolute truth, there are certainly many uncertainties in the finally used knowledge rules. When further implementation is required, a debate is needed as to what extent absolute numbers can be used and when a more relative approach could be sufficient.

2.5.6 Does the method address uncertainty?

Uncertainty can be expressed explicitly within the rules used if needed. Often uncertainty is addressed within a rule showing different options for classification (e.g. the upper and lower sustainability boundaries of an indicator). Where and how this uncertainty is dispersed can then be assess spatially under different alternatives, as well as summarised as the total potential uncertainty in the region of interest.

2.5.7 Steps required to apply the method within a case study

The QUICKScan software encompasses a modelling environment that needs to be filled with spatial and/or statistical data during the preparation phase. The tool is not restricted to a specific geographic location or spatial resolution. Knowledge rules, capturing participant knowledge, are used to combine data and derive indicators. Typically the rules use classifications to describe quantitative data and typologies to give qualitative data meaning. Rules may be linked together to form a chain of rules. Alternative (chains of) rules are used to capture different options. Derived data from alternatives can be aggregated (e.g. by administrative units or biophysical units, such as catchments or climatic zones) to be displayed in tables and charts for overviews.

Figure 2.5.3 shows the different phases which are generally formulated using QUICKScan in a participative setting: (i) scoping; (ii) preparation; (iii) the workshop(s); and (iv) reporting. The scoping in the first phase is intended to identify and formulate key questions together with the stakeholders (Figure 2.5.3). The second phase is needed to prepare the spatial datasets to be used in the workshop. The third phase is the workshop itself which focuses on creating a common understanding about the key questions, their options and alternatives. To ensure good outputs and ease participation in this phase, the chained rules are often first defined in a simplified way, and then refined in iterations based on results and stakeholder needs. New iterations are also often used to incorporate new insight and demands. If needed, a summarising report in the form of a PowerPoint or a Document is produced describing the results from the workshop and the prior phases (Figure 2.5.3).

Below is an example of how an exploratory two day workshop could be organised and carried out:

A) Before the workshop:
- Define the program around a policy question.
- Search, obtain and organise the data needed.

B) At the workshop: example agenda

Day 1 Morning (9:30 - 12:30)

- *Define storylines.*
- *Determine how to measure the impact (key outputs/key indicators).*

Day 1 Afternoon (14:00 - 18:00)

- *Build workflow for policy alternatives*
- *Relate alternatives and key output to data.*

Day 2 Morning (9:30 - 12:00)

- *Present results, discuss and iterate.*
- *Define next steps and needs.*

C) After the workshop:

- Produce the report.

  Send report to stakeholders and iterate if needed to take account of feedback and additional demands.

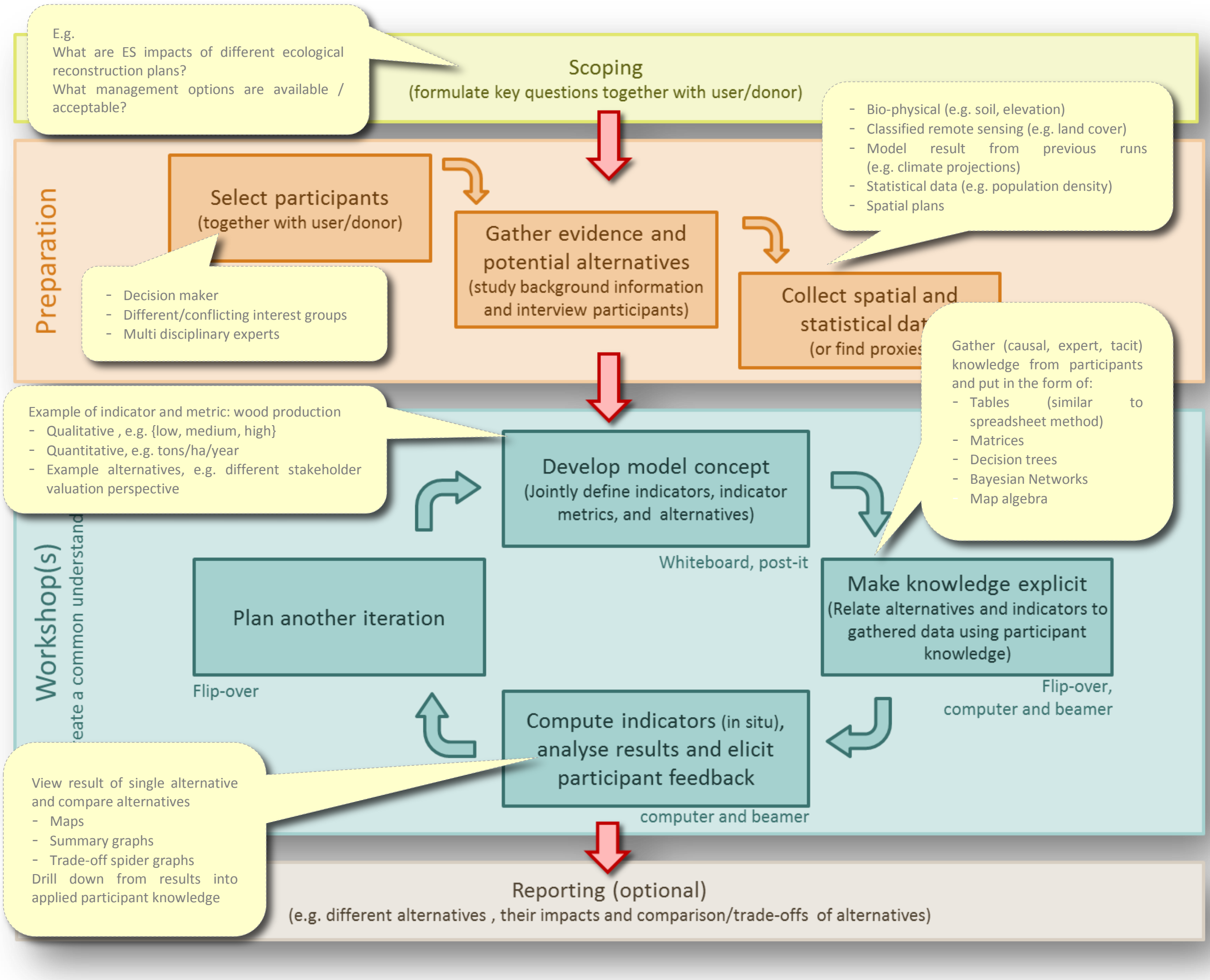

Figure 2.5.3: The different phases in the QUICKScan process.

In summary, it can be said that organising one or more workshops with stakeholders is the essential part of implementing a successful QUICKScan method. Figure 2.5.4 provides a summary of the three elements that are crucial to run a successful QUICKScan workshop: people, process, and technology.

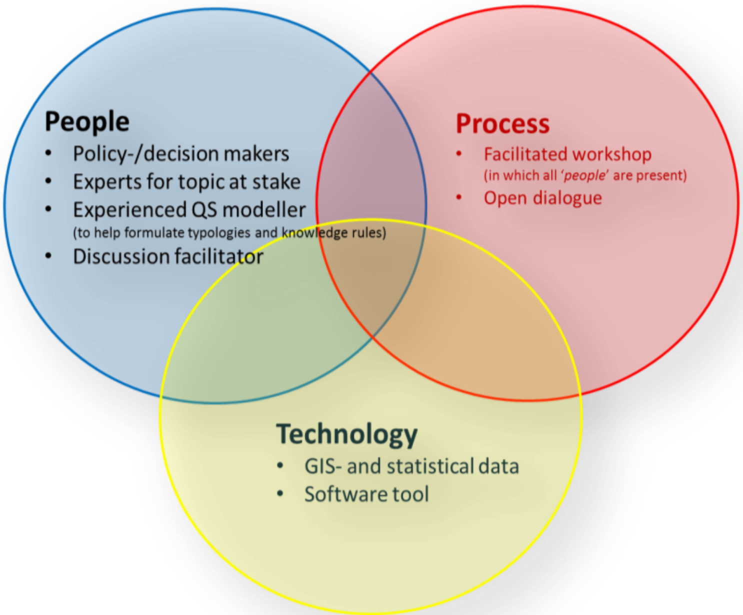

Figure 2.5.4: Overview what is needed to organise a QUICKScan workshop.

2.5.8 Illustration of practical applications of the method using the OpenNESS case studies

There are six OpenNESS case studies which selected to use QUICKScan (Table 2.5.1). Of these, three are still in progress at the time of writing (2, 3 and 27). An overview of the three completed case studies is given in Table 2.5.2.

Table 2.5.1: An overview of OpenNESS case studies applying QUICKScan.

Case #	Case name	Country
02	Landscape-ecological planning in urban and peri-urban areas: Trnava	Slovakia
03	Valuation of urban ES in Oslo: developing a spatially representative blue-green area factor	Norway
09	Cairngorms National Park management	UK
12	Living on the edge in a drying region: Kiskunság	Hungary
17	Adaptive management plan for the Lower Danube River	Romania
27	Sustainable urban planning in the metropolitan region of Barcelona	Spain

Figure 2.5.5 shows the spatial distribution of the case studies which have, or are, applying QUICKScan. Further detail on the practical application of the method is provided for the case study in Hungary (no. 12) and the UK (no. 9).

Table 2.5.1 Short overview of the QUICKScan application in three case studies.

Case Study	Objective	Data	Type	Participants	Setting
Adaptive management plan for the lower Danube river, Romania	What are ES impacts of different ecological reconstruction plans?	10x10 m resolution: land use, flooding regimes, protection status and administrative units	Explorative assessment	Environmental NGO, water manager, municipality official, farmers, fisheries organisation, tourist organisation	1 day workshop with 12 individuals in which ES were identified, prioritised and rules defined for quantifying the value of these ES. Two scenarios were developed and the implications for the ES assessed.
Central area of the Kiskunság National Park, Hungary (40x40km)	Local experts and nature management organisations together (re)thinking ongoing land use developments, developing sustainable land use and water management options, and consequently helping to reveal conflicts over land use change and management.	25x25 m resolution: land cover, topographical wetness, accessibility, elevation, distance from roads, administrative units and topography	Explorative assessment	Forest managers, nature conservation, water authorities and ecologists	1 day workshop in which ES were identified, prioritised and rules defined for quantifying the value of these ES. Relevant services for five different bird groups were prioritised at the local level by evaluating preferences according to the capacity of the pasture landscape to deliver the priority services.
Map current and future ES in Glenlivit, Scotland	What are current priority ES? How will they change under different land use scenarios? What are the trade-offs?	10x10 m resolution: land cover, topographical wetness, accessibility, elevation, distance from rivers, administrative units and topography	Explorative assessment	Nature conservation, tourism, foresters, farmers, sociologist, ecologist, hydrologist, business developer	1 day workshop in which ES were identified, prioritised and rules defined for quantifying the value of these ES. Three scenarios were developed and the implications for the ES assessed.

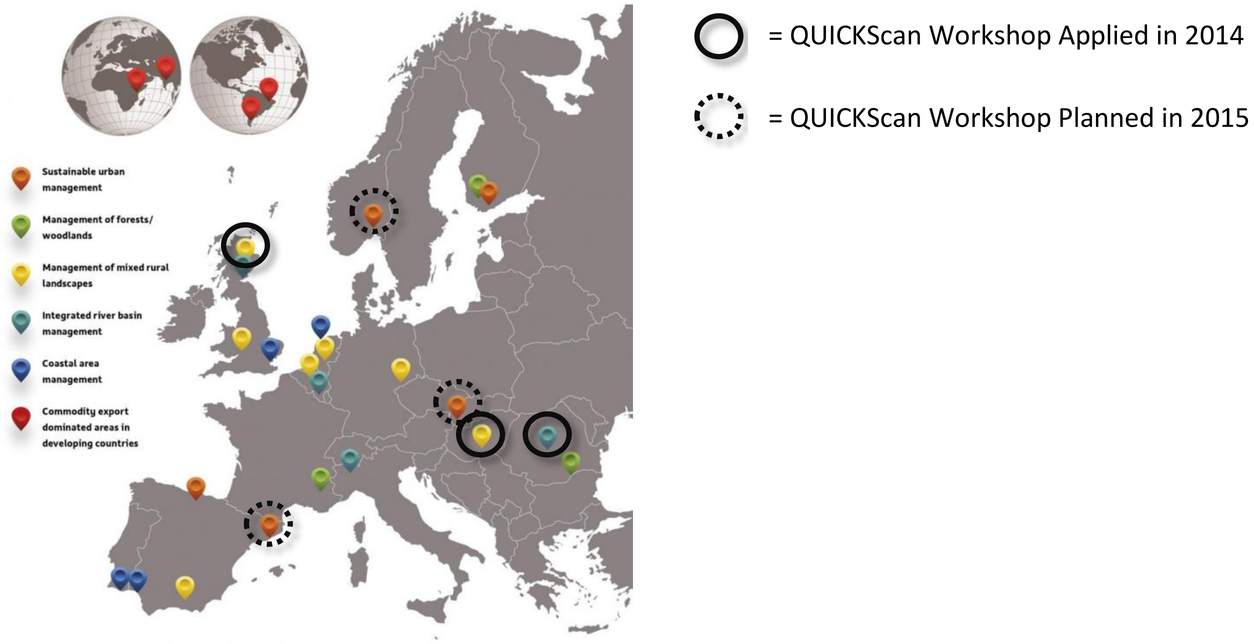

Figure 2.5.5: Application of QUICKScan in the OpenNESS case studies.

Kiskunság region in Central Hungary

Figure 2.5.6 shows an example of typical output of the QUICKScan tool for the Kiskunság region in Central Hungary where options for water management related to ecosystems and their services were evaluated. Three different scenarios were evaluated, showing the effects on indicator species and habitats related to protected regions, policy options and choices for water availability in the region.

Input data of the study area (40x40km) were analysed at a resolution of 25m raster cell size. The datasets considered were:

- CORINE land cover (level 4, 60 classes);
- A digital elevation mode with derived parameters such as topographic wetness;
- A detailed road network;
- Nature protection types (SCI, SPA, N2000, RAMSAR, OKCS);
- A map showing the results of a multi-annual habitat quality inventory.

Maps were combined using sets of expert rules (knowledge matrices, scripts) forming basic capacity indicators per bird group. Final output is a combined habitat capacity index for the three different scenarios. Results were evaluated for both the individual species groups (in e.g. spider diagrams), and the differences for the total index (see Figure 2.5.7)

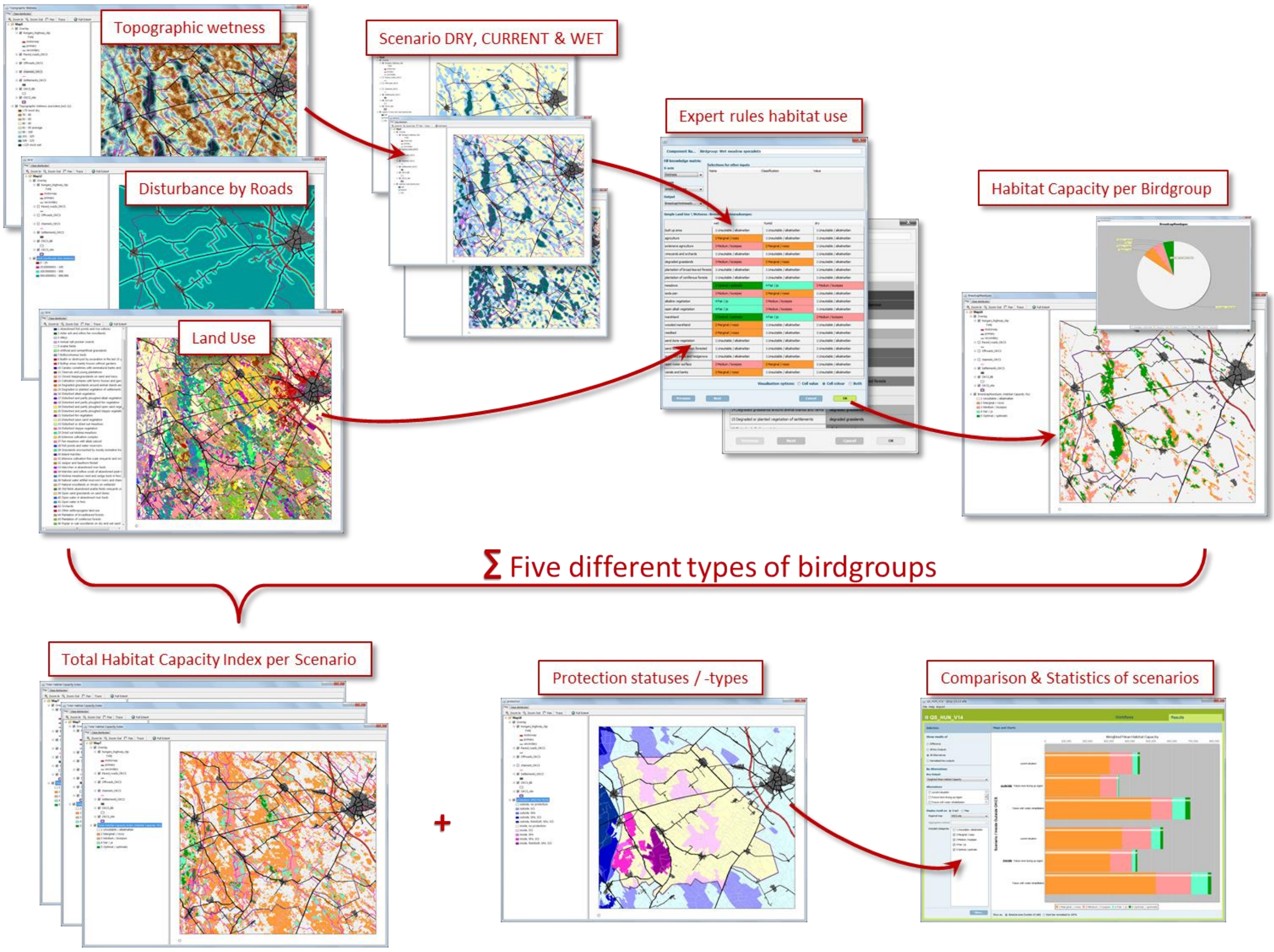

Figure 2.5.6: Simplified overview of QUICKScan approach for the Openness case study area of Kiskunság.

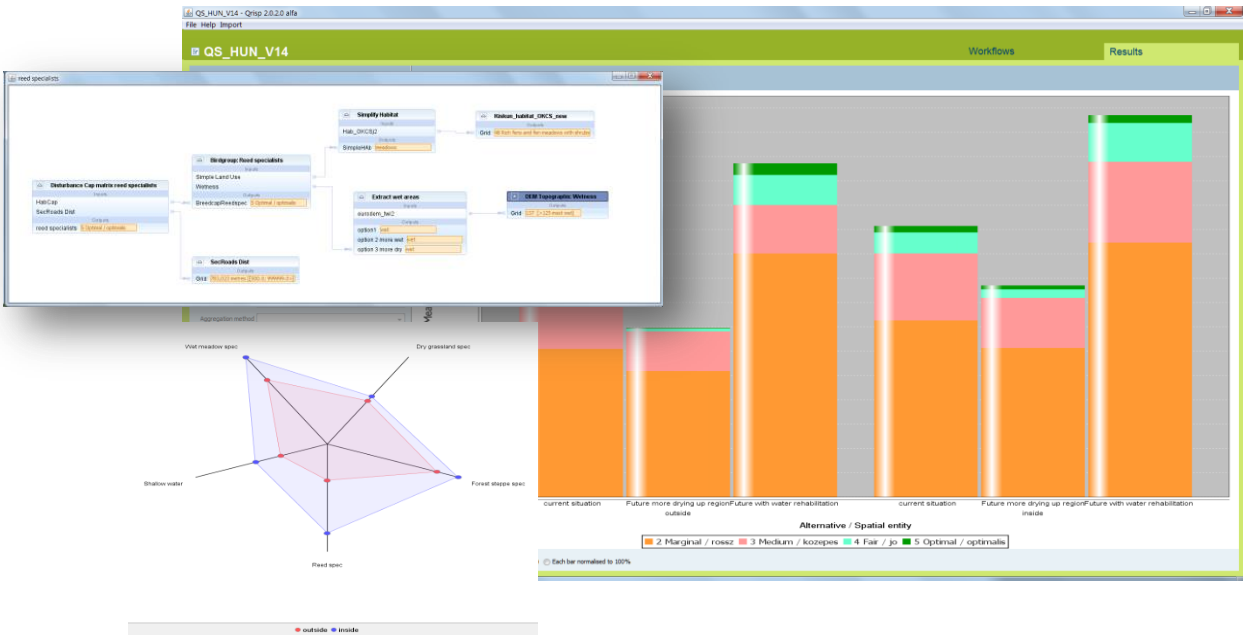

Figure 2.5.7: Example of some QUICKScan outputs from the Openness case study area of Kiskunság.

Cairngorms National Park, Scotland

In the Cairngorms National Park case study, the QUICKScan tool was used to assess the utility of geospatial planning within the region of Tomintoul, the highest village in the Scottish Highlands. A workshop was organised involving 15 local stakeholders and seven experts to discuss their general knowledge needs in relation to the Tomintoul and Glenlivet Landscape Partnership and specifically to evaluate the utility of the QUICKScan tool and the ES cascade conceptual framework (Figure 2.5.8). Five ES, which are delivered in the case study area, were evaluated using the QUICKScan tool. During the workshop the participants co-created benefit matrices and ran scenarios related to riparian woodland creation and substantial expansion of commercial forestry. The potential conflict zones (between services and between providers and receivers of the services) were taken into account.

Figure 2.5.8: Photo from the QUICKScan stakeholder workshop held in the Cairngorms case study area.

2.5.9 Further reading and references

For further reading and references see the QUICKScan website: http://quickscan.pro, which includes an overview of the most important QUICKScan reports and case studies. The following references are mentioned on the website (http://quickscan.pro/showcases.html):

EEA (2011), *Green infrastructure and territorial cohesion*, EEA technical report 18.

Eshitera, A. (2013), *Assessing Agricultural Land Carrying Capacity for Sustainable Livelihoods and Resettlement of Internally Displaced Persons in South Darfur*, MSc thesis, supervisors: Boerboom,L., Dopheide, M., Faculty of Geo-Information Science and Earth Observation of the University of Twent

Eupen M van, B. Pedroli, C Huang, X. Wang (2007), *Impact modelling of scenarios on vegetation and fauna in the Yellow River Delta*. Yellow River Delta Environmental Flow Study Sino-Dutch Study Programme Final Report 2007 YRCC, Yellow River Water Resources Protection Bureau, Alterra, Delft Hydraulics, Arcadis Euroconsult.

Roos-Klein Lankhorst, J., de Vries, S., Buijs, A. (2011) *Mapping landscape attractiveness, a GIS based landscape appreciation model for the Dutch countryside*, Exploring the visual landscape, Advances in physiognomic landscape research in the Netherlands, edited by Steffen Nijhuis, Ron van Lammeren, Frank van der Hoeven (pp 147 – 161); Research in Urbanism Series (RiUS), Volume 2, ISSN 1875-0192 (print), ISSN 1879-8217 (online). http://rius.tudelft.nl/article/view/210/265

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Verweij, P. van Eupen, M., Roos-Klein Lankhorst, J., Nieuwenhuizen, W. (2010), *Qualitative reasoning in participatory spatial planning: the use of OSIRIS in the Yellow River Delta*, in: International Environmental Modelling and Software Society (iEMSs) 2010 International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada; David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.) www.iemss.org/iemss2010/index.php?n=Main.Proceedings

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Xingong Wang, Yu Lian, Chong Huang, Xiaojun Wang, Ruiling Wang, Kai Shan, Bas Pedroli, Michiel Eupen, Amgad ElMahdi, Mahtab Ali (2012). Environmental flows and its evaluation of restoration effect based on LEDESS model in Yellow River Delta wetlands. *Mitigation and Adaptation Strategies for Global Change*, 17(4): 357.

2.6 InVEST

Grazia Zulian & Ignacio Palomo

2.6.1 Introduction to method/model

InVEST is a set of models for mapping and valuing the ecological or economic value of multiple ES at a local to regional scale. InVEST has a tiered design, from a simple Tier 0 to Tier 1 and 2 models, and it is constantly under development. In the last years it has evolved from mapping only ES supply to also incorporate ES demand for some services. InVEST requires a land use map and spatial and non-spatial data associated to land use types.

In general Tier 0 models map relative levels of ES and thus highlight regions where particular services are in high supply or demand. Tier 1 models are theoretically grounded but simple. They are suitable when more data are available than are required for Tier 0, but they still have relatively simple data requirements. More complex Tier 2 models are under development for biodiversity and some ES. Currently, InVEST covers levels 0 and 1 in terms of complexity.

InVEST can be downloaded for free and most of the models run on a stand-alone platform, not directly connected to ArcGIS. Since the InVEST model is fully documented (see section on further reading), we do not aim to repeat this here. Instead, we only introduce the InVEST model as a potential and interesting tool for mapping single or multiple ES within the OpenNESS case studies.

InVEST currently includes 16 models that analyse different aspects of marine and terrestrial environments:

- **Aesthetic quality**: Maps the visibility of features on a seascape or landscape.
- **Biodiversity**: Characterizes habitat quality and quantifies relative habitat loss.
- **Carbon**: Quantifies and values carbon storage and sequestration in terrestrial ecosystems.
- **Coastal protection**: Quantifies and values the benefits of nearshore habitats for coastal protection.
- **Coastal vulnerability**: Assesses the relative risk to coastal areas from storms.
- **Crop pollination**: Quantifies and values the contribution of wild pollinators to agricultural production.
- **Habitat risk assessment**: Evaluates the risk to marine or terrestrial habitats from anthropogenic factors.
- **Managed timber production**: Values timber harvest.
- **Marine fish aquaculture**: Estimates the harvest weight and value of farmed salmon.
- **Marine water quality**: Models concentration of pollutants at sea.
- **Offshore wind energy**: Measures the electricity generation potential of wind over ocean and large lake surfaces.
- **Recreation**: Maps recreational use across a landscape and predicts future recreational use under alternative scenarios.
- **Reservoir hydropower production** (water yield): Quantifies water yield in a catchment and the amount and value of hydropower produced by a reservoir.
- **Sediment retention**: Quantifies soil loss and retention and values the avoided cost of water treatment or dredging.
- **Water purification**: Quantifies nutrient retention, and values the avoided cost of water treatment.

- **Wave energy**: Models and values harvested energy from wave power facilities.
- **Overlap analysis**: Identifies areas of potential conflict between various human uses.

2.6.2 Why would I use this method/model?

The power of InVEST lies mainly in the capacity to map multiple ES which enable users to do a trade-off assessment of certain land use or management scenarios (Goldstein et al., 2012). The InVEST platform provides associated tools such as the scenario generator that allows creating different land use scenarios to compare ecosystem services under these scenarios. Case studies can also map and model single ES. The carbon module, for instance, is frequently used as a model to map carbon stocks at local and regional levels.

2.6.3 Requirements

Requirements		Comments
Data	☐ Data is available ☑ Need to collect some new data ☑ Need to collect lots of new data	
Type of data	☑ Qualitative ☑ Quantitative	Spatially-explicit data sets (vector or raster) and additional information such as the values for different different variables for the existing land use types in the study area.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	A stand-alone software is provided and is freely available
Time resources	☐ Short-term (< 1 year) ☑ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Time and economic resources depend on the expertise of the researchers and GIS specialists and on the existing data.
Economic resources	☐ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	Case studies which use InVEST to quantify four to five ES should probably assume 3-5 person-months to set up a complete InVEST project.
Other requirements		

2.6.4 Advantages

- The Natural Capital Project (http://www.naturalcapitalproject.org/index-2015.html) provides a standalone version of the tool, so there is no need for ArcGIS; any GIS software can be used.
- A complete set of tools is available, and a wide community of users is active around the world, all information is available here: http://www.naturalcapitalproject.org/models/models.html.

- It allows modelling of ES using multiple datasets, thus results are presumably more accurate than single-indicator based ES maps.
- It is possible to compare ES under different land use scenarios.

2.6.5 Constraints and limitations

- Previous versions of InVEST were provided as a toolbox to ArcInfo from ESRI but the latest version is a stand-alone version.
- Typically, working with InVEST requires a good command of GIS and good knowledge of spatial data formats.
- Data preparation needs vary with the individual sub-models. Some such as climate regulation are not intensive in terms of data needs, however, data preparation for other ES can be quite long and demanding. A good knowledge of spatial data formats is needed.
- The user can not verify and control the intermediate steps of the models.

2.6.6 Does the method address uncertainty?

Early versions of InVEST did not account for uncertainty. However, recent versions have incorporated uncertainty analysis. Uncertainty analysis with InVEST helps when there is lack of data (or when there is uncertainty associated with data) for some of the variables that are needed to run the different models. The outputs of the uncertainty analysis include confidence rasters and standard deviations.

2.6.7 Steps required to apply the method within a case study

An InVEST project would include the following steps:

1. Getting familiar with the models and data needs by reading the manual. It is available on the Natural Capital InVEST web page (http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/);
2. Deciding which ES to model.
3. Collecting, managing and handling the spatial data needed as input;
4. Running the models for current ES delivery/demand and/or for different land use scenarios;
5. Reporting and interpreting the results.

All the different ES models within InVEST require different understanding and implementation. These specific details are provided in the User Guide (see further reading).

2.6.8 Illustration of practical applications of the method using the OPENNESS case study

InVEST has been applied in the Doñana National Park (CS19) and Sierra Nevada (CS10) case studies, and it is being explored as a potential tool in two forest case studies: forestry in Finland (CS6) and the Carpathian Mountains, Romania (CS7) (Table 2.6.1). Other case studies (5, 6, 21, 24, 26 and 27) have expressed interest in the model, but have not yet begun working with the tool. An illustration of the application of InVEST is provided for the two Spanish case studies.

Table 2.6.1: An overview of OpenNESS case studies currently applying InVEST.

Case #	Case name	Country
6	Forestry in Finland	Finland
7	Forestry in Carpathian Mountains	Romania
10	Sierra Nevada National Park	Spain
19	Doñana National Park	Spain

Illustration from the two Spanish case studies

In Sierra Nevada (CS10) and Doñana (CS19), InVEST has been used to model climate regulation (see Palomo et al., 2014 for details). Data requirements to run this model have been a land use map and the following variables associated with carbon storage: carbon storage in above and below ground biomass, soil organic matter, and dead organic matter. To run the model it was necessary to perform a literature review to gather the values of these variables for the different land use types that exist in the study areas assessed. Outputs are presented in tons of elemental carbon, but their economic value could be estimated as well. Figure 2.6.1 shows different ES mapped in the Doñana Case study. Climate regulation (as carbon storage) was mapped using InVEST while the others where mapped based on indicators or on other existing models.

2.6.9 Further reading

All information on InVEST is available here: http://www.naturalcapitalproject.org/

The software can be downloaded here: http://www.naturalcapitalproject.org/download.html

The user forum is an additional tool which provides information and real support about different topics and practical problems:

http://ncp-yamato.stanford.edu/natcapforums/discussion/7/welcome-to-the-natural-capital-project-forums/p1

2.6.10 References

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Palomo, I., Martín-López, B., Alcorlo, P., & Montes, C. (2014). Limitations of Protected Areas Zoning in Mediterranean Cultural Landscapes Under the Ecosystem Services Approach. *Ecosystems*, 17(7), 1202-1215.

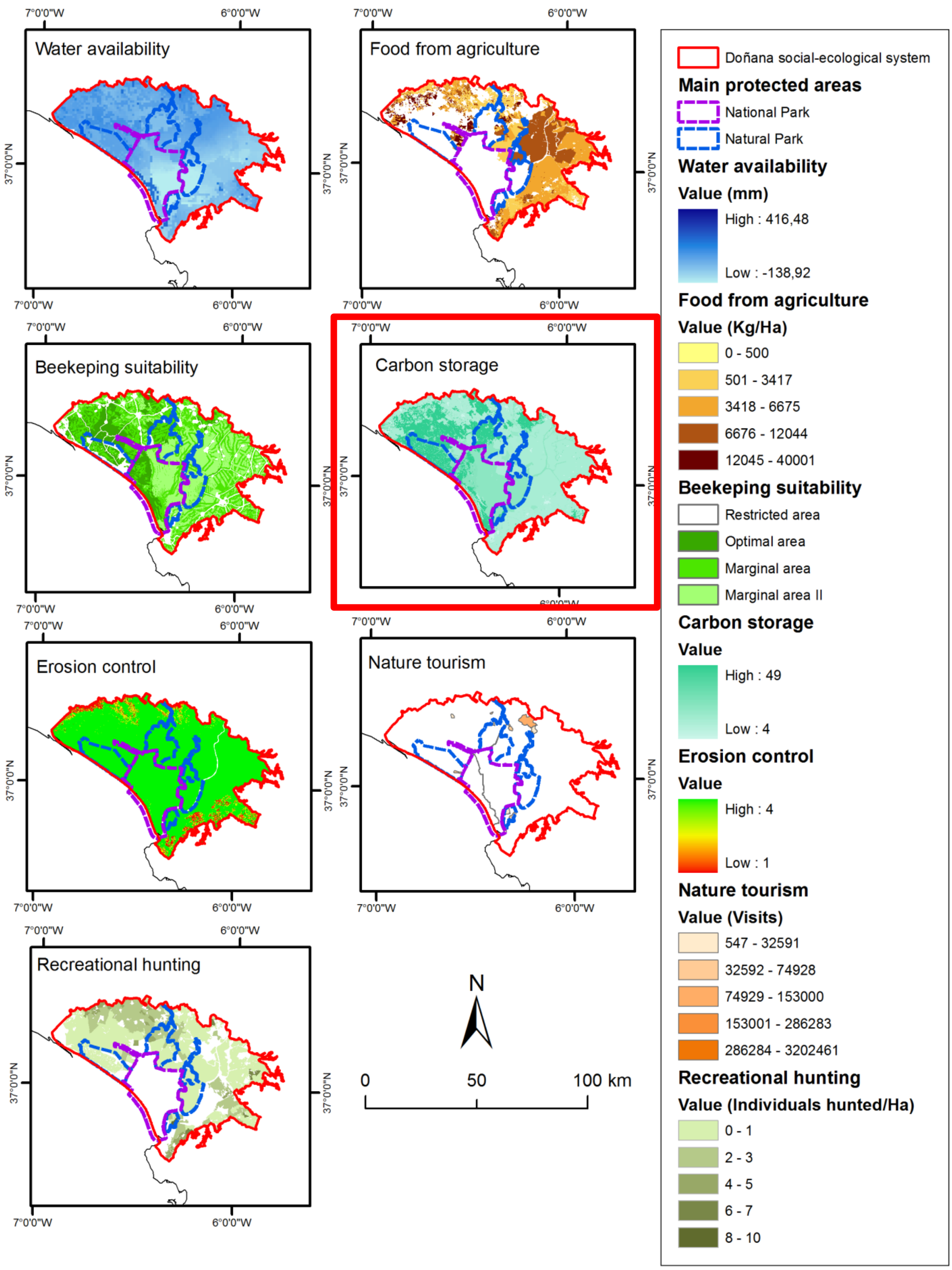

Figure 2.6.1: The different ES mapped in the Doñana Case study. InVEST was used for the carbon storage model (red box) which can then be compared with the other ES.

3 Further WP3 methods

In addition to the six main methods described in Section 2, a number of other biophysical methods were also used within selected OpenNESS case studies. These are briefly described in this Section.

3.1 Species distribution models

Patrizia Tenerelli, Sandra Luque, Frederci Archaux, Marie Le Roux, Paula Harrison & Robert Dunford

3.1.1 Why would I use this method?

Species distribution models (SDMs) (Franklin, 2009) have shown great potential in helping to achieve conservation planning goals by refining our knowledge of species distributions (Jetz et al., 2012). SDMs extrapolate species distribution data in space and time, usually based on a statistical model. These models identify areas that are ecologically suitable for the presence of species (Soberon & Peterson, 2005; Hirzel et al., 2002; Franklin, 2009). Use of SDMs can help to support management decisions with regard to biodiversity (Pawar et al., 2007; Baldwin, 2009; Franklin, 2009). Many examples can be cited that have made extensive use of SDMs for different applications, for example, assessing global impacts, prioritising or targeting areas for protected status, assessing threats to those areas, predicting species distributions in unsurveyed areas and designing reserves (Araùjo & Williams, 2000; Pearce & Ferrier, 2000; Thuiller, 2003; Araújo et al., 2004; Elith et al., 2006; Romero-Cacerrada & Luque, 2006; Elith et al., 2010). SDMs can be applied to vegetation or animal distribution modelling; several examples exist in Europe of their application to species, species groups, guilds, alliances or communities (for vegetation). There is a wide variety of SDM methods, each with their own characteristics. Two SDM methods have been used in the OpenNESS case studies: (i) BIOMOD (Thuiller, 2003; Thuiller et al., 2009; http://cran.r-project.org/web/packages/biomod2/index.html) in case study 5 (forest planning in the Vercors Mountain Range, France); and (ii) SPECIES/NeuralEnsembles (Pearson et al. 2002; Harrison et al., 2006; https://www.kent.ac.uk/kbs/documents/staff/neuralensembles/index.html) in case studies 11 and 22 (biodiversity off-setting in Warwickshire and Essex, UK, respectively. The SPECIES model is also embedded within the CLIMSAVE platform (discussed in Section 4) which allows biodiversity impacts to be explored at a European scale across a number of combined climate and socio-economic scenarios.

3.1.2 Requirements

The majority of SDMs (e.g most of the modelling approaches within BIOMOD and SPECIES) require data on the presence and absence of species, but it is possible to work only with presence data[4]. The presence/absence species data may be related to a wide variety of environmental variables, including habitat parameters, temperature, soil moisture, NDVI[5], slope, aspect, distance to wetlands or rivers, and evapotranspiration index. The environmental variables that should be included depend on the knowledge of the species or groups of species to be modelled. The information which is entered into the model should relate in some way to the distribution of the species being modelled (e.g. they should limit or control the

[4] Presence/absence data maps in detail where a species is present and also where it is absent; presence data only maps roughly where it is known to be present.

[5] Normalised difference vegetation index – an indicator of photosynthetic activity and hence vegetation productivity.

distribution of the species in some manner). Some of the models used, such as Maxent, were specifically designed for presence-only data, and to overcome problems of small samples.

Requirements		Comments
Data	☑ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data	Depending on the availability of data within the case study and the species in question. The resolution of the case study will also determine the extent to which suitable data are available both in terms of species and contextual datasets. Collecting primary species data is a considerable task: in most cases SDMs depend on secondary data collation rather than collection of primary data.
Type of data	☐ Qualitative ☑ Quantitative	
Expertise and production of knowledge	☑ Work with researchers within your own field ☐ Work with researchers from other fields ☐ Work with non-academic stakeholders	In general, SDMs require expertise from the ecology/biodiversity field, but input from non-academic stakeholders can be useful to validate the results.
Software	☑ Freely available ☐ Software licence required ☑ Advanced software knowledge required	Depends on the species distribution model in question. Some are freely available for download, others are embedded in particular institutions. BIOMOD is implemented in R statistical coding landuage and is a freeware, open source, package. SPECIES is implemented as standalone interface.
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Depending on the level of available data can be performed in less than a year. Will depend on the level of skill of the programmer and the level of pre-processing required to create the driving variables.
Economic resources	☐ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	
Other requirements		

3.1.3 Advantages

- Can identify areas where climate and/or habitat is appropriate for a given species;
- Can be used to explore multiple future scenarios;
- Spatial outputs produced with accompanying goodness-of-fit statistics;
- Freely available.

3.1.4 Constraints and limitations

- Some species are very hard to model as the factors driving their present-day distributions are unclear;
- As with any modelling, some species fit better with the driving variables and produce projections that are more statistically significant than others;

- Relatively advanced statistical process underly the models; mathematical and technical expertise are required to interpret the results;
- The projections reflect the climate, environmental characterisitics and/or habitat niche that a species could potentially use – it does not usually take into consideration other factors such as predation, competition or disease, or changes over time in factors such as habitat distribution.

3.1.5 Brief description

Further information is provided in this section on the BIOMOD modelling platform as this is freely accessible and was developed to facilitate the simultaneous implementation of different SDM approaches that can be compared in order to choose the most suitable and accurate for each species or group of species considered. BIOMOD is a platform for ensemble forecasting of species distributions, enabling the explicit treatment of model uncertainties and the examination of species-environment relationships (Thuiller et al., 2009). It includes the ability to model species distributions with several techniques (see a summary in Figure 3.1.1), test models with a wide range of approaches, project species distributions into the future using different climate scenarios and dispersal functions, assess species temporal turnover, plot species response curves, and test the strength of species interactions with predictor variables. Computationally, BIOMOD is a collection of functions running within the R (CRAN) software (programmed in the R language) and allows the user to apply a range of statistical models to several dependent variables using a set of independent variables. Thus, BIOMOD attempts to span the different approaches that can be used in habitat suitability modelling. It does not aim to be exhaustive, but it presents the most commonly used modelling approaches and the ones considered to be the most interesting and robust and which are implemented in R (see http://cran.r project.org/bin/windows/base/).

Model		Concept	Technique	Environmental variables types	Key references
SRE	**Rectilinear Envelope**	Environmental envelope	Equivalent to Bioclim. Climatic Envelope Model is a GARP-simulation	Cont	Busby 1991, Nix 1986 ; Walker & Cocks, 1991; McMahon et al. 1996
CTA	**Classification Tree Analysis**	Decision tree	Classification and regression	Cont/Cat	Breiman et al., 1984
RF	**Random Forest**		Classification and regression	Cont/Cat	Breiman, 2001
GBM	**Generalized Boosting Model**	Regression and decision tree	Combination of regression decision Trees & "boosting"(method combining several simple models to improve predictions performance)	Cont/Cat	Jerome H. Friedman, 1999
FDA	**Flexible Discriminant Analysis**	Regression analysis	Classification method by using Friedman's (1991) multivariate adaptive regression spline, using the MARS function for the regression part of the model.	Cont/Cat	Hastie, T., Tibshirani, R and Buja, A.,1994 Manel, D., Dias, J. M., Buckton, S. T. and Ormerod, S. J.,1999
MARS	**Multivariate Adaptive Regression Splines**		Linear model	Cont/Cat (only Cont in Biomod2)	Friedman, 1991
GAM	**Generalised Additive Models**		Additives model	Cont/Cat	Guisan et al., 2002, Pearce & Ferrier, 2000
GLM	**Generalised Linear Models**		Linear models / additives models/least square fitting	Cont/Cat	Guisan et al., 2002, Pearce & Ferrier, 2000
ANN	Artificial Neural Networks	Machine learning	Neural nets	Cont/Cat	Pearson et al., 2002
Maxent	Maximum entropy		Maximum entropy	Cont/Cat	Phillips et al., 2006

Figure 3.1.1: Summary of the models that can be used within BIOMOD (Le Roux, 2013). 'Cont/Cat' = Continuous/Categoric.

Instructions to implement BIOMOD2 are freely available in Thuiller (2012), Thuiller et al. (2012) and Georges & Thuiller (2013). The steps in the BIOMOD2 modelling process are:

1. Gather all available and meaningful GIS information. All GIS layers have to share the same projection system (e.g. WGS 84). GIS layer resolution depends on the original data, but may be degraded to speed calculation if fine-resolution layers are not crucial for the species studied. The spatial extent needs to be specified (the calculation time will depend on its surface area). All layers need to be supplied as rasters (using conversion tools if necessary in GIS software). Raw GIS layers may need to be adapted, e.g. by first producing a map of distance to a river from an original river map and then converting this to a distance-to-river map as a raster.
2. Data on observed species distributions can be provided either as .csv data with three columns providing geographical coordinates and presence/absence data, or as a raster from GIS software. Note that more than three columns can be provided if you are modelling more than one species.
3. Install BIOMOD2, R-Cran, the latest version of Java and Maxent (following the instructions provided in Georges & Thuiller, 2012); the following links will be needed:
    - http://cran.r-project.org/web/packages/biomod2/index.html
    - http://www.cs.princeton.edu/~schapire/maxent/
    - http://cran.r-project.org/bin/windows/base/
    - http://www.oracle.com/technetwork/java/javase/downloads/index.html).

   Different R packages need to be installed: biomod2, abind, sp, raster, rastervis, lattice, latticeExtra, RColorBrewer, hexbin, grid, nnet, gbm, survival, splines, gbm, mda, class, randomForest, rpart, pROC, plyr, rgdal, zoo (for further information see http://cran.r-project.org/web/packages/available_packages_by_name.html). The tutorials listed in the links above explain how to carry out the analyses.

3.1.6 Further reading/references

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Harrison PA, Berry PM, Butt N & New M (2006). Modelling climate change impacts on species' distributions at the European scale: Implications for conservation policy. *Environmental Science and Policy*, 9: 116-128.

Hirzel, A.H., Haussez, J., Chessel, D. & Perrin, N. (2002). Ecological-Niche Factor Analysis: How to compute habitat suitability maps without absence data? *Ecology*, 7: 2027-2036.

Jetz, W., McPherson, J. & Guralnick, R. (2012). Integrating biodiversity distribution knowledge: toward a global map of life. *Trends in ecology & evolution* (Personal edition), 27(3): 151-159.

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Pearson RG, Dawson TP, Berry PM, Harrison PA (2002). SPECIES: A spatial valuation of climate impact on the envelope of species. *Ecological Modelling*, 154: 289-300.

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Soberon, J. & Peterson, A. (2005). Interpretation of models of fundamental ecological niches and species distribution areas. *Biodiversity Informatics*, 2: 1-10.

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Thuiller, W., Lafourcade, B., Engler, R. & Araújo, M.B. (2009). *BIOMOD – a platform for ensemble forecasting of species distributions*, pp. 369-373.

3.2 ECOPLAN-QUICKScan

Jan Staes & Francis Turkelboom

3.2.1 Why would I use this method

The ECOPLAN-QUICKScan tool is a script/method that is useful to make results from mapping and simulations insightful to stakeholders. The tool converts spatial datasets on ES supply (e.g. maps of carbon stored) into a set of average values per unit area (e.g. carbon stored per hectare for each region). This allows different regions or scenarios to be compared. The target audience is local experts in, for example, spatial planning, environment or industry. The tool can help project planners with vision building and/or raising awareness on ES supply.

3.2.2 Requirements

The input is raster datasets on ES-stocks or ES-delivery for a current situation and/or simulation results for (multiple) scenarios. Units can be quantitative or monetary, but they need to be specified as a value per unit area. A set of polygons is also needed that defines the specific areas of interest (specific sites, municipalities, provinces, catchments etc.).

Requirements		Comments
Data	☐ Data is available ☑ Need to collect some new data ☑ Need to collect lots of new data	Depending on the case study, large amounts of data may need to be collected
Type of data	☐ Qualitative ☑ Quantitative	
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	The outputs are designed for discussion with stakeholders and to facilitate comparisons between regions
Software	☑ Freely available ☐ Software licence required ☑ Advanced software knowledge required	The software is coded to run in QGIS. Post-processing scripts need to be run to prepare data for QUICKScan. Software will become freely available by the end of next year.
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	The ECOPLAN-QUICKScan system is composed of FOS scripts that run in Q-GIS, so any developer can take them and edit them. The current system is designed to work with Flemish Data, but with programming skills they can be made applicable for other data sets
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	
Other requirements		

3.2.3 Advantages

- Comparing areas provides insight into the characteristics of a region relative to its surroundings and/or comparable sites/catchments;
- Comparing scenarios for a defined area reveals clearly the total aggregated impact of each scenario on ES delivery;
- Requires limited effort by the end user: the end user selects specific areas and /or scenario simulation results from a drop-down menu in a table;
- Results are made available in tabular form and graphs.

3.2.4 Constraints and limitations

- Requires some VBA and Excel programming to adapt the tables and infographics to a new dataset;
- Reliant on availability of input data.

3.2.5 Brief description

ECOPLAN-QUICKScan is a technical tool to process mapping and modelling results to generate insightful data for specific areas. Map layers representing supply or delivery of different ES are selected with the aid of a Python script, then zones of interest are clipped and data for each zone is summarised. This procedure is also undertaken for land-use/land-cover data to make results area-independent for comparison. The totals are written to a text file that can be further processed in Excel. Examples of the output for a comparison of the value of ES between two sites are shown in Figure 3.2.1.

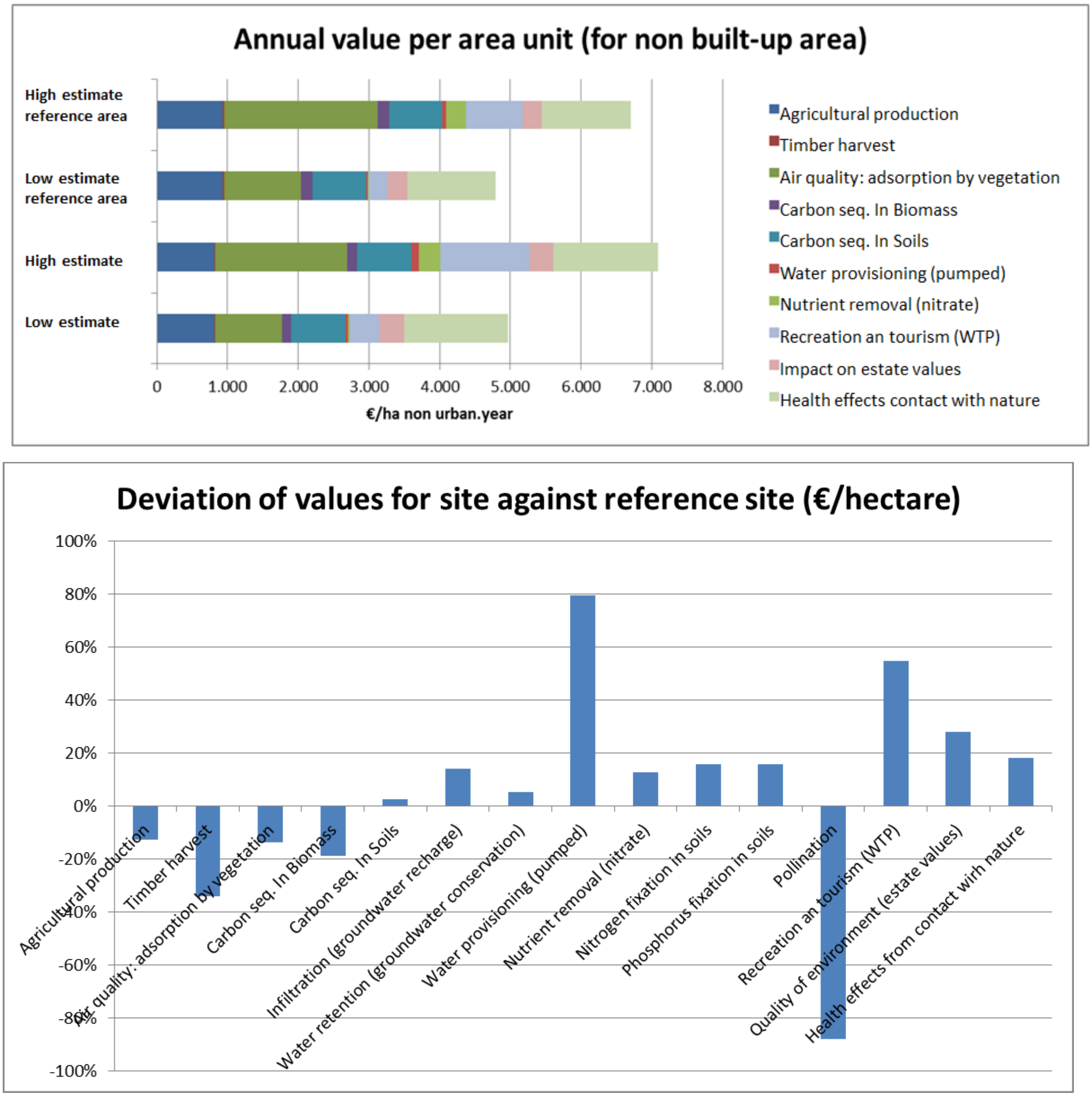

Figure 3.2.1: Illustrative output for ECOPLAN-QUICKScan.

3.2.6 Further reading/references

Broekx, S., De Nocker, L., Liekens, I., Poelmans, L., Staes, J., Van der Biest, K., Meire, P. and Verheyen, K. (2013) *Estimate of the benefits delivered by the Flemish Natura 2000 network*. Study carried out on the authority of the Agency for Nature and Forests (ANB/IHD/11/03) by VITO, Universiteit Antwerpen and Universiteit Gent 2013/RMA/R/87 (March 2013). Online at https://www.uantwerpen.be/en/rg/ecoplan/research/products/

3.3 MapNat smartphone application

Jörg Priess

3.3.1 Why would I use this method?

The MapNat tool is designed to be applied by citizens and scientists who are interested in mapping the use of mainly cultural, but also some provisional and regulating, services and disservices. Motivations to use the app may include interest in mapping personal use of nature's resources or to support scientists and planners in generating information about the demands for a large number of ES and disservices perceived by users. It is an easy-to-use direct mapping tool, providing not only immediate feedback of the mapped services, but also access to the services mapped by other users. Thus, citizens are enabled to identify locations with ES of interest, whereas scientists or planners might be more interested in assessing the spatio-temporal pattern of ES demand.

3.3.2 Requirements

- The MapNat App only requires an ANDROID (v 4.XX) based smartphone with a GPS device;
- For installation of the App and for up- and downloading data and maps, internet access is needed;
- No knowledge on ES or their classification is required;
- Basic knowledge of English, if the App does not support their own language.

Requirements	Comments
Data	☑ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data
Type of data	☑ Qualitative ☐ Quantitative
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months
Other requirements	Smartphone needed (currently ANDROID)

3.3.3 Advantages

- MapNat App is easy to use;
- It is applicable by citizens and scientists;
- It has global applicability and comparability of results;
- Users can download or export the ES they map from their phones and display or evaluate them for their own purposes;
- Unlike many other smartphone apps MapNat does not collect any personal information, unless users decide to register voluntarily;
- The ES categories used in the app are compatible with the widely used CICES (V 4.3) list.

3.3.4 Constraints and limitations

- The perspective for which the app is designed is to map ES demand (ES flow), i.e. of a citizen using one or multiple ES, or a scientist reporting the use of ES by the people he or she is observing;
- The thematic focus is on cultural services, and a couple of regulating and provisioning services which are considered to be relevant for direct use by citizens, such as using drinking water or fire wood.

3.3.5 Brief description

MapNat enables its users to map ES in three different ways as points, lines or areas on a map. Once the user selects a location, he/she is guided to a list to select the ES which is being used. Users can deliver additional information, e.g. about the vegetation, or provide comments or a photograph. Mapped uses are immediately visible on the map display, which also shows the records of all other users displayed in different colors, depending on the type of ES or disservice. Internet connection is not needed during use, but is required for up- and downloading data as well as refreshing the map display.

3.3.6 Further reading/references

EEA (2014). *Common International Classification of Ecosystem Services (CICES) v4.3* (URL: www.cices.eu; last access: December 12, 2014).

Maes J, Teller A, Erhard M, Liquete C, Braat L, Berry P, Egoh B, Puydarrieux P, Fiorina C, Santos F, et al. (2013) *Mapping and Assessment of Ecosystems and their Services. An analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020*. Publications office of the European Union, Luxembourg.

Priess J.A., Elger R. and Hauck J. 2014. The ESM-App – a new smartphone application to map ecosystem services. In: Ames, D.P., Quinn, N.W.T., Rizzoli, A.E. (Eds.), *Proceedings of the 7th International Congress on Environmental Modelling and Software,* June 15-19, San Diego, California, USA. ISBN: 978-88-9035-744-2.

3.4 RUSLE (Revised Universal Soil Loss Equation) Erosion model

Jörg Priess, Christian Schweitzer & Christian Hoyer

3.4.1 Why would I use this method?

The Revised Universal Soil Loss Equation (RUSLE) is an empirical erosion model recognised as a standard method to calculate the average risk of erosion on arable land. It developed from the Universal Soil Loss Equation (USLE) developed in the US Department of Agriculture and has other similar variants such as the Modified USLE (MUSLE) and ABAG (Allgemeine Bodenabtragsgleichung = 'General Soil Loss' in German). As all these models use similar algorithms and produce comparable results, we focus on RUSLE here.

The method is efficient in terms of costs for data provision, model parameterisation and modelling. The results of the RUSLE model can also be coupled with the SITE land use model.

3.4.2 Requirements

Requirements		Comments
Data	☑ Data is available ☑ Need to collect some new data ☑ Need to collect lots of new data	This will strongly depend on the case study; all three may or may not apply.
Type of data	☐ Qualitative ☑ Quantitative	
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☐ Work with non-academic stakeholders	
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	
Other requirements		

In addition to equipment with appropriate computer technology and GIS software, the following input data are required as GIS datasets:

- Average annual precipitation (raster dataset);
- Digital soil map with information regarding the top soil layer;
- Digital Elevation Model (DEM);
- Digital land use data about land use classes and objects that inhibit erosion (barriers);
- Data on crops.

3.4.3 Advantages

- RUSLE provides international applicability and comparability of the results and methods, as the method has been adapted to and applied in many world regions.
- The results are plausible in terms of assessing risks of water erosion.
- The algorithms can be implemented based of literature values or adapted to empirical / statistical data by using standard GIS software.
- Required input data are usually available and easy to obtain.

3.4.4 Constraints and limitations

- RUSLE is used to estimate the average long-term risk of erosion on arable land. It is not designed for modeling soil erosion and sediment transport under individual rainfall events.
- Due to the relatively simple empirical approach, the typical erosion processes such as splash erosion, soil transport and soil deposition are not considered as a dynamic process.
- Antecedent soil moisture and soil stratification are not considered.

3.4.5 Brief description

The RUSLE model links erosion factors influencing soil erodibility (K factor), erosivity (R factor), land cover and management (C factor), slope length (L factor) and slope (S factor). By multiplying these factors, the mean relative soil loss in tons per hectare per year is calculated. The calculation can be based on GIS grid cells or polygons such as crop fields. The factors contributing to erosion risk are location-specific and climate-specific. Due to the countless applications of RUSLE, various nomograms, equations and modelling approaches are available supporting users to determine the individual RUSLE factors (see e.g. the USDA reference below, which provides excellent online support).

3.4.6 Further reading/references

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USDA website: Revised Universal Soil Loss Equation (RUSLE) - Welcome to RUSLE 1 and RUSLE 2. http://www.ars.usda.gov/Research/docs.htm?docid=5971

3.5 Blue-green factor scoring

David N. Barton, Erik Stange & Claudia Fongar

3.5.1 Why would I use this method?

Green space factors and points systems have been used in several European cities as a policy instrument to attain desired levels of green and blue surfaces in new property developments (Farrugia et al., 2013; Fongar, 2015; Kruuse, 2011; Szulczewskaa et al., 2014). Different green and blue 'elements' are scored based on their importance for a particular ES, or a bundle of services, and an area-weighted score is calculated for a proposed property development.

The aim of blue-green factor (BGF) scoring is safeguarding blue-green structures and elevating the status of such structures within urban environments through awareness-raising. Green space factors are a non-economic valuation method because they score the relative importance of different green structures. They are also a policy instrument. The BGF may be used for certifying new building development in relation to achieving a minimum total score that can be differentiated for different parts of a city depending on demand for the ES in question. At the same time, property developers are given flexibility in designing how to incorporate blue-green structures into building plans. The BGF developed for Oslo municipality (OpenNESS case study 3) focuses on the urban flood control function of green and blue structures. Other green space factor scoring systems may weight structures differently based on other ES.

A practical reason for using the approach is that there are few methods that evaluate ES supply at the spatial resolution of a property (rather than a pixel). The scoring system can be easily implemented using an Excel spreadsheet. An App for Android Smartphones has also been developed that allows a property owner to carry out a rapid assessment of the BGF at property level (Figure 3.5.1). Pixel-based extrapolation of BGF scoring to whole catchments is being tested in Oslo.

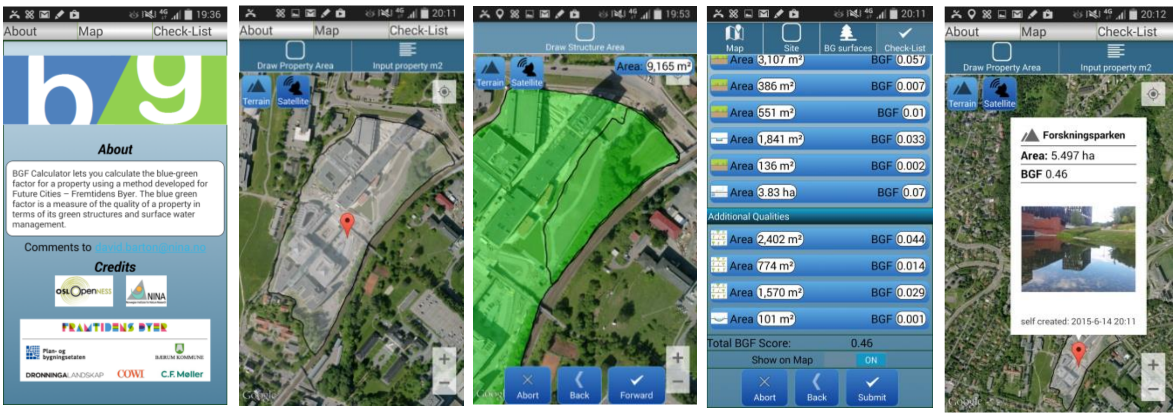

Figure 3.5.1: Selected screens from the BGF App for Android Smartphones. For further information contact: David.Barton@nina.no.

3.5.2 Requirements

Requirements		Comments
Data	☐ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data	Area calculations for blue and green structures can be calculated using the BGF App.
Type of data	☑ Qualitative ☑ Quantitative	Weighting (predetermined scores) Surface areas and counts
Expertise and production of knowledge	☑ Work with researchers within your own field ☐ Work with researchers from other fields ☐ Work with non-academic stakeholders	
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	Excel spreadsheet (upon request) Android Smartphone App (upon request)
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Smartphone-based assessment of a single property can be carried out in about 1 hour.
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	
Other requirements		

3.5.3 Advantages

- Ease of use (Excel spreadsheet, Smartphone App);
- Speed of use;
- Draws on existing data;
- Participatory approach – can be applied by stakeholders themselves;
- Spatially-explicit;
- Expert knowledge not required for its use.

3.5.4 Constraints and limitations

- Property-specific weighting;
- Weighting not adjusted for spatial context, such as catchment location, hydrological characteristics of neighbouring properties;
- BGF structures and weights have been selected and developed by an expert panel to specifically address urban flood control, with some additional weight being given to importance of biodiversity habitat. Weights should not be applied to other ES.

3.5.5 Brief description

Through the Cities of the Future program, Oslo Municipality Planning and Building Agency, Bærum Municipality, Dronninga Landskap AS, Cowi AS, and C. F. Møller collaborated in developing a 'blue-green factor' (BGF) scoring system to guide new urban development towards the overall goals of the Green Plan for Oslo (FramtidensByer, 2014). BGF was inspired by the Biotopflächenfaktor (Berlin), Grönytefaktor (Malmö) and Green area factor (Stockholm). The BGF proposal has been developed and tested on a number of case studies. However, the final proposal has so far not been incorporated into municipal building codes or regulation.

The BGF scores the 'importance' of each structure based on performance criteria mainly in relation to water infiltration and storage capacity. Scores are given for different kinds of blue-green surfaces in relation to their hydrological regulating effect. Additional points are then given for water and vegetation features that enhance run-off control in conjunction with aesthetic qualities and biodiversity habitat (Figure 3.5.2).

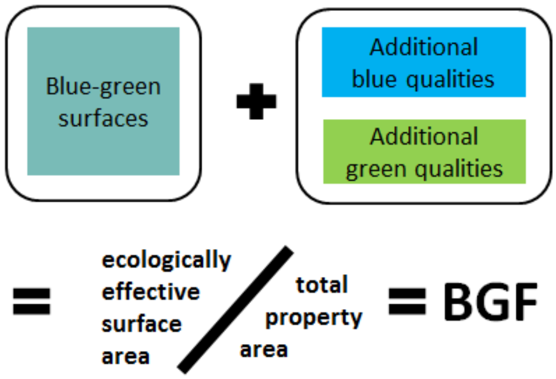

Figure 3.5.2: Blue-green factor calculation. Source: translated from Framtidens Byer (2014).

Each structure score is divided by the total plot area resulting in normalised BGF scores for each structure. The total score is calculated through either adding all individual BGF scores or dividing the total value scores by the total plot area. The sum of scores is divided by the total property area, so that each property has a normalised BGF score/m2 which can be compared across properties (Figure 3.5.3). Scoring of each structure is based on the judgement of technical experts in architecture, urban planning, hydraulics and hydrology. Judgements were tested and adjusted through a number of case studies in Oslo (Framtidens Byer, 2014):

- **Blue-green surfaces**
    - Open permanent water surfaces are relatively more important than potentially permeable or impermeable surfaces with regard to their run-off storage capacity.
    - Vegetation surfaces with direct drainage to soil or bedrock are more important than surfaces with no drainage with regard to their infiltration potential. The deeper the soil for non-connected surfaces the higher the water storage capacity. Non-connective surfaces refer to soils and vegetation placed above built structures, such as sub-terrain parking or green roofs.

- **Blue additional qualities**
  - Natural edges and rain beds slow water flow rates, and increase water basin holding capacity, in addition to providing aesthetic and habitat qualities to water surfaces.
- **Green additional qualities**
  - **Trees** are scored individually relative to size and growth potential, determining their importance for rainfall interception and evapotranspiration, and for their functions as habitat and for aesthetics. Trees may constitute a large share of the total BGF score for a property.
  - **Native vegetation, perennials and other ground cover** provide additional scores for their importance for biodiversity habitat and aesthetics.
  - **Hedges, bushes and green walls,** give additional scores for both their hydrological properties and their aesthetic value .
  - **Contiguous green areas and connection** give additional score for their importance as recreation areas and connectivity with other urban green infrastructure structure.

Value	Symbol	Factor
		Plot Area (including the built area) Fill out the area
		1.BLUE-GREEN SURFACES
1		Open permanent water surface that can receive rainwater
0.3		Partially permeable surface like gravel, crushed stone, and reinforced grass surface
0.2		Impermeable surfaces with drainage to vegetated areas or an open drainage magazine
0.1		Impermeable surfaces with drainage to a local closed storm water drainage
1		Surfaces with vegetation associated with soil or bedrock
0.8		Surfaces with vegetation, not associated with soil > 80 cm
0.6		Surfaces with vegetation, not associated with soil 40 – 80 cm
0.4		Surfaces with vegetation, not associated with soil 20 – 40 cm
0.2		Surfaces with vegetation, not associated with soil 5 -20 cm

		2. Additional qualities = Blue and Green additional qualities that give extra points. The same area can therefore be counted a number of times below
		Blue additional qualities
0.3		Natural edges to water srufaces
0.3		Rain bed or equivalent
		Green additional qualities, Points below (trees) should be filled in as a number
1		Existing large trees > 10 m
0.8		Existing trees that can be expected to grow to over > 10 m
0.6		Existing trees that can be expected to grow to be small to medium, 5 - 10 m
0.7		Newly planted trees that are expected to be > 10 m
0.5		Newly planted trees that are expected to be 5 - 10 m
		Points below should be filled in as m2
0.6		Native vegetaion
0.4		Hedges, bushes and multi-stemmed trees
0.4		Green walls
0.3		Perinnials and other ground cover
0.1	75m2	Contiguous green areas over 75 m2
		Points below are filled in with the number 0,05
0.05		Connection to existing blue-green structures.
		TOTAL BLUEGREEN FACTOR (BGF)

Figure 3.5.3: Blue-green factor scores. Source: translated from Framtidens Byer (2014).

The assessment approach recognises that ES of green infrastructure are ‘bundled’, and difficult to disentangle. The BGF therefore has a deliberate focus on regulating hydrological services in order to be simple to implement. For this reason structures providing biodiversity habitat, aesthetics and recreation are seen as ‘additional’ ES. Their relative importance in the overall BGF score is also smaller than for the hydrological regulating services.

The BGF focus on simplicity means that each structure is scored the same no matter where the assessment takes place. The assumption is that the marginal value of each structure in terms of surface area or number of individual trees is the same whether upstream or downstream in an urban catchment. BGF scoring also does not presently differentiate between developed (landscaped) and natural properties with high density of trees.

3.5.6 Further reading/references

Guidance document in Norwegian can be downloaded here: http://www.miljodirektoratet.no/Global/klimatilpasning/Bl%C3%A5gr%C3%B8nn%20faktor/BGF%20Veileder%20byggesak%20Hoveddelen%202014.01.28.pdf

An extensive explanation can be found in Fongar (2015) (to be made available at the OSLOpenNESS case website http://www.openness-project.eu/node/78)

Farrugia, S., Hudson, M.D., McCulloch, L., 2013. An evaluation of flood control and urban cooling ecosystem services delivered by urban green infrastructure. International Journal of Biodiversity Science, Ecosystem Services & Management, 9, 136-145.

Fongar, C., 2015. Identification of bluegreen structures and percieved values in public urban green spaces: a comparative case study of a natural and a constructed green space in Oslo, Master of Science in Natural Resources Management. Specialization Geography. Norwegian University of Science and Technology, Faculty of Natural Science and Technology, Department of Geography, p. 127.

FramtidensByer, 2014. Blågrønn Faktor. Veileder byggesak. Hoveddelen. Plan- og bygningsetaten, Oslo Kommune, Bærum Kommune, Dronnningalandskap, COWI, C.F. Møller.

Kruuse, A., 2011. The green space factor and the green points system. GRaBS Expert Paper 6 (Green and Blue Space Adaptation for Urban Areas and Eco Towns).

Szulczewskaa, B., Giedycha, R., Borowskib, J., Kuchcikc, M., Sikorskib, S., Mazurkiewiczd, A., Sta´nczykea, T., 2014. How much green is needed for a vital neighbourhood? In search forempirical evidence. Land Use Policy 38, 330– 345.

3.6 Photoseries analysis

Patrizia Tenerelli, Sandra Luque & Berta Martín-López

3.6.1 Why would I use this method?

Revealed preference for Cultural Ecosystem Services (CES) and spatially-explicit data on location for nearby CES provision can be obtained from popular social networks. Photoseries databases can be acquired from photo-sharing websites such as Flickr, Panoramio and Instagram. The analysis of community-contributed photos can be used as a complementary technique to interviews, questionnaires or focus groups to assess preferences for CES, assuming that visitors are attracted by the location where they take photographs. The method allows those CES to be identified which are perceived as the most important by the people who take the photographs and to map their distribution.

3.6.2 Requirements

The number of photographs uploaded on the most popular social media for photo sharing (Flickr, Panoramio or others) should be compared in order to identify the platform with the highest number of photos. There is not a given definition for the necessary numbers of photos; for case studies with a large area extension a sampling strategy may be used. Guidance on sampling can be obtained from Richards & Friess (2015) who simulated different levels of sampling effort using a boot-strap resampling method. Rights in relation to the use of the photos will depend on the country and the use. Only photos entered as public should be used and the photo and the users' personal data must not be published. GIS information on environmental characteristics and infrastructures which may affect the CES should also be captured.

Requirements		Comments
Data	☑ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data	Public photos can be downloaded from social networks.
Type of data	☐ Qualitative ☑ Quantitative	Number of uploaded photographs. Socio-biophysical features associated with CES supply.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	Different professionals should discuss the photo content in order to agree on the interpretation. Other methods such as interviews, questionnaires or focus groups should be integrated in order to take into account socio and psycho-cultural aspects which are related to values.
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	
Other requirements		

3.6.3 Advantages

- Photoseries analysis represents a pragmatic way of gathering space-and time-referenced data on observed people's preferences related to CES which are difficult to obtain in a cost-effective way through traditional data gathering techniques (e.g. social surveys);

- It allows further understanding on the spatial distribution of CES in areas with low baseline information (Martínez-Pastur et al., in press);
- It permits the identification of socio-biophysical features of landscapes that are associated with the provision of CES and with the spatial trade-offs and synergies among CES (Martínez-Pastur et al., in press).

3.6.4 Constraints and limitations

- Socio- and psycho-cultural aspects are crucial in order to define different values from the point of view of individuals and society. This method doesn't allow information related to the user characteristics to be directly obtained which could reveal significant correlations with the photo content;
- People's attitude to taking photographs change with the different recreation activities (Wood et al., 2013). Certain activities are therefore less well represented, for example rock climbers may take less photos than people having a picnic;
- The photo-sharing community may not be representative of specific social groups: the represented population will then be dependent on the level of access to information technology, education and age, and the user's ability/willingness to correctly geotag the photos;
- To appraise the importance of CES services through the number of uploaded photographs entails an inherent bias related to the interpretation of the photos by researchers and to the capacity to photograph certain CES. For example, it is quite challenging for researchers to identify sacred areas or traditions in photographs (Martínez-Pastur et al., in press).

3.6.5 Brief description

The photoseries analysis consists of a classified set of pictures downloaded from a selected social network. An Application Programming Interface (API) can be used to retrieve all the geotagged public pictures uploaded on the image hosting website for a given area (e.g. Flickr API). Some APIs allow the query to be limited to photographs with the most precise recorded accuracy level (street level); other sampling strategies may be used to reduce the number of pictures.

A hierarchical classification scheme is used to classify the different CES, and the different sub-categories are selected according to the specific study area characteristics. The photo classification is conducted through a systematic visual analytic process. This process can also be performed in a GIS environment which allows the different information layers to be overlaid, such as satellite images and thematic maps. All photos which are not related to CES and those which are tagged with the wrong location should be deleted through the systematic visual analysis, based on expert knowledge and multi-media supporting data (background satellite images, virtual globes and land use/land cover data). In general, it is possible to classify around 50 photos in 1 hour. Different professionals should discuss the photo content in order to agree on the interpretation.

Once the classified photoseries has been created the data can be analysed on a GIS platform in order to identify spatial trends. Different multivariate statistical analysis and spatial regression models can be applied to identify environmental properties which represent the major predictors of nearby recreation and other associated CES.

3.6.6 Further reading/references

Flickr Application Programming Interface (API): https://www.flickr.com/services/api/explore/flickr.photos.search

Casalegno, S., R. Inger, C. DeSilvey, and K. J. Gaston. 2013. Spatial Covariance between Aesthetic Value & Other Ecosystem Services. PLoS ONE 8:e68437.

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Martínez Pastur, G., P. L. Peri, M. V. Lencinas, M. García-Llorente, and B. Martín-López. In press. Spatial patterns of cultural ecosystem services provision in Southern Patagonia. Landscape Ecology.

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Richards, D. R., and D. A. Friess. 2015. A rapid indicator of cultural ecosystem service usage at a fine spatial scale: Content analysis of social media photographs. Ecological Indicators 53:187–195.

Willemen, L., A. J. Cottam, E. G. Drakou, and N. D. Burgess. 2015. Using Social Media to Measure the Contribution of Red List Species to the Nature-Based Tourism Potential of African Protected Areas. PloS One, 10(6), e0129785.

3.7 Eco Chain Participatory Biodiversity Management

S. B. Roy & Raktima Mukhopadhay

3.7.1 Why would I use this method?

Perennial flows of natural capital such as biological resources, water and clean air are essential for achieving sustainable development for well-being. Disruption of ecosystems and the decline of ES are often caused by over-exploitation of biological resources. Without accountable public governance, compatible with the appropriate social institutions, no 'Scientific Theory' or 'Policy' will be effective (Roy & Mukhopadhyay, 2015). Approaches where the community and government functionaries work together in 'Participatory Biodiversity Monitoring and Management' are more likely to be successful.

Eco Chain is an approach to raise the awareness of local people with respect to the interdependence and relationships between different components of ecosystems in a given landscape which are interconnected like a chain, i.e. it is necessary to maintain biodiversity to preserve its associated ES. The approach aims to motivate people to conserve habitats and biodiversity through the process of Participatory Biodiversity Management. This blends scientific principles with indigenous knowledge and includes participation of the stakeholders in:

1. Identifying the problems;
2. Assessing the available resources and trade-offs;
3. Setting the goals; and

4. Developing action plans to reach the goals.

The method effectively involves local communities in finding solutions to arrest ecosystem degradation such as deforestation, which has its primary immediate negative impact on the indigenous local community themselves. It encourages local communities to spontaneously take responsibility to act and to monitor progress. Furthermore, including indigenous knowledge helps to build synergies between different approaches for conservation.

Finally, the approach has been shown to work and the Joint Forest Management program in India shows highly encouraging results in terms of checking deforestation through community participation. Through collaborative work between the community and forest field staff within the Indian Institute of Bio-Social Research and Development (IBRAD), simple yet scientific criteria and indicators were developed, as well as a template and checklist that can be used to diagnose forest degradation. Further work is expected to illustrate how the data collected are used to take up possible corrective action to improve ES through a cascading effect.

3.7.2 Requirements

The key to the entire approach is the identification of proactive leaders and raising awareness and engagement within the community to monitor drivers of degradation by developing effective social institutions. The local community and local government staff need to work together to conserve the ecosystem as a social movement, instead of as a project based on externally directed activities (Roy, 1996). To follow the Eco Chain approach it is necessary to have some trained staff, preferably with a social science background, who would work with the community and the local officials. Before conducting the session at the village level it is necessary to inform local officials and community leaders about the approach. An awareness-raising session is then organised in the village. The inclusion of different stakeholder groups is encouraged for collective social action for conservation. Conscious effort is made to involve women and other groups engaged in livelihoods that are dependent on biological resources.

A large photograph/banner with a map of the local area is created to demonstrate the current status of the forest ecosystem. This is used during the introductory session to facilitate discussion, and to make people understand the spatial distribution of different ecosystems in the area. It also stimulates the thought processes of the local people to understand the status and forces of degradation and the corrective actions that may need to be taken.

After the first awareness-raising session, the next step is to prepare inventories to assess the status of biodiversity, both species and genetic diversity, as well as their threat status. This is done by laying out quadrats on sample plots (normally 1% of the forest area is covered by laying the grids on the topographic sheet maps) that are georeferenced with GPS readings. This requires quadrats, GPS, measuring tapes, coloured paint and paint brushes.

Requirements		Comments
Data	☑ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data	Maps can be downloaded from Google Earth, threat can be assessed following Red Lists.
Type of data	☑ Qualitative ☑ Quantitative	Forest density and diversity, fragmentation status, water and soil condition, people's institutional mechanisms.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	Different stakeholders would discuss the interdependence of ecosystems following the map and transect walk. Other methods such as group discussions are integrated to involve the people in understanding the interdependence between social and psycho-cultural aspects.
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	
Time resources	☐ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☑ Long-term (more than 2 years)	
Economic resources	☑< 6 person-months ☐ 6-12 person-months ☐> 12 person-months	
Other requirements		

3.7.3 Advantages

- The approach provides information to support conservation strategy decision-making jointly between government agencies and the local community;
- The approach helps to prepare participatory plans for sustainable harvesting of biodiversity in a way that balances economic benefits for the community with the conservation of biodiversity and improved flow of ES.

3.7.4 Constraints and limitations:

- It is difficult to make the community aware of the implications of loss of biodiversity and decline of ES and to develop their own social norms to restrict the overharvesting of timber and other forest products;
- It is difficult to have a strategy for long-term community level planning unless they are trained appropriately in Participatory Biodiversity Monitoring and skill development for livelihood improvement based on available natural resources;
- It is difficult to involve the public forest field staff as they have little faith in the application of traditional knowledge.

3.7.5 Brief Description

The criteria to assess the degree of deforestation and biodiversity loss and understand the health of a given habitat, developed by involving the forest community, are the degree of forest cover fragmentation, standing biomass assessments, canopy cover, species richness, and quality of soil and water. The Eco Chain approach was developed for the two forest protection committees of Jamkanali and Jamirdiha of the Bankura district of West Bengal, India to assess their forest status and biodiversity, but the approach can be replicated elsewhere. An overview of the process is as follows:

Stage 1: Initial awareness-raising meeting

The first step is to raise awareness of the benefits the community will derive when their own ecosystem and its habitats are well conserved. A meeting is organised at which the forest staff and the community work together on visualising this and also on delineating their immediate loss, if the ecosystem is not conserved by their own efforts. The following sub-steps are followed during this awareness-raising stage:

- Conduct a meeting with community, local officials and local self government staff in the village itself.
- After introduction, show them the map and landscape (e.g. using freely available Google Earth images).
- Brainstorm with the participants to identify different components of the ecosystems such as forest, water bodies, agricultural field, grasslands, etc. in the designated landscape.
- Ask the participants about the relationships between these components.
- Make a list of interactions between the different components and ask them to write on the chart about the result of interactions (e.g. what happens when one component, say water, interacts with others like grassland, forest, etc.)
- On the chart write five items: i) Water ii) Forest iii) Agricultural fields iv) Animals and v) Humans and ask them three key questions:
    i. Which one of the components do the villagers not require for their survival;
    ii. How are these components inter-related and inter-dependent;
    iii. How can these components of the ecosystem be protected.
- After writing the answers though group discussion, each group presents their findings and (if appropriate with the particular stakeholder group) the best one can be awarded and recognised.

Stage 2: Institution building

After the presentation, volunteers are identified from among the group as proactive leaders who recognise the value of conserving the benefits from biodiversity. These leaders are tasked with forming a group of volunteers of like-minded people to work with the local government functionaries on Participatory Biodiversity Management. The drivers of degradation are then identified though participatory rural appraisal. The drivers are then ranked and the community are asked to identify solutions.

Stage 3: Diagnosis of status of health of the habitat and recording of baseline data by developing participatory criteria and indicators by involving the community

To assess the status of the habitat and develop a baseline, participatory transect walks and baseline surveys are performed for each unit of sub-ecosystems (e.g. freshwater, agricultural ecosystem, and the forest and its varied components). Baseline data should be collected on the nature and degree of degradation based on the following six criteria:

(i) The **degree of fragmentation**: This can be assessed by drawing a transect line on the map in the forest and walking the transect with the community. Community discussion about the degree of fragmentation is encouraged. Remote sensing maps can also be used to quantify the degree of fragmentation. Fragmentation of the forest can also be marked by community members using GPS.

(ii) **Canopy openness in the forest understorey is minimised**: Identify the canopy density of the forest by involving the community.

(iii) **Species guild structure**: Identify terrestrial, avifauna and aquatic species within the forest quadrat by involving the community following the quadrat method and laying sample plots. The community oversees how the abundance of insects, avian guilds and fruiting intensity in well-pollinated tree species is maintained.

(iv) Identification of **REET[6] and keystone Species**: Identification of flagship species and keystone species of the area are identified by consulting the community. They are also asked (a) which species are becoming rare, extinct, threatened at the local level and (b) how those species can best be restored (i.e what kind of corrective plan of action is needed). Species abundance data can be collected for use as an indicator for monitoring the effects and effectiveness of forest management. The process helps members of the community appreciate the diminishing rate of provisioning ES.

(v) **Soil structure, quality, moisture and rate of decomposition:** Discuss with the community about the status of soil, soil health and status of soil degradation and prepare plan of action on how to reduce overuse of chemical fertilisers to restore the soil health.

(vi) **Water condition**: Identify the water bodies and their status of degradation and plan for conservation through rainwater harvesting and other measures. All-season water levels in rivers and streams are a key indicator in this context and may indicate if sufficient forest cover remains to regulate flows, especially in dry seasons.

Stage 4: Develop conservation action plans

Action plans for conservation, eco-restoration and enhancing productivity are developed in consultation with the teams. These may include:

- Scientific management of land and rainwater such as in-situ moisture conservation, introduction of scientific production systems, network of run-off management structures;
- Developing a strategy for recharging of groundwater;
- Considering mechanisms for in-situ and ex-situ conservation of biodiversity;
- Organise trait-based training for livelihood development.

Stage 5: Equitable benefit sharing plans

The final stage involves working with the community to plan actions for equitable benefit sharing and building this into the conservation action plans.

[6] Rare, extinct, endangered or threatened

3.7.6 Further reading/references

www.ibradindia.org

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Roy S.B. (2013): Assessment of the functioning of Institutions: Criteria and Approaches; Journal of the Anthropological Survey of India, Vol. 61 (2) and 62(1), page 681

Roy S.B. and Mukhopadhyay Raktima (2015): Bilateral Matching Institution: Issues in Participatory Biodiversity Conservation and well - being of the community; paper accepted for publication in the Journal Man in India (No.5 2015), Serials Publications

Roy S.B. and Mukhopadhyay Raktima (2015): Participatory Biodiversity Management: Approaches to Institution Building to improve Ecosystem Services and Well Being; Paper sent for publication in the International Journal of Economic Research, Vol 12 No 3

4 European and global scale methods

4.1 Introduction

A number of global and European models were made available to provide context for the work done within the case studies. The intention was that the case studies would be able to cookie-cut the outputs from these models to a case study context by overlaying the boundary of the case study on the global/European model output. Of the available models, the OpenNESS consortium can offer specialised experience and support with three: ESTIMAP; the CLIMSAVE Integrated Assessment Platform (IAP) and GLOBIO-ES.

As the project has evolved, it has become clear that ESTIMAP can be customised to a case study context, and as such case studies have preferred to use this customised version of the model rather than a broadscale cut-out from the European scale dataset. For this reason only the CLIMSAVE IAP and GLOBIO-ES are still considered at the European and global scale. The application of both models is being developing in close collaboration with WP2 so that they can simulate the OpenNESS scenarios currently under development. This will provide interested case studies with the ability to see how the boundary conditions of their case studies may change in the different OpenNESS socio-economic scenarios. Currently case study 8 (bio-energy in central Germany) is actively working on using the global and European model outputs, whilst three other case studies have expressed an interest (Table 4.1.1).

Table 4.1.1: Case studies currently using or considering using gobal and European-scale modelling.

Case #	Case name	Country
8	Bio-energy in central Germany	Germany
2	Trnava urban case study	Slovakia
21	Costa Vicentina	Portugal
27	Barcelona	Spain

4.2 GLOBIO-ES

Clara Veerkamp & Maryia Mandryk

4.2.1 Why would I use this method?

GLOBIO-ES is a tool to assess past, present and future impacts of human activities on biodiversity and ES. Since 2000, GLOBIO has been extensively used for environmental assessment. Impacts on biodiversity are captured in terms of the biodiversity indicator Mean Species Abundance (MSA) and ecosystem extent. In 2012, GLOBIO-ES was developed to assess ES provision. The model has been applied at both the national and global scales (Schulp et al., 2012; Global Biodiversity Outlook 4 - Technical Report No 79).

4.2.2 Requirements

Requirements		Comments
Data	☑ Data is available ☐ Need to collect some new data ☐ Need to collect lots of new data	GLOBIO has been run for a number of scenarios and these are available through contact with PBL.
Type of data	☐ Qualitative ☑ Quantitative	
Expertise and production of knowledge	☐ Work with researchers within your own field ☑ Work with researchers from other fields ☐ Work with non-academic stakeholders	
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	GLOBIO has been run for a number of scenarios and these are freely available through contact with PBL.
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	
Other requirements		

4.2.3 Advantages

- *Global scale:* The model operates at the global scale;
- *Scenario analysis:* GLOBIO and GLOBIO-ES are able to perform scenario analyses and answer policy questions related to the state of global biodiversity and ES provision. (NB: This is possible due to its link to the global integrated assessment model IMAGE);
- *Broad range of drivers:* It allows the assessment of a broad range of drivers (e.g. economic development, land use change, climate change) in terms of their effects on biodiversity and ES in a consistent framework at a global scale;
- *Can explore policy-relevant impacts:* This enables the exploration of possible future changes with a scenario analysis, e.g.:
    - It can assess rates of terrestrial biodiversity loss in the absence of additional policies and measures;
    - It can assess how ES provision changes over time in the absence of additional policies;
    - It can identify the key pressures causing biodiversity loss and ecosystem degradation;
    - It can show how nature conservation policies and measures to reduce the key pressures of biodiversity loss and ecosystem degradation contribute to meeting the targets of the UN Convention on Biological Diversity (CBD).

4.2.4 Constraints and limitations

- *Parameter uncertainty:* As with any model there are associated uncertainties in the final parameters. These arise from parameterisation of cause-effect relationships, and uncertainties about the input data. Land use and land-use intensity parameters are particularly recognised to show the greatest uncertainties, although these have been relatively well studied;

- *Coarse spatial resolution:* The spatial resolution of land use and landscape composition is still rather coarse, and biodiversity and some ES (e.g. pest control and pollination) patterns often strongly depend on small landscape elements;
- *Limited models and scenarios:* The effect of climate change on biodiversity is based on a limited set of species distribution models and climate change scenarios. As the patterns of climate change are uncertain, and differ strongly between global climate models, the local impact of climate change on biodiversity is also subject to substantial uncertainty;
- *Resource restrictions:* Requires significant time, resources and expertise inputs;
- *Dependent on IMAGE*: GLOBIO currently strongly relies on outputs from the IMAGE global integrated assessment model, which needs to be run in advance to produce a consistent scenario;
- *Specialist software*: IMAGE is run from PBL in the Netherlands. As such, an interested party should contact PBL, the Netherlands Environmental Assessment Agency, to discuss the possibility of applying GLOBIO for policy-related assessments. Examples of previous GLOBIO applications can be found here: http://www.globio.info

4.2.5 Brief description

GLOBIO-ES works with cause-effect relationships between environmental variables and ES which have been developed based on literature review. The methodology closely links to the IMAGE (Stehfest et al., 2014) and GLOBIO (Alkemade et al., 2009) frameworks, and uses several spatially-explicit inputs on environmental drivers from IMAGE (e.g. climate, agricultural production) and GLOBIO (e.g. land use and land use intensity) to simulate future changes in ecosystem functions and services on a global scale.

Ecosystem function is modelled as the potential of the ecosystem to provide a service, and a service is modelled as the actual use of the function by humans (De Groot et al., 2002; Haines-Young and Potschin, 2010). GLOBIO-ES is available at a 0.5°x0.5° grid spatial resolution. Currently, 11 ES can be assessed with the GLOBIO-ES model, while the MSA value is simulated in GLOBIO. An overview of the ES currently assessed in GLOBIO-ES is given Table 4.2.1.

The close link to the IMAGE-GLOBIO framework enables the assessment of interactions between human development (e.g. consumption patterns) and the natural environment (e.g. climate) based on so-called key drivers (population growth, economic development, policy and governance, technology, lifestyle and natural resource availability). The future directions of these drivers are inferred from the storyline or narrative (such as from the OpenNESS storylines). With the help of the IMAGE-GLOBIO framework the key drivers are quantified and translated into land use and land use intensity data. External higher resolution data on land cover are derived from GLC2000 (Bartholome and Belward, 2005) and data on infrastructure from the GRIP database (Meijer and Klein Goldewijk, 2009). These data are combined with the World Database on Protected Areas (WDPA) (UNEP-WCMC, 2005) that distinguishes protected and non-protected areas. Change in land use and land use intensity is a key variable to assess ES provision and biodiversity in future environments.

The GLOBIO-ES model is being used to assess the effect of different OpenNESS scenario drivers on the state of biodiversity and ES in Europe and on a global scale towards 2050. Moreover, GLOBIO-ES modelling is applied in OpenNESS to quantity the effects of EU policy measures on biodiversity and ES in regions outside Europe.

Table 4.2.1: ES modelled in GLOBIO-ES following CICES typology (Haines-Young and Potschin, 2013).

Section	Division-Group	Class: Ecosystem service indicator used in GLOBIO-ES
Provisioning Services	Nutrition – biomass	**Cultivated food crop products:** max potential crop production [mg/km^2 cropland]; actual crop yield [ton/km^2 cropland] or [Kcal/grid cell]
	Nutrition – biomass	**Livestock products:** potential grass production; actual livestock production [ton/km^2 grassland]
	Nutrition – biomass	**Wild plants and animal products:** wild food availability [ton/km^2]; wild food accessibility [ton/km^2]
	Nutrition– biomass	**Fish products:** fish availability [kg/km^2]; fish accessibility [ton/km^2]
	Nutrition – water & Materials – water	**Surface water supply for drinking and non-drinking purposes:** annual water replenishment [m^3/grid cell]; annual water demand fulfilled by function [%]
Regulation & Maintenance services	Maintenance of physical, chemical, biological conditions – atmospheric composition and climate regulation	**Carbon sequestration:** Net ecosystem productivity [ton/km2/year]; % of country's emissions captured by ecosystems
	Mediation of flows – mass flows	**Soil erosion regulation:** erosion risk reduction by vegetation [%]; decrease of erosion risk in high utilised areas
	Maintenance of physical, chemical, biological conditions – lifecycle maintenance, habitat and gene pool protection	**Pollination:** Yield reduction fraction; pollinator-dependent yield [ton/km^2]
	Maintenance of physical, chemical, biological conditions – pest and disease control	**Pest control:** predation rate [%]; crop yield protected against pest [ton/km^2]; area protected against pest [km^2/grid cell]
	Mediation of flows – liquid flows	**Flood regulation**: flood risk reduction by ecosystems [%]; flood risk reduction in areas where protection is needed [%]
Cultural services	Physical and intellectual interactions with biota, ecosystem and land/seascapes – physical and experiential interactions	**Nature-based tourism:** landscape attractiveness index; accessibility index of attractive sites
Biodiversity		**Biodiversity:** Mean species abundance (MSA)

4.2.6 Further reading/references

GLOBIO Webpage: http://www.globio.info/

IMAGE website:
http://themasites.pbl.nl/models/image/index.php/Welcome_to_IMAGE_3.0_Documentation

Alkemade, R., van Oorschot, M., Miles, L., Nellemann, C., Bakkenes, M., ten Brink, B. (2009), GLOBIO3: A Framework to Investigate Options for Reducing Global Terrestrial Biodiversity Loss. *Ecosystems* 12, 374-390.

Bartholome, E., Belward, A.S. (2005), GLC2000: a new approach to global land cover mapping from Earth observation data. *International Journal of Remote Sensing* 26, 1959-1977.

De Groot, R.S., Wilson, M.A., Boumans, R.M.J. (2002), A typology for the classification, description and valuation of ecosystem functions, goods and services, *Ecological Economics* 41, 393-408.

Haines-Young, R., Potschin, M., (2013), *Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012*. European Environment Agency.

Haines-Young, R.H., Potschin, M.P., (2010), The links between biodiversity, ecosystem services and human well-being, in: D.G. Raffaelli, Frid, C.L.J. (Eds.), *Ecosystem Ecology*: a new synthesis. Cambridge University Press.

Meijer, J., Klein Goldewijk, K., (2009), *Global Roads Inventory (GRIP*). PBL Netherlands Environmental Assessment Agency, http://geoservice.pbl.nl/website/GRIP.

Stehfest, E., van Vuuren, D., Kram, T., Bouwman, L., Alkemade, R., Bakkenes, M., Biemans, H., Bouwman, A., den Elzen, M., Janse, J., Lucas, P., van Minnen, J., Muller, M., Prins, A. (2014), *Integrated Assessment of Global Environmental Change with IMAGE 3.0 Model description and policy applications*, The Hague: PBL Netherlands Environmental Assessment Agency.

UNEP-WCMC, (2005). *World Database on Protected Areas*.

4.3 CLIMSAVE Integrated Assessment Platform

Robert W. Dunford & Paula A. Harrison

4.3.1 Why would I use the method?

The CLIMSAVE Integrated Assessment Platform (IAP) provides options for the assessment of ES at a European scale using an integrated system of models for a number of different sectors. It can also be used to analyse the impacts of different climate and socio-economic scenarios on ES, and allows adaptation options to be explored. This enables ES synergies and trade-offs to be investigated at a European scale. The tool is freely available online and is interactive; it is appropriate for use on an individual's desktop or as part of a participatory discussion about potential futures. The model provides output at a 10' x 10' scale across Europe and all data for any model run are freely exportable as a .csv file. The data can be cookie-cut (using GIS) to a particular study area. It provides indicators related to the following ES: *Provisioning services:* food production; timber production; drinking water; *Regulating services:* water (forest soil water storage; river basin storage; water flow regulation); flood protection; climate (forest carbon balance) and pollination; *Cultural services:* recreation (skiing days); aesthetics (landscape 'naturalness' index).

4.3.2 Requirements

Requirements		Comments
Data	☑ Data is available ☐ Need to collect some new data ☐ Need to collect lots of new data	The tool is freely available online
Type of data	☐ Qualitative ☑ Quantitative	The tool provides quantitative outputs for a number or indicators including abiotic and biophysical parameters and ES indicators.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	There are no requirements in terms of who you would need to work with. The tool can be run independently online. However, the tool can equally be run with groups as a co-learning/exploration exercise.
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	
Other requirements		

4.3.3 Advantages

- The CLIMSAVE IAP is available online and can be run on any PC independent of specialist software (MicroSoft Silverlight is required but is free to download);
- It is particularly good at exploring synergies and trade-offs between ES at a European scale, how these change as a result of different adaptation options, and how they differ under different future scenarios;
- It is possible to explore both different future climate scenarios and different socio-economic scenarios and link these in any combination.

4.3.4 Constraints and limitations

- The tool is only available at either a pan-European scale or, at a country-scale, for Scotland;
- Individual countries are not modelled independently even though they are individually parameterised in many of the sub-models. Europe is treated as a whole and it is food provision at a European scale that drives many land use decisions;
- It is relatively simple to use: sliders are moved and options are chosen and then run; however, interpreting the results can be challenging, and is often made easier with support of a CLIMSAVE modeller.

4.3.5 Brief description

The CLIMSAVE IAP (http://www.climsave.eu/climsave/) is an interactive web-based tool that enables the user to explore complex issues surrounding impacts, adaptation and vulnerability to climate change at a European scale. It is freely available online and provides outputs from an integrated network of simplified sectoral models for urban growth, agriculture, forestry, water supply and demand, flooding and biodiversity. It has a user-friendly interface (see Figure 4.3.1) which allows the user to explore different scenario settings and how these affect a range of sectoral and ES indicators. There is also a Scottish version of the IAP available at a 5km x 5km grid resolution.

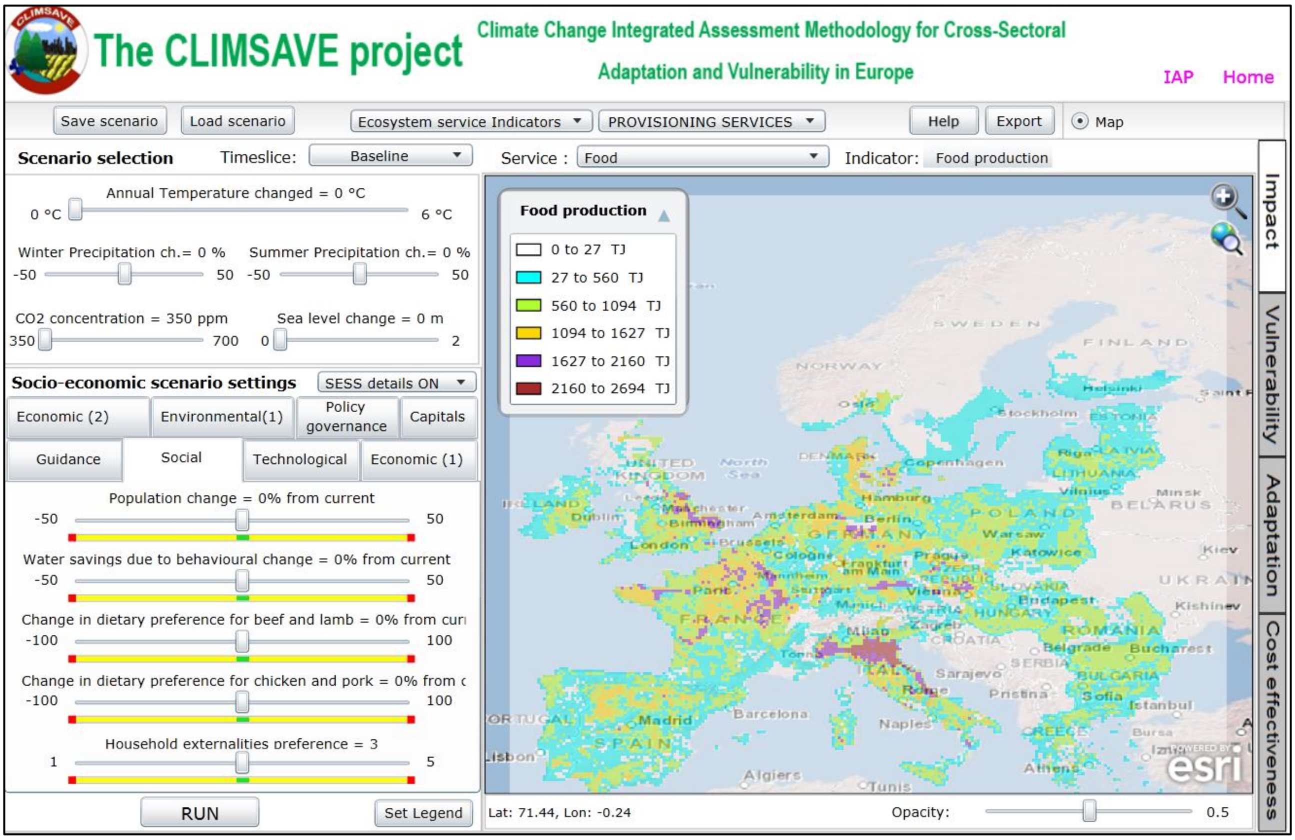

Figure 4.3.1: The CLIMSAVE user interface.

The CLIMSAVE IAP can be run for the 'baseline', using contemporary climate and socio-economic inputs, or for scenarios in the 2020s or 2050s. The tool is the product of a stakeholder engagement process in which four diverging scenarios of the socio-economic future of Europe were developed. The IAP also includes climate scenarios for five GCM[7]s which can be modified both in terms of SRES emissions scenarios[8] and climate sensitivity (high/medium/low). Any combination of socio-economic or climate scenario can be explored within the two future time-slices. In addition, the cross-sectoral implications of adaption measures on ES provision can also be explored by making use of the adaptation screen.

[7] Global Climate Models: HadGEM, GFCM21, IPCM4, CSMK3 and MPEH5

[8] Taken from the IPCC's Special Report on Emission Scenarios (2000)

The IAP is being applied to the OpenNESS socio-economic scenarios by manipulating the scenario settings. Model output for Europe can then be provided to any OPENNESS case studies for 'baseline' or for any combination of climate scenario with the OpenNESS socio-economic scenarios. The tool is designed to be exploratory and to be used at the European scale; it is not intended to provide definitive predictions at a local scale. As such, rather than cookie-cutting, the tool is probably best used by overlaying the extent of the target area so that it is possible to interpret the regional context with reference to similarities and differences elsewhere in Europe.

4.3.6 Further reading/references

Harrison, P.A., Holman, I.P., Cojocaru, G., Kok, K., Kontogianni, A., Metzger, M. and Gramberger, M. (2013) Combining qualitative and quantitative understanding for exploring cross-sectoral climate change impacts, adaptation and vulnerability in Europe. *Regional Environmental Change*, 13(4): 761-780.

Dunford, R.W., Smith, A.C., Harrison, P.A. and Hanganu, D. (2015) Ecosystem service provision in a changing Europe: adapting to the impacts of combined climate and socio-economic change. *Landscape Ecology*, 30(3): 443-461.

Harrison, P.A., Dunford, R., Savin, C., Rounsevell, M.D.A., Holman, A.S., Kebede, A.S. and Stuch, B. (2015) Cross-sectoral impacts of climate change and socio-economic change for multiple, European land- and water-based sectors. *Climatic Change*, 128: 3-4.

5 Discussion and conclusions

This Section discusses why different case studies chose to test certain methods and their views on the various advantages and disadvantages of the main methods resulting from this testing. This information is being used to develop and evaluate more generic guidance tools for ES method selection in different contexts, and preliminary ideas are presented in the form of a set of decision trees. These decision trees, and other possible formats for providing guidance, will be further refined for D3.4 (the final guidelines) and for implementation into the Oppla web platform.

5.1 Why did case studies choose particular methods/models

Deliverable 5.2 collected a questionnaire-based dataset in which case study leaders were asked to fill in using their own words:

(i) which methods they selected for use within the project;
(ii) the key problem that they intended to address with this method; and
(iii) their reason for the selection of that particular method.

Table 5.1.1 lists their responses, grouping them into four major categories (methodological requirements, research-oriented, stakeholder-oriented and decision-oriented), with some reasons fitting into more than one category (as shown in the third column). Figure 5.1.1 shows a hierarchical classification of the reasons given. The classification was developed to be applied to both WP3 (biophysical) and WP4 (valuation) methods.

Table 5.1.1: Reasons given by the OpenNESS case study teams about why they selected a specific method/model.

Broad reason	Specific reason	Can also belong to…
Methodological requirement:		
Data	Existing data available	
Expertise	Available in the team Available in the consortium Ease of use	
	Local knowledge	Stakeholder-oriented
Time resources	Speed of use Ease of use	
Economic resources	Small team required Cost-effective	
Spatial scale	Enables spatial analysis Spatially-explicit	
Temporal scale	Enables temporal analysis Temporal scales	
	Scenarios can be explored	Decision-oriented Research-oriented
Uncertainty	Can explore/address uncertainty	Decision-oriented Research-oriented

Broad reason	Specific reason	Can also belong to…
Research-oriented:		
Uncertainty	Can explore/address uncertainty	Methodological requirement Decision-oriented
Novelty	Knowledge advancement Method addresses a research need	
'Well-accepted' approach	Recognised approach Established approach	
Improvement of methods	Test the utility of method Refine existing approach Approach that combines previously un-combined elements Approach that goes beyond simple models Build experience	
Comparability	Possibility to replicate in other research sites Results are comparable with other research sites	
Stakeholder-oriented:		
Facilitate stakeholder participation	Stimulate sharing views and knowledge Encourage stakeholder discussion Foster social learning Method easy to explain to non-academic stakeholders	Methodological requirement
Co-design and co-production of knowledge	Chosen by stakeholders Explore suitability of approach with stakeholders Include expert knowledge from outside the research team Include local non-academic stakeholders	
	Local knowledge	Methodological requirement
Uncertainty	Can explore/address uncertainty	Methodological requirement Research-oriented
Decision-oriented		
Raising awareness	Gain/improve understanding of the system Dissemination and pedagogical objectives	
Issues of concern	Covers many ecosystem services Facilitates representation of cultural/spiritual values Trade-offs can be addressed	Stakeholder-oriented Methodological requirement
Planning management relevance	Is relevant for planners/managers	Stakeholder-oriented

Analysing the major groupings of reasons for selecting biophysical methods, methodologically-oriented considerations are the most common (41%, with 11% being scale-related). Research-oriented considerations are also important (28%) and decision-oriented and stakeholder-oriented reasons contribute 16% and 15% respectively (Table 5.1.2).

Table 5.1.2: Frequency of groupings of reasons for selection of biophysical methods.

Reason given (major grouping)	% of responses
Methodology-oriented	41%
Research-oriented *(of which scale-oriented*	28% *11%)*
Decision-oriented	16%
Stakeholder-oriented	15%

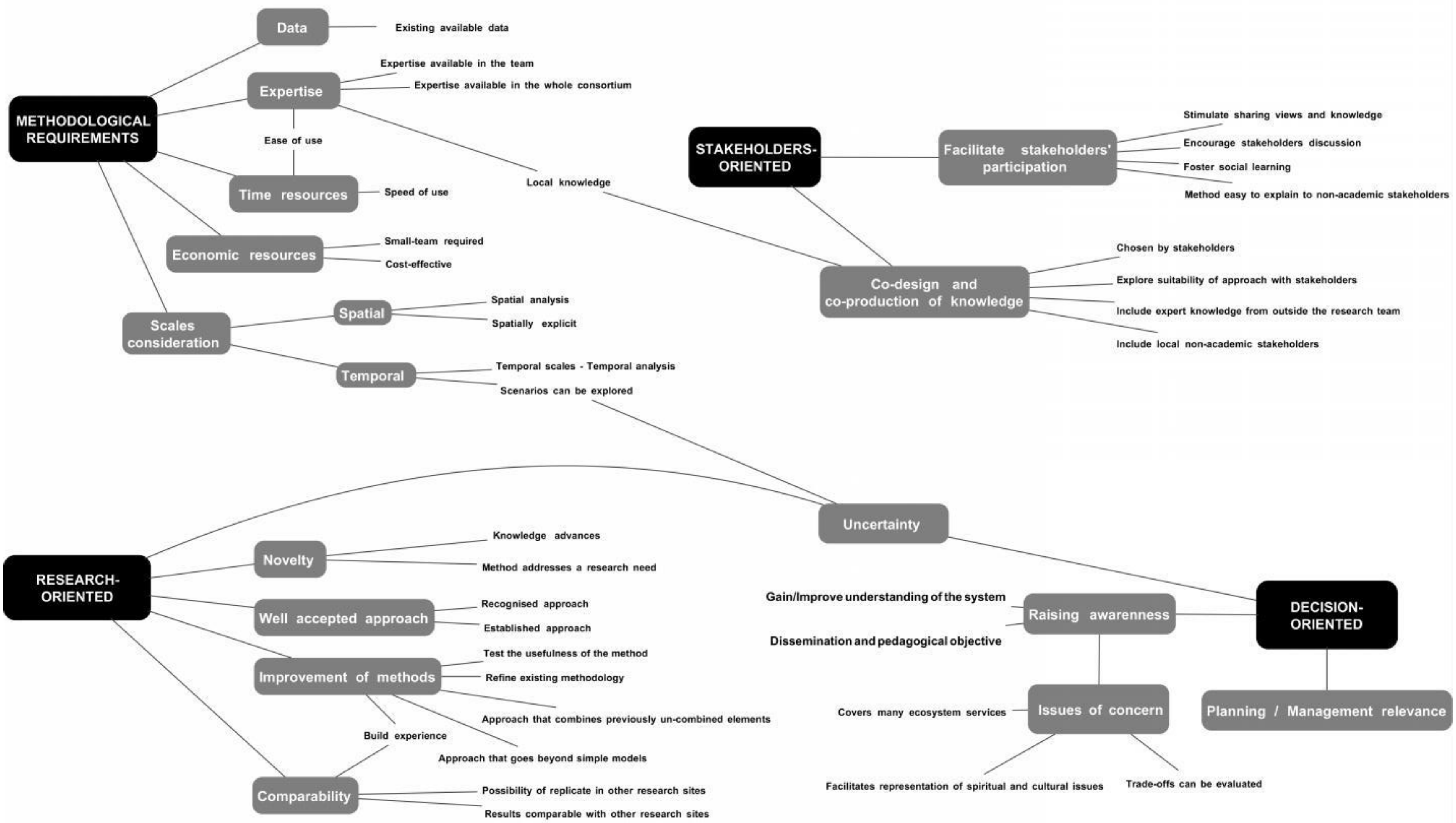

Figure 5.1.1: Hierarchical map showing the reasons for selection of methods/models.

Looking at individual reasons (Figure 5.1.2), the consideration most commonly mentioned (17%) is the research-related criteria 'novelty', which includes all comments which reflect the importance of approaches that advance knowledge, address a new area or prioritise a research need. As the questionnaire was given to the research-leaders of the case studies, perhaps this result is not surprising. The second and third most commonly mentioned considerations are pragmatic, methodological issues relating to the availability of expertise and data (both >10%). Spatial scale and stakeholder participation are also important considerations at 9% of the total. Compared to these, decision-related considerations and other research-related considerations are more rare, with none exceeding 8% of the total and most being less than 6%.

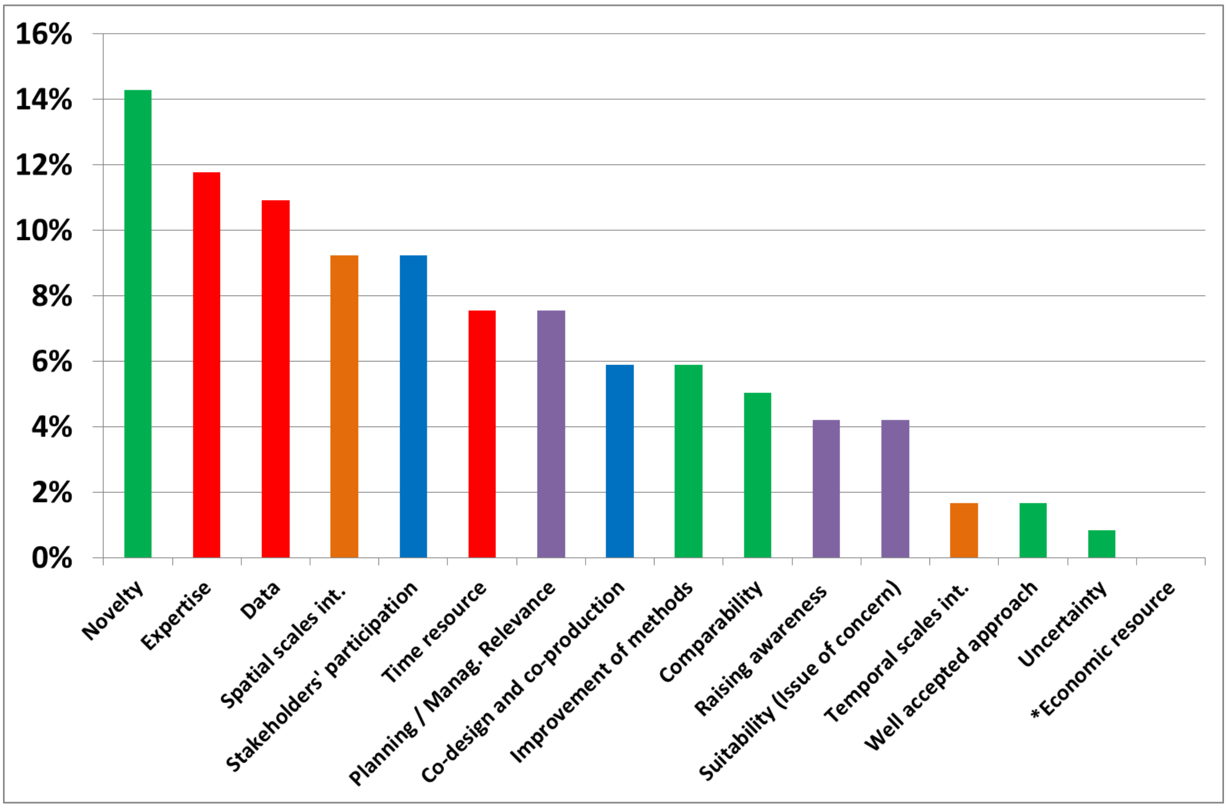

Figure 5.1.2: Reasons (considerations) for selection of the six main biophysical methods from interpretation of the D5.2 questionnaires. Units are the proportion of the total references linked to biophysical methods (n=119). Colours show the hierarchical groups: Green = research-oriented; red = methodology-oriented; orange = scale-oriented; blue = stakeholder-oriented; purple = decision-oriented. (*No responses for the six biophysical methods referred to economic resources).

Looking at the considerations by individual model highlights some interesting patterns (Figure 5.1.3). Spreadsheet approaches have a higher proportion of decision-oriented considerations (purple) than other approaches, with planning- and management-relevance and awareness-raising only mentioned in relation to spreadsheets. ESTIMAP and InVEST have a higher proportion of research-related considerations than the other methods, including BBNs which have a similar number of responses to ESTIMAP. The 'well accepted approach' consideration is only used with reference to ESTIMAP. 'Uncertainty' is only mentioned with reference to BBNs – which is understandable as they are an approach designed to deliberately explore issues of uncertainty via conditional probability. Stakeholder-based considerations are mentioned with reference to all methods with the exception of InVEST. As InVEST doesn't have an explicitly stakeholder-facing approach this is reasonable, but it may also reflect the low number of responses related to InVEST. Scale-related issues are raised with reference to all methods; however, spatial scale dominated the Spreadsheet, QUICKScan, InVEST and ESTIMAP approaches whereas temporal scale is only highlighted with reference to BBNs and STMS. This is again expected as these approaches are much better suited to deal with temporal stiuations, with STMs particularly being designed to explore change through time. Pragmatic methodological considerations are important (>=25-30% in most methods), though time is only highlighted as a consideration with the Spreadsheet and QUICKScan approaches, where comments show that the speed of these methods is an important factor. ESTIMAP is unusual in that it has very few considerations related to methodological concerns, despite being a relatively technologically advanced and data-intensive approach. This may reflect the level of technical support on ESTIMAP offered within the consortium.

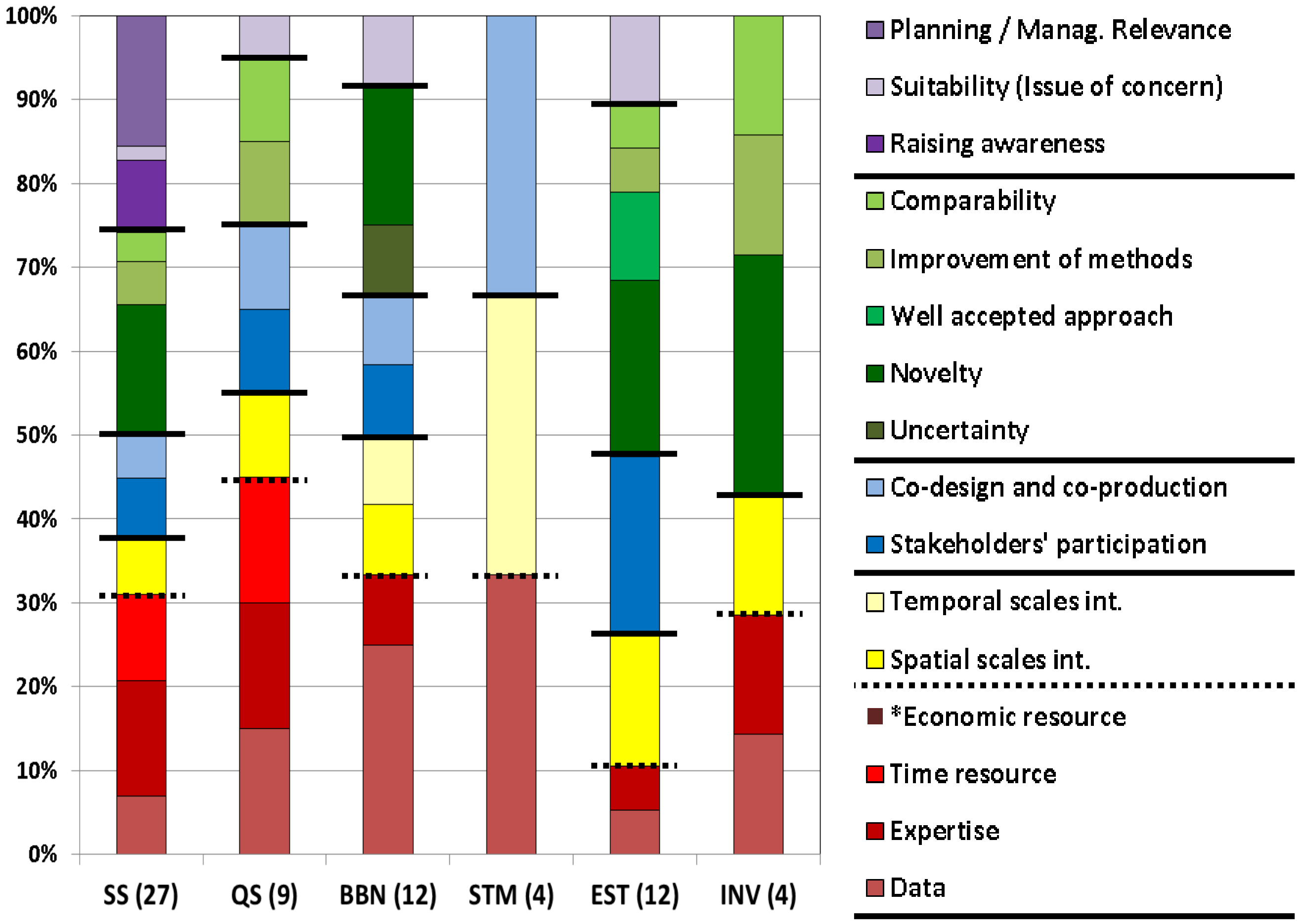

Figure 5.1.3: Reasons (considerations) from the interpretation of the D5.2 questionnaires matched to the six main methods as a proportion of total case study sub-projects assessing the given approach. SS = Spreadsheets/GIS; QS = QUICKScan; BBN = Bayesian Belief Networks; STM = State and transition models; EST = ESTIMAP; INV = InVEST. The number in brackets is the number of responses on which the proportions are based. Dividing lines separate the main groups of considerations. (*No responses for the six biophysical methods referred to economic resources).

5.2 Advantages and disadvantages of the methods

To build on the findings from D5.2, a session focusing on evaluation of methods was organised at the Barcelona Annual Meeting (April 2015). Case study representatives were split into groups and asked to summarise their views on the methods they had chosen to undertake. Each group filled in a table on an A0 poster. For each of the six selected methods, they stated whether they used the method, and answered three follow-up questions:

(i) If they chose not to apply the method, why did you decide not to use the approach?
(ii) If they chose to apply the method, what do you consider to be the main advantages of the approach?
(iii) If they chose to apply the method, what do you consider to be the main disadvantages of the approach?

Table 5.2.1 summarises the results. It highlights that, for some methods, factors that act as advantages and disadvantages are often two sides of the same coin. The spreadsheet approach, for example, is widely praised for its ease of use, its speed of application and the fact that it is spatially-explicit and can involve stakeholders. However, these strengths are also its weaknesses: it is seen by some to depend too strongly on expert knowledge and simplistic generalisations, which one participant stressed gave it a 'false impression of completeness'. Similarly, BBNs are shown to be well suited to handle uncertainty in a flexible, participatory manner, however, they are seen to be difficult to understand and use in a public setting due to the fact that they use probabilities rather than 'real actions'. The opposite is true for ESTIMAP and QUICKScan. The ESTIMAP approach is seen to have the advantage of being a simple, easy to understand, spatially-explicit approach that can be tailored to particular case studies, whilst at the same time the approach is criticised for requiring GIS skills that extend beyond basic levels. The level of support is also given as an advantage of the approach and it may be that without this support the approach seems daunting. Similarly, QUICKScan is seen to have the advantage of being quick and encouraging stakeholder involvement and co-production of knowledge but at the same time the technical expertise required, and the need for detailed local knowledge to make the approach believeable are seen as negatives. STMs and InVEST were discussed by very few respondants but both highlighted their key advantages, i.e. the ability to address change and assess trade-offs between services respectively.

The most common reasons cited for not using a method were pragmatic issues. A lack of experience with the method and problems with data availability were mentioned at least once with reference to each of the six methods. A lack of time and resources was also mentioned as a key factor for QUICKScan, InVEST and ESTIMAP. The perception of difficulty/complexity was also highlighted as a reason for not using a number of the more technical approaches (BBNs, STMs and InVEST) and the inappropriateness of the tool at the spatial scale of the case study was raised as an issue for ESTIMAP and InVEST. QUICKScan was unique in that the commercial nature of the software was seen as a barrier to its uptake by three of the case studies.

Table 5.2.1: Overview of advantages and disadvantages of the methods identified through the Barcelona session. Numbers in brackets are the number of comments on a particular consideration.

Advantages/ Reasons why used	Disadvantages/ Reasons not used
Spreadsheet/GIS	
Advantages (16): Easy to use (10) Quick (4) Can involve stakeholders (5) Spatially explicit (3) Can use available data (2) Suitable for planning (2) Can explore scenarios (1)	**Disadvantages (13):** Simplistic/generalisations/expert-based (9) Dependent on available data (2) Social data is hard to collect (1) Difficult to tailor to local context (1) False impression of completeness (1) **Why not used (3):** Lack of available data (1) Lack of expertise (1)
ESTIMAP	
Advantages (6): Simple, easy to understand (4) Flexible to case study (3) Able to incorporate stakeholder knowledge (3) Spatial approach (3) Can use existing data (1) Constant support from method leader (1)	**Disadvantages (6):** Goes beyong basic GIS expertise (3) Limited input parameters, over simplification (1) Demanding in terms of local knowledge (1) Reliant on data (1) **Why not used (11):** Lack of available data (3) Lack of expert (2) Time constraints (3) Unclear on added-value over existing approaches (2)
BBNs	
Advantages (7): Can be used in a participatory manner (5) Can explicitly handle uncertainty (2) Easy to apply and flexible (1) Good for visualisation (1) Can be relevant for planning (1)	**Disadvantages (5):** Difficult/ Complicated / Needs expert knowledge (4) Difficult in a public awareness-raising setting (1) Probabilities subjective/not 'real actions'(2) Spatial BBN not flexible like a GIS (1) Data requirements (1) **Why not used (11):** Looked complicated/ no expert (5) Lack of available data (3) Time constraints (1)
STMs	
Advantages (1): Can assess change (1)	**Disadvantages (1):** Data availability (1) **Why not used (11):** Lack of expertise (3) Lack of available data (2) Time/ Resources lacking (2) Appears difficult (1) Unclear on added value over existing approaches (1)
QUICKScan	
Advantages (4): Transparency (2) Visually impressive (2) Quick approach, real-time results (2) Encourages stakeholder participation (2)	**Disadvantages (3):** Technical expertise/ complexity of software (2) Several technical problems (1) Constant need for support from method leader (1) Need for detailed local knowledge to make believable (1)

Advantages/ Reasons why used	Disadvantages/ Reasons not used
Co-design and co-production (1) Support from method leader (1)	**Why not used (12):** Time/ Resource lacking (4) Licencing issues (3) Unclear on added value over existing approaches (3) Lack of expertise (2) Lack of available data (1)
InVEST	
Advantages (2): Spatial approach (2) Allows integration/ trade-off analysis (2)	**Disadvantages (3):** Input data hard to get and demanding (2) Black box/ Inflexible (1) Has errors (1) **Why not used (14):** Time/resources lacking (5) Lack of available data (3) Different approach used instead (3) Lack of expertise (2) Approach looks complicated (1)

Other less specific arguments also used included: ‘we may still use this method, we just haven’t yet; ‘the method is not appropriate/relevant to the specific problem in our case study’; ‘we are using a different method instead’. Another important reason that was raised regularly for STMs, ESTIMAP and QUICKScan was ‘it is unclear what added-value this method offers over current practice/another method’, with the similarity to standard GIS-based approaches (with which users were more familiar) being questioned.

5.3 Decision trees for choosing particular methods/models

By drawing on the considerations identified in D5.2 and the advantages and disadvantages of the different methods highlighted in Barcelona, preliminary decision trees were constructed with the aim of helping to guide future practitioners in choosing ES methods appropriate for their context. The work took place in collaboration with WP4 (valuation methods), and a hierarchical decision tree was constructed that, at the top level, guides stakeholders to one of four main classes of methods: (i) modelling approaches; (ii) mapping approaches; (iii) socio-cultural techniques; and (iv) monetary methods.

A preliminary top-level decision tree is presented in Figure 5.3.1. A second level of decision trees has been developed for the user to follow once they have been led to one of the four main classes. Preliminary decision trees for the biophysical methods (modelling and mapping) are presented in Figure 5.3.2 and Figure 5.3.3 below. These decision trees are seen as a very preliminary first step to structure all the knowledge gained on the different methods. They are currently being refined through consultation with the case studies (see below) and a number of improvements have already been identified, for example to emphasise the importance of local knowledge and stakeholder engagement in a wider range of situations.

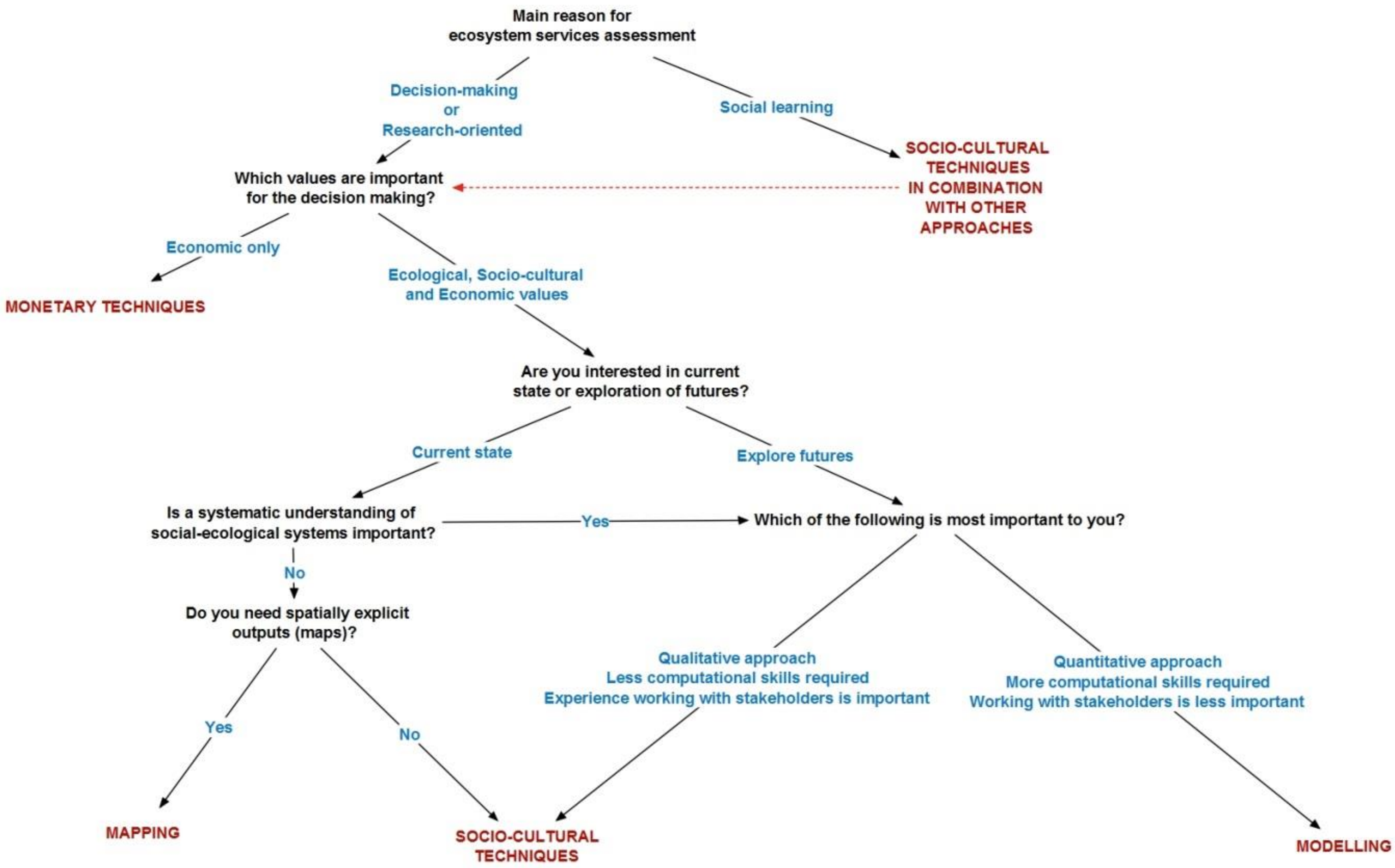

Figure 5.3.1: Preliminary example of a decision tree for selecting different methods at the top level of the hierarchy.

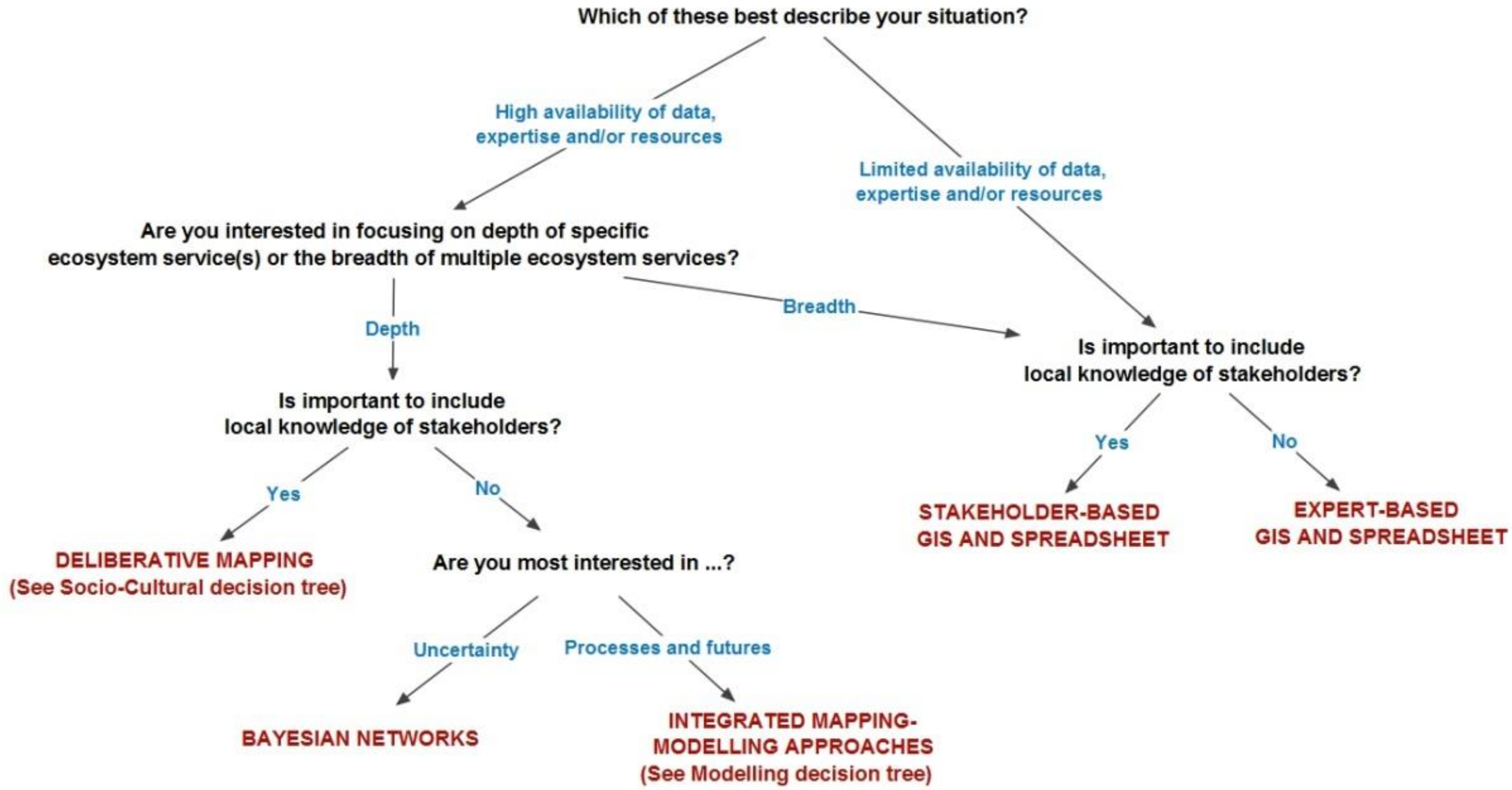

Figure 5.3.2: Preliminary example of a decision tree for selecting different methods related to ES mapping approaches (methods in red are examples based on the OpenNESS case studies and do not represent an exhaustive list of possible methods).

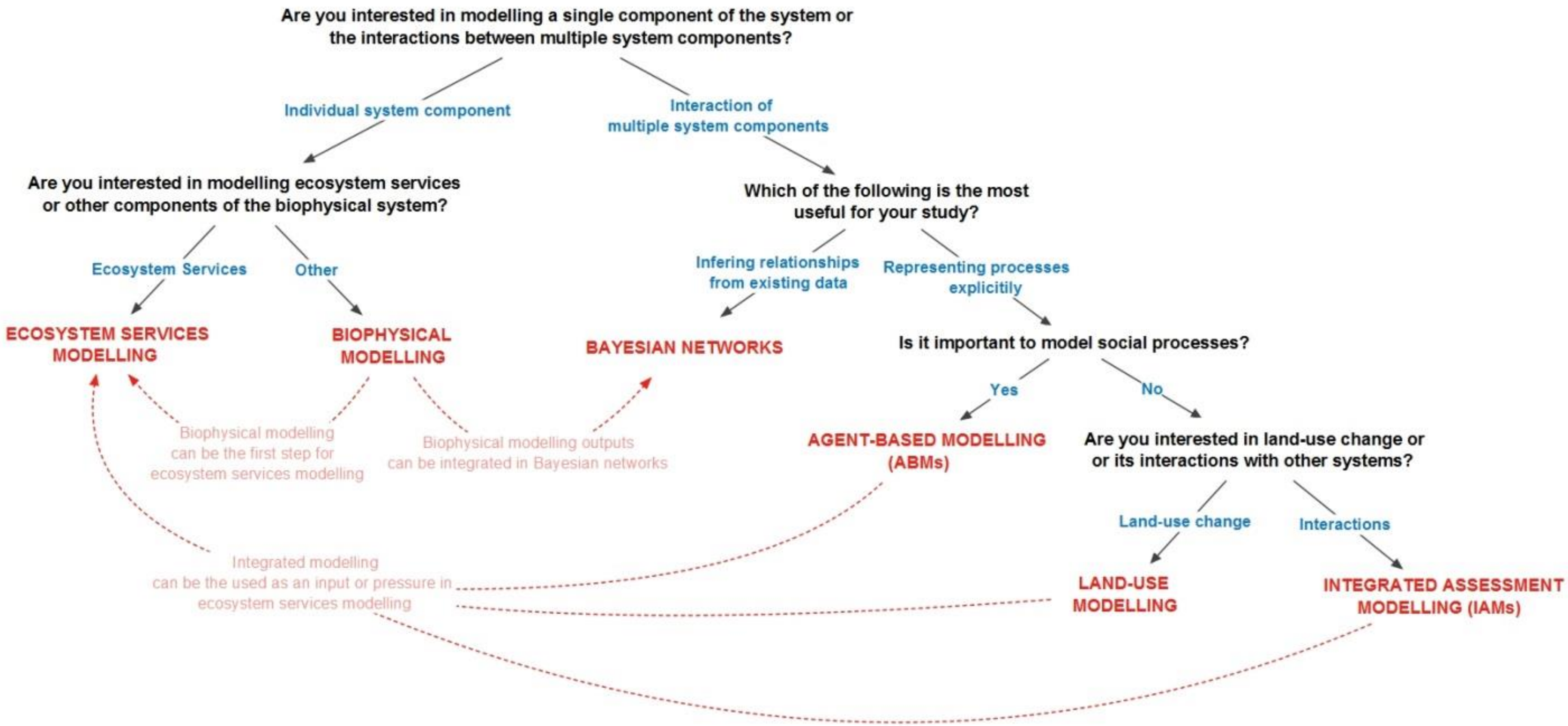

Figure 5.3.3: Preliminary example of a decision tree for selecting different methods related to ES modelling approaches.

To better understand the decision-making process surrounding tool selection, a series of sessions were organised at the cross-project workshop in Leuven (October 2015) to test the decision trees in the contexts of the OpenNESS case studies. Case studies were assembled in groups of four, each with a designated facilitator from the WP3-4 team that developed the decision trees. Thus, each case study worked one-on-one to describe: (i) the decision process that they followed in practice when they decided which methods to use; (ii) the extent to which the decision trees the WP3-4 team had developed matched the case studies' 'true' experience of deciding between methods; and (iii) how they would improve the decision trees so that they might be more useful for others.

The outputs from this 1.5 day set of sessions are currently under analysis. Twenty individual case studies were assessed and each produced between 1 and 5 annotated decision trees (e.g. Figure 5.3.4) and an A0 map describing their decision processes surrounding the methods they chose to combine (e.g. Figure 5.3.5).

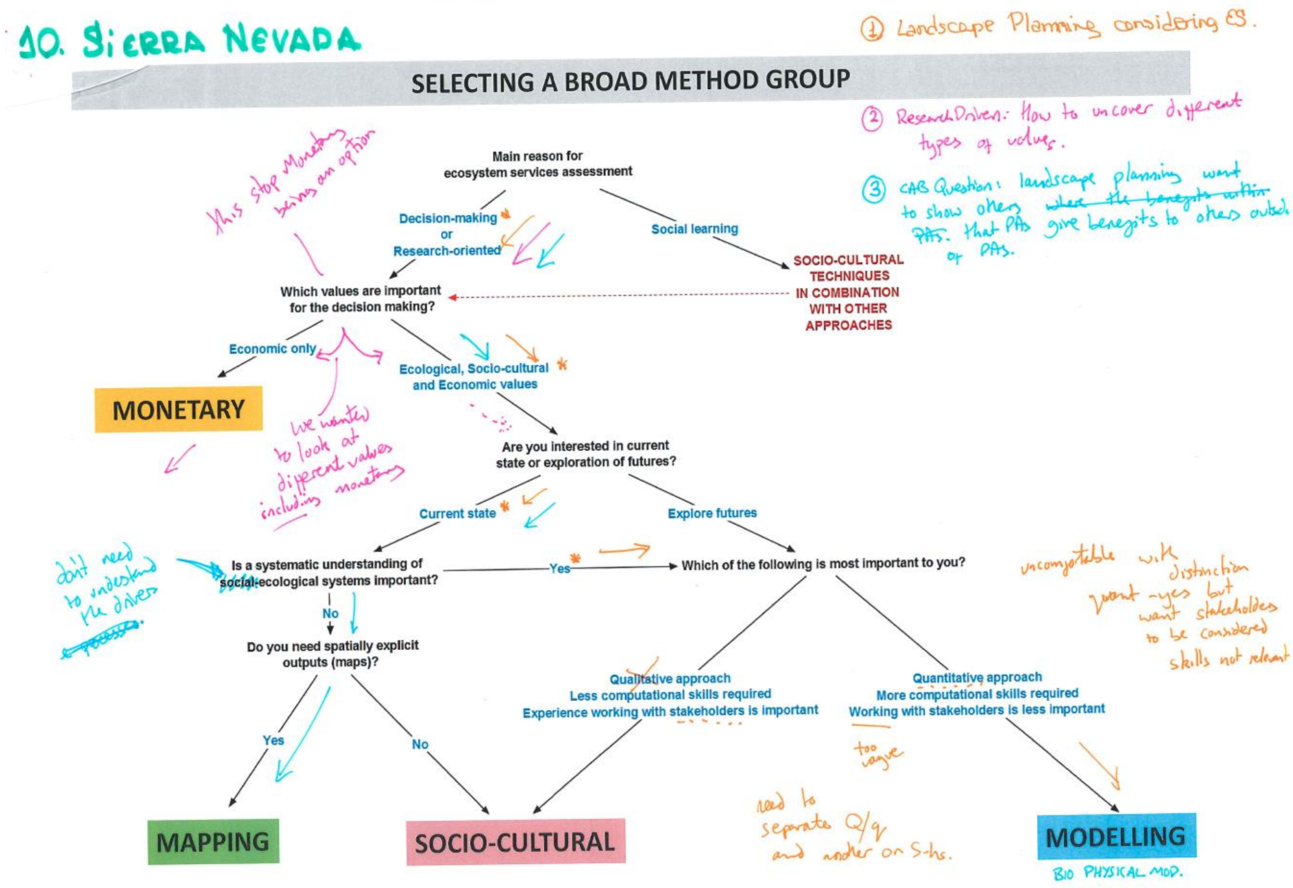

Figure 5.3.4: Example of an annotated decision tree (from CS10 Sierra Nevada, Spain) on which case studies explained where the decision tree led them, and how this matched (or didn't match) the decisions they took in practice as well as highlighting how the trees could be improved to make them easier for others to follow.

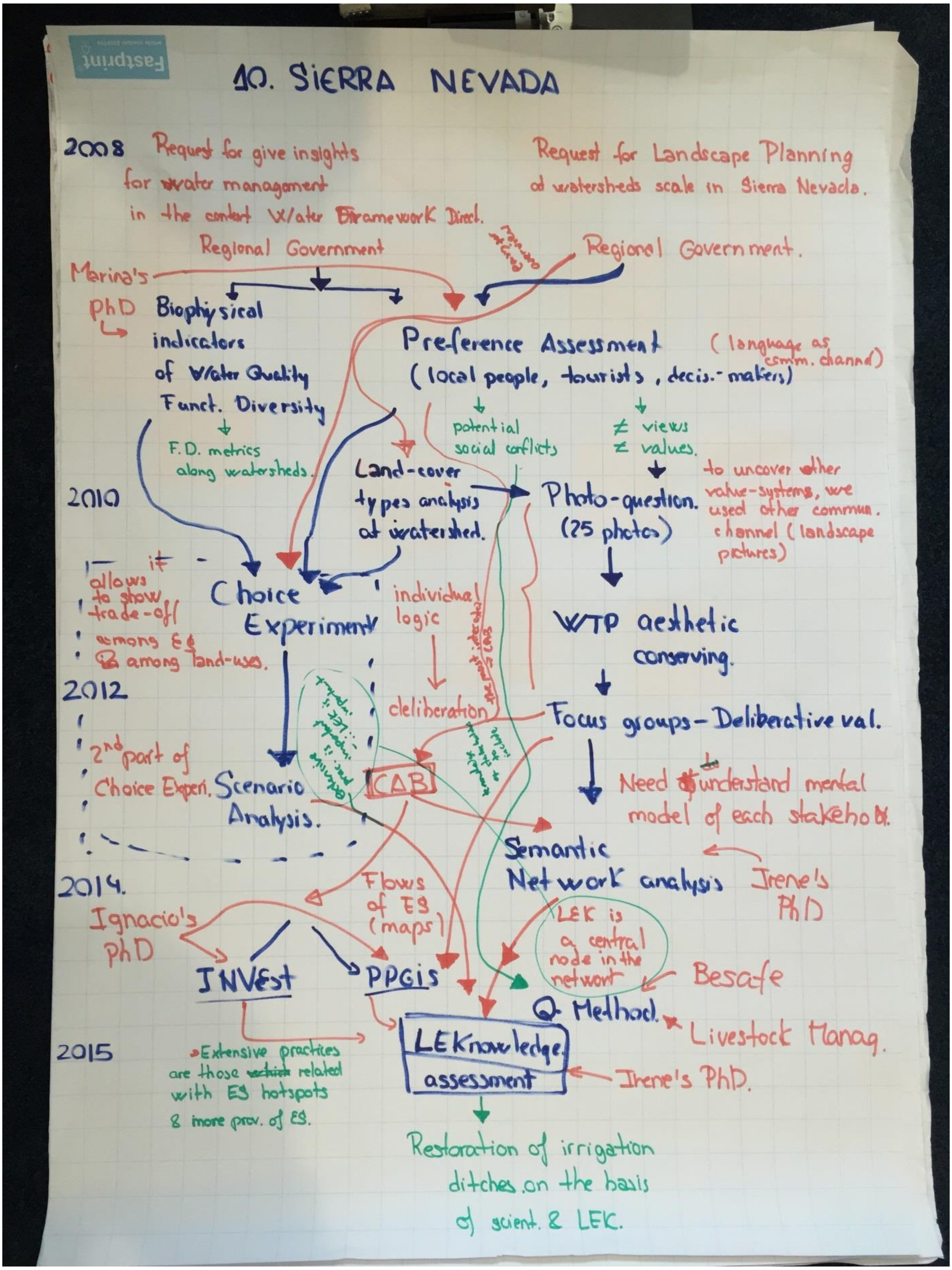

Figure 5.3.5: Example of the free-form decision tree (from CS10 Sierra Nevada, Spain) on which case studies explained how they came to the decision as to which methods and models to combine.

Early findings indicate that most case studies found the decision trees (or parts of them) broadly useful, but it is necessary to accept that they present a simplified view compared to the real context of the case studies. Many case studies also stated that it would have been useful to have them at the beginning of the project. Several suggestions were made for potential improvements which would make the decision trees more widely applicable and useful for a non-specialist. These included:

- Introductory material is needed which explains the purpose of the decision trees and that it is important for users to reflect on the purpose of their case study and its local context before starting to work with the decision trees.
- There is a need to show how the four broad categories (mapping, modelling, socio-cultural and economic) overlap or link to each other. Guidance on how the methods complement each other and how they can be used together would be valuable.
- Do we need different decision trees/entry points for different user (researchers, decision-makers and planners were identified) or can we design a set of trees that is useful to all? Starting with a question related to the purpose of the ES study may help.
- The bimodal structure was problematic in several cases; a multi-modal structure or matrix with less strict (i.e. yes/no) choices was preferred.
- There were parts when users were challenged to go down routes that they didn't want to or got to dead ends. Different ways to get to the same method would be useful. In particular, it was difficult to get to the monetary valuation decision tree.
- Some questions were difficult to understand; the language needs to be simplified. A way of explaining the terms in the decision trees (e.g. tooltips when implemented) would be useful.
- The questions should be more concrete and contain only one statement, not several. This will be difficult to handle where multiple selection criteria are involved in the choice of a method as path-dependency problems will become more evident.

5.4 Conclusions

This deliverable has provided guidelines for the application of the six main methods/models which have been applied broadly across a large number of the OpenNESS case studies and summaries for a number of additional biophysical methods selected for use by individual case studies and those applied at the global and European scales. It has also summarised progress in the development of practical guidance to help researchers and practitioners in their selection of biophysical methods, building on the case studies' assessment of these tools. To develop final, comprehensive guidance to assist practitioners in selecting methods for the final project deliverables D3.4 (and D4.4), there is a need to extend the work presented so far by:

(i) improving our understanding of how methods are combined to address real practitioner problems;
(ii) further developing guidance to assist practitioners in their decision-making on which tools to use;

(iii) further testing different ways of structuring and visualising this guidance as interactive tools within Oppla (together with the OPERAs project).

The first step (how methods are combined) will build on existing data collected at the Barcelona annual meeting, where case study representatives were asked to display, using the ES cascade framework as a backdrop, how they linked methods in practice to achieve the work in their case study sub-projects. This highlighted a number of interesting aspects that will be investigated in further work, including the fact that the ES cascade is rarely followed in a systematic order. Case studies do not necessarily start by assessing biophysical parameters, evaluating the services they provide and then assigning values to these. In fact, in a number of cases, valuation methodologies are used at the start of the chain to determine which ES should be the focus of a study. This can then be followed by the use of biophysical methods to quantify the supply of the selected services, before valuation is applied once more through expert weighting of the quantified ES supply values. These chains of linked methods will be further investigated by WPs 3 and 4 in Deliverables 3.4 and 4.4 using the Barcelona session data and the case study free-form decision trees from the Leuven workshop.

The second and third steps (developing guidance) will build on the preliminary decision trees, the case-study annotated decision trees from Leuven and the feedback from the post-workshop discussion in Leuven. The decision trees themselves will be improved, taking the feedback into consideration, and mechanisms to include them as guidance within Oppla will be explored. Furthermore, alternative decision-support methods will be explored, building on the decision trees. These may include implementing the decision trees in a BBN, as a matrix of multiple suitabilities (recognising that often many methods may be suitable for a particular context) or as an interactive website-style decision tree. This work will also be presented in Deliverables 3.4 and 4.4, and ultimately the information underlying the decision-support tools will be implemented in Oppla.