JNCC Report 815

Review of Land Use Decision Support Tools: An assessment of spatial prioritisation and optimisation tools for ecosystem services and benefits

Barber, R., Conquest, A., Hawker, J., Neaves, J., Randle, B. and Roberts, E.

April 2026

ISSN 0963 8091

JNCC's report series serves as a record of the work undertaken or commissioned by JNCC. The series also helps us to share, and promote the use of, our work and to develop future collaborations.

For further information please contact:
JNCC, Quay House, 2 East Station Road, Fletton Quays, Peterborough PE2 8YY.

https://jncc.gov.uk/

Communications@jncc.gov.uk

This report was produced for JNCC under an external contract, by Land Use Consultants (LUC) under C23-0607-1845.

This document should be cited as:
Barber, R., Conquest, A., Hawker, J., Neaves, J., Randle, B. & Roberts, E. (2026) Review of Land Use Decision Support Tools: An assessment of spatial prioritisation and optimisation tools for ecosystem services and benefits. *JNCC Report 815*. JNCC, Peterborough, ISSN 0963-8091. https://jncc.gov.uk/resources/12347f68-65f0-4574-a95a-8d27e71fc04b

Acknowledgments:
We would like to thank the developers of the tools reviewed in this report for their time and valuable feedback on the draft material. We also wish to acknowledge Anna Deasey and Izzy Hartley for their contributions in the early stages of this work, and Gwawr Jones and Emma Wright for their ongoing input.

Evidence Quality Assurance:
This document is compliant with JNCC's Evidence Quality Assurance Policy.

Summary

This report was commissioned by the Joint Nature Conservation Committee (JNCC) and produced by LUC in 2024. It provides a high-level overview of land use decision support tools available in the UK at the time of writing, based on publicly available information (user guidance documents and published literature) supplemented by voluntary input from tool developers.

The aim of the project was to develop an understanding of the technical approaches used by existing land use decision support tools that spatially prioritise or optimise interventions to achieve multiple ecosystem services (ES) and environmental benefits. The key objectives for the project were to:

- Critically review and describe the analytical methods used by decision support tools to prioritise or optimise interventions to deliver environmental benefits.
- Describe the relative strengths and limitations of these tools to inform future analytical processes to spatially prioritise land management interventions

Building on previous work by JNCC, this review investigates 13 tools that met identified criteria: where the tool:

1) explores ES/benefits relevant to land use decision making in the UK,
2) performs prioritisation/optimisation, and
3) includes three or more ES or benefits.

To aid comparison, tools are grouped into broad categories based on their primary functions, modelling approaches, and use cases. These groupings are indicative, as in practice, the boundaries between many of these categories overlap.

This review is intended as a starting point for readers to explore the range of tools available, understand their broad capabilities, and identify those most relevant to their context. For the most current and detailed information, readers should refer directly to tool developers or their websites (see Table 1).

Contents

1. Introduction ... 1
1.1. Background ... 1
1.2. Aims and objectives ... 1
1.3. Land use decision tools and their use in an agri-environment context ... 1
1.4. Previous reporting by JNCC ... 3
2. Methods ... 5
2.1. Rapid evidence review ... 5
2.2. Review of priority tools ... 6
2.2.1. Reviewed criteria ... 6
2.2.2. Typologies for categorisation ... 7
2.2.3. Assessment of literature ... 7
2.2.4. Developer engagement ... 7
2.3. Review of other tools ... 7
2.4. Ecosystem services (ES) – context for this report ... 8
3. Review of existing tools ... 9
3.1. Overall review of priority tools ... 9
3.2. Basis of the tools: modelling of ecosystem services or relative scoring of benefits ... 13
3.2.1. Modelling of ecosystem services and benefits ... 13
3.2.2. Relative scoring of benefits ... 16
3.2.3. Type of user input data ... 17
3.3. Method of prioritisation or optimisation ... 17
3.3.1. Prioritisation and optimisation – context for this report ... 17
3.3.2. Category 1 – Analytical methods to prioritise or optimise proposals ... 18
3.3.2.1. Linear programme (LP) algorithms – ROOT ... 18
3.3.2.2. Simulated annealing algorithms – SCP + Marxan ... 19
3.3.2.3. Cost-benefit analysis – LUCT ... 20
3.3.2.4. Trade-offs & synergies – LUCI, HydroloGIS, NEVO ... 20
3.3.3. Category 2 – Retrospective, post-hoc analysis ... 21
3.3.3.1. Spatial pattern of services – InVEST, ARIES, EcoservR ... 22
3.3.3.2. Tabulated scoring values – NATURE Tool, EBN, ARIES, Ciriabest ... 23
3.3.4. Category 3 – Tools which present simple mapped priorities ... 23
3.3.5. Additional sub-categorisation of prioritisation methods ... 24
3.4. Identification of potential interventions or User defined interventions ... 25
3.5. Mapped outputs ... 26
3.6. Spatial scale ... 26
3.7. Relevance to sectors ... 26
3.8. Cost-effectiveness ... 28

3.9. Scale of existing user base 28
3.10. Ease of use/usability 29
3.11. Data requirements 29
3.12. Tool adaptability 30
3.13. Performance and reliability 30
3.14. Ecosystem services/benefits – human wellbeing 31
3.15. Transparency 31
4. Other tool reviews 35
4.1. Agricultural relevance 35
4.2. Popularity and awareness 36
4.3. Mapping 36
4.4. Monetary value and funding opportunities 37
4.5. Socio-economic 38
4.6. Artificial intelligence (AI) 38
5. Technical recommendations 39
5.1. Recommendations regarding tool methods 39
5.1.1. Modelling of ecosystem services vs relative scoring of benefits 39
5.1.2. Method of prioritisation or optimisation 39
5.1.3. Identification of potential interventions or user defined interventions 40
5.1.4. Mapped outputs 41
5.1.5. Scale 41
5.1.6. Relevance to sectors 42
5.1.7. Data requirements 42
5.1.8. Tool adaptability 42
5.2. Recommendations regarding end user tool interface and usability 43
5.3. Agricultural sector specific recommendations 43
5.4. Summary of key considerations for future tool development 44
6. References 45
6.1. Individual tools 45
6.2. Other references 49
7. Glossary 51
8. List of Acronyms 57
9. Appendix 1: Individual tool reviews 58
10. Appendix 2: Other tools considered in the rapid evidence review 122

1. Introduction

1.1. Background

Land use decision-making is a complex process that involves navigating multiple and often competing pressures. Striking a balance among these pressures is essential for sustainable and responsible land use planning. Competing pressures include food production, biodiversity conservation, energy production and urbanisation.

Decision support tools can be found across the environmental and land use sector, from agricultural practice support to conservation habitat creation. These tools are designed to provide clear recommendations based on outcomes of different decisions or data inputs. There is a wide range of land use decision support tools that have been developed, each with different processes, different focuses, a range of scales and a range of analytical methods to identify potential management interventions.

To aid land use decision-making in an agri-environment context, JNCC has been developing an approach to spatially prioritise interventions with the aim to resolve multiple pressures, deliver multiple ecosystem services (ES) and provide better value for money.

Other aspects of land use planning can benefit from spatially prioritising interventions or land cover change to help increase environmental benefits. Particularly, local, regional and national planning.

1.2. Aims and objectives

The aim of this project was to develop an understanding of the technical approaches used by existing land use decision making tools that spatially prioritise or optimise interventions to achieve multiple environmental benefits. The 'land manager' is considered to be the fundamental end user and will be considered throughout the analysis.

The key objectives for this project are to:

- Critically review and report on the analytical methods used by previously identified land use decision support tools to prioritise or optimise interventions to deliver environmental benefits.
- Describe the ES/environmental analytical methods used by land use decision support tools to identify environmentally impactful actions, especially where tools have modelled demand for services.
- Describe the relative strengths and limitations of these tools to inform the development of JNCC's analytical process to spatially prioritise land management interventions.

1.3. Land use decision tools and their use in an agri-environment context

Examples of current land use decision support tools include Marxan (and the Systematic Conservation Planning (SCP) approach), the Natural Environment Valuation Online tool (NEVO), and the Natural Capital Planning tool (NCPT).

With such a plethora of tools already existing for land use decision support, there is a need to analyse the operational qualities of these tools, what their strengths and limitations are, and in what spatial/temporal contexts they are most useful.

Choices for income generation are growing for land managers, increasing the burden on them in making the right decisions for their business and identifying the ‘right thing to do in the right place’ – ensuring multiple environmental benefits to optimise land use for nature, climate, people and place.

There are several key issues surrounding land use decisions, including the availability of space and the need for multiple benefits within areas. Tools must work at an appropriate spatial level, particularly at smaller scales for smaller holdings. Usability and cost will heavily impact the use of tools by land managers. Rose *et al*. (2016) identified fifteen factors that are influential in convincing farmers and advisers to use decision support tools, with performance, relevance to user and compatibility with compliance demands acting as strong influences.

Land manager priorities will differ, and it is important to recognise that spatial solutions will vary depending on the initial question posed. Outputs will often have trade-offs; where different outcomes are affected by scale, competing land uses, logistical considerations or cost, for example. Tools vary in their ability to help the user assess trade-offs and this is an important consideration in assessing functionality and usefulness. The mechanisms of trade-off tools also may have issues with subjectivity, particularly if the user is able to specify objectives or preferred services within the tool. This could lead to certain services being undervalued or not represented at all. Identifying trade-offs is a vital issue when considering the limited amount of land in the UK, and what interventions may provide the ‘best’ services in a restricted landscape.

Different tools use different methods to prioritise/optimise land use changes for ES provisioning, and each process faces several challenges and limitations which makes selecting the right tool for the scenario difficult. Key issues for modelling methods are the real-world complexities of ES how a model will accurately address these. Interactions between ES differ spatially and temporally, and there are limits to model methodologies. For example, tools vary in their consideration of land use and habitat heterogeneity, where one area of the same land cover may be impacted differently by factors such as slope, rainfall, soil type, etc., thus providing different levels of ES benefits.

Spatial scales and resolution are also an issue for land use decision making tools. Some tools define their spatial units (resolution), LUCT uses a hexagonal cell framework of 0.41 ha. Fine spatial scales are much better for assessing decisions within a sub-field scale, where larger spatial scales (2 km^2 within NEVO) would provide inaccurate information. Datasets within models may also be a different resolution to the scale the tool uses (e.g. inputs and outputs at 0.5 ha, with a dataset using a 2 ha resolution) leading to inaccuracies and unreliable prioritisation outputs.

Data inputs and data sources can vary from simple comma-separated value (csv) files to more complicated GIS rasters and vectors. These requirements and outputs may limit who can use the tools, and how easy they are to interpret.

Other key issues to address for tool use for the end user include accessibility, accuracy and data including licencing. Hosting policies within tools can create barriers or break them down depending on how well these are setup with land managers in mind. The ability to retain and share data between land managers within Land App is particularly good for collaborative work, and this differs significantly between tools across the public and private sector.

More readily affordable and freely available tools, such as the NATURE Tool, may cost the end user less but may not be as spatially or service explicit as a more expensive private bespoke tool like HydroloGIS. It is important to have an awareness of what makes a good model for a land manager but also appreciate the need for user/stakeholder engagement and education if the value and usability of these tools is to be promoted fully. Tools must be relevant at appropriate spatial resolutions, relatively simple to use, with outputs that are also easy to interpret for non-expert users. It is also important to understand the variation within the land management community (particularly farmers), and their varied opinions and attitudes, which affects their ability and willingness to engage with support tools.

To secure and maximise delivery of the most beneficial ES, it will be essential to provide greater clarity to land managers around the suitability and application of tools to enable them to make informed, evidence-based decisions, based on complete and reliable data at the correct scale.

For this project it was important that a review of the relative strengths and limitations of the multitude of tools available was carried out. When assessing these tools, it was critical to consider the end user, and what would be required to support them in their decision making. Tools must be cost effective and user friendly, with opportunities for intervention recommendations at a smaller spatial scale to target the high number of smaller holdings within the UK. Ideally, they should be able to complement existing and informing proposed Environmental Land Management schemes (ELMs), Biodiversity Net Gain (BNG) and other green finance.

User-centred design is paramount for any future tools, and they should be accessible for land managers or other decision-makers working both individually and collaboratively. When assessing tools, it is important to identify if they have considered and integrated user-centred design, including proving system value, adopting a good marketing plan, and establishing a long-term legacy.

The outputs of the project will also provide valuable information for policy. Analysing the methods, strengths and limitations of existing tools will identify those that will promote bigger and better use of digital processes, data and technology within land management. Identification of the most context-appropriate tools will also help secure large-scale adoption of the most important actions in the right place.

The use of robust tools will be highly relevant for future ELM policy and design, potentially pipelining of applications/projects and ensuring priority applications are fully identified and considered. Decision support tools supporting all these elements should incentivise ambitious, joined up and targeted action in the UK, aiming towards the 25 Year Environment Plan outcomes.

1.4. Previous reporting by JNCC

With multiple policy priorities requiring land to achieve targets (food production, housing, energy, etc.), assessing what actions to take and in what location is vital. JNCC’s role in land use is to consider multiple productivity and environmental aims and build a system that recommends the ‘right thing to do, in the right place, at the right scale’.

Currently in post EU-exit England, there is a transition from existing Agri-Environment Schemes (AES) to ELM. With the development and implementation of these schemes (alongside other public and private finance opportunities) there is a need for spatial prioritisation of land use interventions.

JNCC has been exploring opportunities surrounding spatial prioritisation of land use and their previous research has been incorporated in this report.

Initially this consisted of an exploratory exercise to identify tools related to land use decision making.

Fifty-three land use decision tools were identified, and a rapid review was conducted to explore which of these tools met the threshold for further in-depth analysis. The threshold used the following criteria:

- The tool explores ecosystem services and benefits that are most relevant to land use decision making in the UK (such as carbon sequestration, agricultural productivity, flood protection).
- Does the tool perform prioritisation or optimisation of interventions, locations or benefits?
- Does the tool include three or more ES or benefits?

There were other examples of tools that undertook prioritisation; however these were specific to just one or two ES or benefits so were not included in the priority list. Pure mapping tools such as the LandApp were also not included but have been considered in a further review of other tools in this report.

Twelve tools met the threshold for further analysis. A comprehensive spreadsheet of information regarding these priority tools was created, as well as a brief summary of the other tools.

JNCC then conducted a review of the 12 priority tools across a number of criteria including:

- Modelling of ES or scoring of benefits
- Method of prioritisation/optimisation
- Target users
- Skills required to use the tool
- Identification of potential interventions or user defined interventions
- Mapped outputs
- Spatial scale of the tool

General information regarding the tool was also collected, including the environmental outcomes covered in the tool and data requirements. Developers were contacted regarding user numbers and reported audiences, with some developers responding with additional details.

This review builds on the work carried out by JNCC and provides a more in-depth analysis of various elements for the priority selection of tools. An additional priority tool was also assessed within this report. Understanding and comparing the relative strengths and limitations of the tools will help JNCC explore possibilities for the development of novel prioritisation methods.

2. Methods

2.1. Rapid evidence review

To highlight knowledge gaps and areas requiring improvement, information gathered by JNCC was reviewed and supported by a rapid evidence review of published and 'grey' literature. The review focused on needs and gaps identified by JNCC, including:

- The identification of any new/additional tools, including unpublished private tools such as habitat opportunity mapping.
- An assessment of the range of analytical and post-hoc analysis methods used by existing tools.
- A review of evaluation and assessment criteria/methods used in relation to the effectiveness of land use decision support tools.
- An assessment of the level of success of current approaches used to analyse land management interventions to identify environmentally impactful actions.

Principally, the outputs of the evidence review as well as the experience of the project team identified additional tools which were of value to the project but also assisted in structuring the tool evaluation criteria.

Due to land use decision support tools being a rapidly developing area of interest, a rapid appraisal of the list of tools provided by JNCC was carried out. This was undertaken to highlight developments in the topic and provide an additional opportunity to reach out to developers to discuss their tools.

The rapid appraisal allowed for a final list of tools to be selected for an in-depth review against the agreed evaluation criteria. The selected tools were:

- Artificial Intelligence for Environment and Sustainability (ARIES)
- ASSIST E-Planner
- Ciriabest
- EcoservR
- HydroloGIS
- Integrated Valuation of Ecosystem Services and Trade-Offs (InVEST)
- Land Utilisation Capability Indicator (LUCI)
- Land Use Choices Tool (LUCT)
- Systematic Conservation Planning (SCP) and Marxan
- Natural Environment Valuation Tool (NEVO)
- Nature Assessment Tool for Urban and Rural Environments (NATURE)

- Environmental Benefits for Nature (EBN)
- Restoration Opportunities Optimization Tool (ROOT)

2.2. Review of priority tools

Selected priority tools assessed more than three different ES and provided prioritisation / optimisation of land use. ASSIST E-Planner was included as a priority tool due to the high number of relevant ecosystems services and inclusion of intervention suggestions.

Models can be designed to meet the needs of a variety of end users including land managers, policy designers and academia. Indeed, it can be particularly useful when the same underpinning models can be used by different users and at different scales. However, unless stated otherwise, this review is focusing on land managers as end users. This assumes that the most relevant functionality includes easy user interfaces that can be used by land managers directly, or by outputs that could inform a land manager via an additional front-end.

Methods used to review priority tools are broken down into the sections below.

2.2.1. Reviewed criteria

Within both the overall and individual tool reviews, the following criteria were assessed using publicly available information, developer information and a review of existing literature. The majority of these criteria were included in each individual tool review; however some tools had limited available information.

Criteria included:

- Modelling of ES or relative scoring of benefits
- Method of prioritisation or optimisation (the main objective of the review)
- Identification of potential interventions or User defined interventions
- Mapped outputs
- Spatial scale
- Relevance to sectors – including compatibility with compliance/accreditation demands
- Cost-effectiveness
- Scale of existing user base
- Ease of use/usability
- Data requirements
- Tool adaptability – including scope and flexibility for development (e.g. addition of additional information/data)
- Performance and reliability – including strengths, limitations, data resolution, modelling assumptions, etc.

2.2.2. Typologies for categorisation

Where possible, criteria were separated into a small number of categories to allow for grouping of tools. This included method of prioritisation or optimisation, data requirements, ease of use/usability and tool adaptability. These can be found within each relevant criteria in the overall tool review in Section 3 and Table 2.

2.2.3. Assessment of literature

For the review, information was gathered from a variety of sources. Primarily research was conducted on the tool and developer webpages, where user guidance documents detailing tool methods were available. In some circumstances tools were downloaded or accessed to interpret methodologies and access any in tool guidance information.

Guidance, launch and tutorial webinars were also accessed to gather additional information for some of the tools. The literature was consulted for evidence of tool usage, reviews and case studies.

There were restrictions and limitations to the amount of publicly available information for some tools, and consequently some criteria have not been reviewed in as much detail as others. Some tools were either new or behind a paywall and had very limited information, including Ciriabest and HydroloGIS.

2.2.4. Developer engagement

Following on from initial queries from JNCC, LUC attempted to contact the developers for each tool.

Initial questions e-mailed to contacts included requests for information on user sector, targeted and actual audience, and the number of users. There was also a follow up request to discuss the tools methodologies if the developer was happy to present these. Of the 13 developers contacted, eight responded with additional information through email or video call:

- The Environmental Benefits from Nature tool
- InVEST (Integrated valuation of Ecosystem Services and Trade-Offs
- ARIES
- ASSIST E-Planner
- EcoservR
- Systematic conservation planning + Marxan
- HydroloGIS
- NATURE Tool (Nature Assessment Tool for Urban and Rural Environments)

2.3. Review of other tools

The rapid evidence review highlighted five additional tools to be included within this, though these tools were not selected as priority for a full review. Elements of these additional tools were explored through developer information or the literature, and an overview of selected elements can be found in Section 4. The rationale for tools not being selected for full review included the following:

- They did not prioritise or optimise interventions.
- They considered too few ES or other benefits.
- They were purely a mapping portal.

2.4. Ecosystem services (ES) – context for this report

Within this review, ES are defined as direct and indirect contributions of ecosystems to societal functioning including provisioning, regulating, cultural and supporting services. ES in the report may be expressed as:

- **Ecosystem service supply:** the quantity and quality of ES available within a given ecosystem or area.
- **Ecosystem service demand:** the human or societal need or desire for ES, reflecting the extent that humans rely on or value the services.
- **Ecosystem service flow:** the transfer of ES from the natural environment to human beneficiaries, representing the actual utilisation and consumption of the service.

A description of other technical terms can be found in the Glossary. Explanations of acronyms are provided in the List of Acronyms.

3. Review of existing tools

3.1. Overall review of priority tools

The 13 priority tools have been split into broad categories depending on how ecosystems services/benefits are assessed and valued, and the methods of prioritisation/optimisation that they use. These categories can be found in Table 1. and reviewed in detail in this Section.

Table 1. Overall tool summaries.

Name of tool	Developers	Modelling of ESs or relative scoring of benefits	Generates mapped outputs	Method of prioritisation / optimisation	Identifies potential interventions or user defined interventions
ARIES	Basque Centre for Climate Change	Modelling of ESs	Yes	Post-hoc exploration of spatial pattern of services and tabulated scoring values	User defined interventions
Ciriabest	CIRICA (Construction Industry Research and Information Association)	Scoring of land use benefits and costs	No	Post-hoc exploration of tabulated scoring values	User defined interventions
The Environ-mental Benefits for Nature tool	NE, U. of Oxford, in partnership with Defra, FC, and EA, Balfour Beatty, WSP, EKN, UKCEH	Scoring of land use benefits and costs	No	Post-hoc exploration of tabulated scoring values	User defined interventions
EcoservR	Natural Capital Hub at Liverpool John Moores University, support from Natural Capital Solutions and FR	Modelling of ESs	Yes	Post-hoc exploration of spatial pattern of services	User defined interventions
E-planner	UKCEH	No	No	Presents ES maps to users showing priority areas	Identifies potential interventions
HydroloGIS	Viridian Logic	Scoring of land use benefits and costs	Yes	Analytical methods: trade-offs & synergies	Identifies potential interventions

Name of tool	Developers	Modelling of ESs or relative scoring of benefits	Generates mapped outputs	Method of prioritisation / optimisation	Identifies potential interventions or user defined interventions
InVEST	The Natural Capital Project	Modelling of ESs	Yes	Post-hoc exploration of	User defined interventions
LUCI	Victoria University of Wellington, UKCEH	Modelling of ESs	Yes	Analytical methods: trade-offs & synergies	User defined interventions
LUCT	ADAS RSK, led by EA and supported by NE FC. FR and Defra Land Use	Scoring of land use benefits and costs	No (but outputs can be mapped by the user)	Analytical methods: cost-benefit analysis	User defined interventions
NATURE tool	Co-developed by NAS, WSP, Northumbria University, EKN and partners	Scoring of land use benefits and costs	No (but mapped outputs can be produced using the same model, as a paid service)	Post-hoc exploration of tabulated scoring values	User defined interventions
NEVO	LEEP @ U. of Exeter, with support from Defra and NERC	Modelling of ESs	No	Analytical methods: trade-offs & synergies	User defined interventions
ROOT	Partnership between IUCN and The Natural Capital Project	Scoring of land use benefits and costs	Yes	Analytical methods: linear programme (LP) algorithms	User defined interventions
Systematic conservation planning + Marxan	Marxan – collaboration of academics	Scoring of land use benefits and costs	Yes	Analytical methods: simulated annealing algorithms	User defined interventions

The following is an introductory summary for each of the priority tools.

- **Restoration Opportunities Optimization Tool (ROOT)** is a decision support tool with the sole purpose of optimising ecosystem service benefits and is targeted at decision makers and restoration practitioners. It does this by utilising a linear programming algorithm and outputs from other ES modelling tools such as InVEST. Users are expected to have a proficiency in GIS and data handing, though strict guidance is provided by the developer. ROOT uses user-defined intervention, ES models, and analytical methods to suggest best locations for positive interventions. Outputs include an agreement map supplemented by summary tables, weightings, and individual solutions. Typically, ROOT is used on large scale restoration projects up to national scales.

- **Land Use Choices Tool (LUCT)** is designed for a broad audience, including local delivery bodies, landowners, and policymakers to support decisions about land use change, particularly for woodland and habitat creation. LUCT runs on Microsoft Windows. Currently, the Environment Agency, with support from developers and ADAS, conducts assessments on behalf of partners and clients. As a result, no technical skills are required from the client to use the tool. LUCT scores environmental benefits and costs based on user-defined objectives, such as meeting a water quality target. Outputs are provided as csv files including information on benefits, possible land uses, cost-benefit, and constraints. It operates at a sub-field scale using a hexagonal grid of 0.41-hectare cells.

- **Systematic Conservation Planning (SCP) and Marxan** is a process designed to support anyone requiring a framework to guide conservation efforts, particularly where stakeholder engagement is important. Marxan is a tool which focuses on this framework. Marxan uses simulated annealing algorithms for optimisation by scoring defined planning units based on their ability to meet targets for restoration. Marxan works on user defined interventions such as land use change or project objectives and allows the user to explore trade-offs between conservation and socio-economic objectives. Marxan requires a high level of competency for data handling, statistics, and GIS, and is therefore typically used by consultants and academics. Outputs include both mapped and quantitative data. SCP can be used at any scale, though typically Marxan is used for large scale projects.

- **EcoservR** is an updated rewrite of the Ecoserv-GIS tool into the R package. It therefore requires users to have an understanding of the R software alongside other GIS skills. The tool has a broad audience including members of the planning, development, and conservation industries. EcoservR is made of modular functions which let the user create a habitat map (asset map) from a range of national datasets and model capacity and demand for seven ES as well as habitat networks. The method of prioritisation includes analysing capacity and demand maps for “pinch points”. EcoservR provides the user with data to be inputted into the free to use software QGIS. The ES maps can be created at user-specified resolution, with 10m recommended for regional scale.

- **Land Utilisation Capability Indicator (LUCI)** is targeted at a broad range of users including policymakers, land managers and academics. The tool models ES based on user defined interventions such as changes to agricultural land use, and priorities/optimises interventions through analytical methods such as the “trade-off tool”. Outputs are generated in a series of ecosystem service maps which are visualised in a ‘traffic light’ format. Users are required to have a minimum knowledge of GIS software and associated skills. LUCI operates on a fine scale of five m^2 which is suitable for most agriculturally based assessments.

- **HydroloGIS** has a broad target audience including land managers, conservation organisations, and private organisations. Its developers Viridian conducts the assessment in house, therefore there are no skills required by the client. HydroloGIS models ES based on user defined interventions such as woodland and hedgerow planting and uses analytical methods to show trade-offs and synergies. It uses a cell-based model to quantify interactions amongst ES and identify the most suitable areas for intervention. The tool is built on the principles of Resource Investment Optimisation

System (RIOS). The outputs are mapped. Resolution varies from 0.5 m to 25 m, therefore encouraging a catchment/watershed scale.

- **ASSIST E-Planner** guides prioritisation of habitat restoration and agri-environment interventions via a web-based mapping interface. Users select the land of interest and choose which benefits they are interested in. E-Planner then provides a high-resolution map for their chosen area with suitable areas for interventions, alongside ratings describing national and local priorities. E-Planner is aimed at farmers and land managers, allowing them to define interventions such as agri-environment options. Importantly E-Planner maps at a high resolution of five m. The tool requires minimal skill.

- **Environmental Benefits for Nature (EBN)** is aimed at a broad audience including environmental consultants, developers, and local authorities; however the tool was ultimately released to support the BNG metric 3.0 and Environmental Impact Assessments (EIA). The tool scores the ability of land covers for delivering ES based on user defined interventions such as land use type condition and extent. The tool is relatively easy to use, functioning in Excel and adjoined by a comprehensive guide, therefore requiring minimal software skills. Outputs are presented in a tabular format alongside pie charts for baseline and post-intervention. The EBN tool is designed to support project-based assessments working with BNG.

- **NATURE Tool** is similar to EBN in that it functions in an Excel spreadsheet and does not provide mapped outputs - however, it’s worth noting that provision and opportunity maps have been developed using the model, as a paid service. It is targeted at those wishing to assess natural capital such as infrastructure developers or local planning authorities and requires basic Excel skills, and relevant GIS skills to provide input data for the tool. NATURE scores land use benefits and costs based on user defined interventions such as housing and infrastructure development or changes to habitats. The user is required to carry out post-hoc exploration for the prioritisation of interventions. NATURE can work on any scale, though the larger the assessment the longer the processing time. InVEST is intended for the public, private, and non-profit sectors including researchers, conservationists, and consultants. GIS skills are required to prepare various inputs and to analyse mapped outputs, with basic to intermediate skills for Python also necessary.

- **Natural Environment Valuation Tool (NEVO)** is a web-based platform which runs a suite of models for multiple ES. The tool is aimed at a broad audience including land managers, local authorities and conservation organisations. It allows the user to explore, alter and optimise land uses for ES and financial benefits. The optimisation feature finds the best location for land use change to achieve a particular objective. The tool also allows the user to alter outputs by changing the price of agricultural, timber or carbon products alongside agricultural inputs or stocking rates. Data is outputted in a csv file or maps and is mapped at 2 km^2 resolution, therefore would work at the landscape level. NEVO requires minimal technical skills to operate the tool but can require extensive input data.

- **InVEST** models ES based on user defined interventions such as land use change. The user is required to carry out post-hoc examinations for optimisation/prioritisation. The workbench contains tools which help the user to visualise outputs, however mapping takes place externally in ArcGIS or QGIS. InVEST is broadly aimed at policy makers, NGOs, consultancies, and researchers, and importantly features two formats which allows both non-technical users and specialists to utilise the tool.

- **Artificial Intelligence for Environment and Sustainability (ARIES)** models ES based on user defined interventions such as changes to land use or spatial data. Users are required to undertake post-hoc analysis in order to prioritise or optimise ES. Outputs of the tool are both in both tabular and mapped formats. ARIES is capable of working at various scales from river catchments to national levels.

- **Ciriabest**, Ciria's latest iteration of their Benefits Estimation Tool, provides the user with valuations of the benefits of blue-green infrastructure (BGI) and natural flood management (NFM) interventions, with a corresponding sensitivity analysis. The tool is largely aimed at the planning and development industries, though broadly targets those who wish to assess impacts of BGI, NFM, and sustainable drainage systems (SUDS). The tool uses scoring for user defined interventions, delivering a cost-benefit analysis, and Net Present Value. Limited information is available on the tool, though it would be expected that some level of IT competency would be required to handle data and understand outputs. The tool does not map outputs but provides shapefiles (that can be mapped using other software) alongside a dashboard showing the ranked benefits of the interventions with monetary values. Due to limited information, the exact scales are unknown, though case studies show its use at regional level.

The full reviews for each individual tool can be found in Appendix 1.

A summary of each tool's strengths and limitations can be found in Table 4 at the end of this Section.

3.2. Basis of the tools: modelling of ecosystem services or relative scoring of benefits

The tools fall into two broad categories of those that undertake complex ES provision modelling and those that use relative scores of ecosystem service values, land use benefits and costs (Table 1). These two groups can be further split by those that allow or require user input data and those that don't (Table 2). ASSIST E-Planner does not fit into either category. Instead, E-Planner does a simple calculation to show whether an environmental opportunity is a local or national priority in the specified spatial extent set by the user. Below are summary reviews of both categories of tool. Within both categories there are overlaps in spatial prioritisation and optimisation methods which are the focus of this report and reviewed in Section 3.3.

3.2.1. Modelling of ecosystem services and benefits

This category consists of the following tools:

- EcoservR
- Land Utilisation Capability Indicator (LUCI)
- Natural Environment Valuation Tool (NEVO)
- Integrated Valuation of Ecosystem Services and Trade-offs (InVEST)
- Artificial Intelligence for Environment and Sustainability (ARIES)

The tools that perform ES modelling can be further split along a continuum of ease of use according to required user technical skills. These are summarised in the 'ease of use' column in Table 2. and explained in further detail in the individual tool reviews. The interface and modelling through NEVO can be done by non-technical users, however the remaining tools require technical skills and/or access to more technical software.

Table 2. Tool appraisal table.

Name of tool	Cost	User data requirements	Ease of use	Tool adaptability
ROOT	Free	High data requirements	Technical skills and software required	Defined tools with limited adaptability
LUCT	Unknown, users must contact the Environment Agency	Simple with advanced options	In-house tool	Defined tools with limited adaptability
Systematic conservation planning + Marxan	Free	Simple with advanced options	Technical skills and software required	Customisable tools
EcoservR	Free	High data requirements	Technical skills and software required	Defined tools with limited adaptability
LUCI	Free for non-profits, unknown for general users	Simple with advanced options	Technical skills and software required	Customisable tools
HydroloGIS	Project specific quotes (starting at £10/km^2)	Simple (incl. site specific data)	Unknown (in-house tool)	Unknown (in-house tool)
E-planner	Free	Simple (incl. site specific data)	Non-technical users, easy to use interface	Defined tools with limited adaptability
The Environmental Benefits for Nature tool	Free	Simple (incl. site specific data)	Non-technical users, more advanced interface	Defined tools with limited adaptability
NATURE tool	Free	Simple with advanced options	Non-technical users, easy to use interface	Defined tools with limited adaptability
NEVO	Free	High data requirements	Non-technical users, easy to use interface	Defined tools with limited adaptability
InVEST	Free	Simple with advanced options	Technical skills and software required	Customisable tools
ARIES	Free	Simple with advanced options	Non-technical users, more advanced interface	Customisable tools

Name of tool	Cost	User data requirements	Ease of use	Tool adaptability
Ciriabest	£600 to £2,500 + VAT	Simple (incl. site specific data)	Non-technical users, more advanced interface (uncertain)	Defined tools with limited adaptability (uncertain)

The modelling methods for each tool are different, including those that use multiple ES and processing models within the tool (a modular approach). For example, InVEST's approach utilises 22 separate models for mapping and valuing ES. In this report a review of specific models has not been undertaken due to the number of models and details required.

The type of models used within the tools can be found in more detail (where information was available) within the individual tool reviews in Section 4. Examples of models used include:

- Bayesian Network Models
- Service Path Attribution Networks
- Monte Carlo simulation
- Resource Investment Optimisation System
- Sediment Delivery Ratio
- Crop Production Percentile and Crop Production Regression models

Strengths of modelling tools in general:

- Modelling allows for consideration of interrelationships between ES and can capture the dynamic aspects of ES compared to scoring.
- Models can predict change over time and how this may impact ES provision.
- The tools allow for integration of various data sources into the model, including biophysical, socioeconomic and spatial data to simulate both supply of ES and demand (for people).
- In general, the tools are far more customisable and adaptable than scoring tools (see 'tool adaptability' and Table 2).

Limitations of modelling tools in general:

- Ecosystems are complex and models have limitations on accuracy with varying degrees of uncertainty. This can limit the reliability of outputs.
- Depending on project size, some models take a very long time to run the process. These can be hundreds of hours (for example the same model run through InVEST and ARIES took 275 and 800 hours respectively (Bagstad *et al.* 2013).
- As well as time, models can be resource intensive in terms of software and hardware, requiring higher computational power.

- Most of the tools require technical skills or resources to learn the process.
- The spatial scale (resolution) of models within a tool may be different, if these are then compared or run in models together the outputs may not be reliable.

3.2.2. Relative scoring of benefits

This category consists of the following tools:

- Restoration Opportunities Optimization Tool (ROOT)
- Land Use Choices Tool (LUCT)
- Systematic Conservation Planning (SCP) and Marxan
- HydroloGIS
- Environmental Benefits for Nature (EBN)
- NATURE Tool
- Ciriabest

The tools that perform relative scoring of benefits can be further split along a continuum of ease of use according to required user technical skills. These are summarised in the 'ease of use' column in Table 2. and explained in further detail in the individual tool reviews. Similarly to the modelling tools, there are examples of more complex tools that require technical skills and/or technical software. However, the NATURE Tool is a good example of an accessible Excel tool for non-technical users (further details can be found in the individual tool review).

In essence the relative scoring tools assign a rank, value or score depending on what land cover/habitat is present (or would be present if an intervention is carried out). The tools do not model ES service flows and deal with each area or ES within its own 'box'. Scores and values are generated in different ways according to the tool, and further information can be found within the individual tool reviews.

Multipliers are a feature of some tools including EBN and NATURE Tool. These multiply a baseline score (typically what habitat/ES/feature is present) by indicators that might assess the condition, location or age of the habitat. These overcome the issues that some tools face with habitat heterogeneity (where any point of the same habitat is given the same value even if there are differences in elevation, temperature, etc.), however they depend on the quality of the reasoning behind the multiplier scores.

Strengths of relative scoring tools in general:

- Scoring tools generally require less computational power and are less resource intensive than modelling tools.
- Scoring methods can offer transparency and reliability in the outputs (data dependent) as they do not seek to infer information from complex ecosystem variables.

Limitations of relative scoring tools in general:

- Whilst in theory scoring is a simpler process than modelling, most of the tools still require technical skills and/or technical software. NATURE Tool is the only nontechnical scoring tool.
- Scores and multipliers can be based on different sources (e.g. peer-reviewed data, government datasets or expert input). The clarity and accuracy of some of these can be questionable, particularly if information has not been published.
- Most of the tools require technical skills or resources to learn the process.

3.2.3. Type of user input data

Across modelling and scoring tools, most allow or require user inputted data either to inform the models/scoring system or as a prerequisite for the tool to function. In the majority of cases a spatial outline of the project is required, and information regarding what the interventions will be (excluding HydroloGIS and E-Planner that identify potential interventions). The type, quality and quantity of data required by tools varies from simple hectarage of a certain habitat, to complex GIS data requirements. Data requirements are reviewed in Section 3.11 and summarised in Table 2.

Types of user input data and their tools include:

- Spatial data – raster, vectors and spatial csv: ARIES, InVEST, EcoservR, SCP + Marxan, LUCI, ROOT
- csv files – simple tabulated information regarding the site or ES: EBN, ARIES, InVEST, EcoservR, ROOT, LUCT
- Cost data – costs associated with interventions such as tree planting: SCP + Marxan
- Site specific data on area/amount of habitat/feature: NATURE Tool, HydroloGIS, EBN, NEVO

There is limited information for the private tool Ciriabest within publicly available information.

ASSIST E-Planner does not require specific user input data. Users can input their single business identifier (SBI) or shapefiles to define a location on the tool's maps, but these can just be zoomed into or selected on the web portal itself. E-Planner uses readily available national information from OpenStreetMap, NEXTMap Britain Digital Terrain Model, National Soil Map of England and Wales, IH 30 Digital Flood Risk Map, Land Cover Map 2015, and Natural England Priority Habitat Inventory, amongst data sets from published literature on watercourse networks and hydrology of soil types.

3.3. Method of prioritisation or optimisation

3.3.1. Prioritisation and optimisation – context for this report

Within this report the terms 'prioritisation' and 'optimisation' are used, sometimes interchangeably, when reviewing multiple tools.

For optimisation, it is important to note that models are unlikely to be able to capture all variables: results are not necessarily a real-world optimal outcome. Instead, the data outputs will return an optimisation of distinct variables and input data that the tool has access to, and there are likely considerations that have not been included. Therefore, the outputs would be considered “optimal”, but they may still not be feasible due to other factors that have not been input into the model.

Prioritisation tools rank outputs, some of which could be similar, giving multiple results, but with less surety regarding whether the first result is significantly better than the others. This can give more of a balanced view of the options due to the presentation of multiple possible outcomes than optimisation, although care is needed when looking at ranked options – assumptions should not be made that there is a significant difference between the rankings. (Similarly, there may be a significant difference between them).

Several tools allude to optimisation within the methods or through ‘optimisation’ models, but it is important to not take this as a ‘single truth’. This is particularly evident for tools that use simulated annealing algorithms.

Tools that use (or claim to use) an optimisation method are SCP + Marxan, HydroloGIS, NEVO and ROOT.

The tools can be broadly divided into three categories, based on the method of prioritisation/optimisation (Table 1):

- Category 1 – Tools which use analytical methods to prioritise or optimise interventions, locations, or benefits. They offer quantified insights into the optimal locations or provide ranked lists of potential interventions.

- Category 2 – The tools in this group model different scenarios and then present the data. Following this initial data reporting, retrospective (or post-hoc) analysis can be undertaken to understand any trade-offs between multiple benefits.

- Category 3 – These tools are focussed on presenting information on priorities through mapped outputs.

These three broad categories can be further split into sub-groups, which are explored in detail below and included in Table 1. Each methodology has its own strengths and limitations. More specific information regarding each tool’s methods can be found in Section 4.

3.3.2. Category 1 – Analytical methods to prioritise or optimise proposals

The tools in this category focus mainly on the prioritisation or optimisation of interventions, locations, and co-benefits. They offer the user clear suggestions or choices on land use change, supported by quantified recommendations. Tools in this group either model ecosystems services or score land use benefits and cost.

Four types of methods of prioritising land use interventions in this group are detailed below:

3.3.2.1. Linear programme (LP) algorithms – ROOT

ROOT is the only tool to use this method of prioritising land use change interventions. The algorithm finds the best solution for interventions which are defined and fixed in quantity and where the user wishes to minimise or maximise an ecosystem service or benefit. ROOT uses these user defined interventions and outputs from other tools (such as InVEST) to run the algorithms.

Strengths of this method:

- The user can input specific objectives for the delivery of ES. The algorithm synthesises these spatially to identify high priority areas within the landscape. Multiple objectives or 'targets' can be considered within the model in order to explore optimal solutions.

- The method is efficient: Within the defined inputs and constraints the tool will find the most optimal solution.

- The Linear Programme algorithms can handle large scale datasets with complex and extensive variables and constraints.

- Data is easy to interpret, which allows decision-makers to readily understand outputs. The Linear Programme algorithm outputs give full landscape solution statistics and individual solution statistics for each individual spatial area (pixel).

Limitations of this method:

- LP algorithms have a linearity assumption: They assume that relationships between variables (ES) are linear, which is not the case in reality.

- Any non-linear relationships cannot be accurately modelled in the tool.

- The method requires appropriate hardware. Performance and reliability for the method is limited by the computational strength of the device/system (which may limit some users).

3.3.2.2. Simulated annealing algorithms – SCP + Marxan

SCP + Marxan is the only tool to use simulated annealing algorithms. The user inputs defined targets or goals for an ecosystem service or benefit, and the algorithm starts with an initial solution for meeting the parameters. This initial output is then iteratively improved by random perturbations. The model looks at iterations of solutions until the 'shortest path' (best solution) is generated. In this case the 'shortest path' is where the best objectives/goals are optimised with the lowest amount of negative impacts on other benefits or objectives.

Strengths of this method:

- This modelling is suitable for complex systems and real-world scenarios where other algorithms do not operate well, because it is not restricted to linear relationships.

- The algorithm can escape the local optimum and can attempt to find the global optimum. This means that the algorithm does not get 'stuck' at a solution that seems the best, but it conducts additional exploration, which may find a global optimum and the best solution across all possibilities. An analogy of this might be where the local UK optima for peaks of mountains would be Ben Nevis, but additional exploration would find a global optimum - the peak of Everest.

- Simulated annealing algorithms can find many near-optimal solutions to complex problems in a relatively reasonable amount of time.

- Multiple objectives or 'targets' can be considered within the model to explore optimal solutions.

Limitations of this method:

- The set speed of the algorithm can impact the outcomes. If the schedule runs too fast then the algorithm may converge on a local optimum, but if too slow it may take too long to converge.
- The method requires appropriate hardware. Performance and reliability for the method is limited by the computational strength of the device/system (which may limit some users).
- It can be difficult to incorporate constraints into the algorithm framework, particularly if they are complex.

3.3.2.3. Cost-benefit analysis – LUCT

LUCT is the only tool that allows the user to select between a cost-benefit analysis and a pure environmental benefit analysis for prioritising land use change interventions, but cost-benefit scores do appear in some of the post-hoc analysis tools such as NATURE Tool. User defined land use change interventions are analysed at an individual spatial cell level (0.41 ha). The tool is a scenario generator and not a simulation model. The overall method is scoring of ES in cells. The tool then normalises these across the benefit that the user wants to consider and generates the mathematical ‘best’ use for land under sets of user preferences and constraints, with a cost-benefit and total benefit output. The qualitative ‘benefits’ scores are calculated from numerous data sources from the public and private sector. Costs are also calculated from multiple data sources including the Farm Management Handbook.

Strengths of this method:

- Cost-benefit analysis provides comparative numerical data that allows decision-makers to make informed decisions.
- This type of analysis could help decision-makers consider levels of uncertainty and economic risk of certain interventions.
- The scenario outputs and prioritisation can be tailored to project specific objectives so that the user can be more confident that the outputs are relevant to the project (e.g. a focus on nutrient reduction for a nutrient offsetting project).

Limitations of this method:

- With users tailoring objectives, the cost-benefit analysis may play down, or ignore, other important ecosystem service changes.
- There is a subjectivity when using cost-benefit analysis to inform land use decisions.
- Data for cost and benefit estimation must be kept up to date. Cost values could change within a matter of weeks (for example cost of trees for planting).

3.3.2.4. Trade-offs & synergies – LUCI, HydroloGIS, NEVO

These tools model trade-offs, synergies and “win-win” scenarios for ES and benefits. Within LUCI analytical methods of prioritisation include a “trade-off tool”. HydroloGIS utilises a tool built on the principles of RIOS. NEVO utilises an ‘Optimise’ tool which considers the best locations for land use change for achieving objectives.

Information regarding NEVO's optimisation tool is unclear within publicly available information. HydroloGIS details are also not available as the software is run in-house by Viridian.

LUCI's "trade-off tool" links combined spatial input data for each pixel (spatial area within the mapping) with a lookup table and applies process representation for flow of water and nutrients over the landscape. For habitat connectivity, this is simulated based on cost-distance approach taking into account characteristics of adjacent habitats. Boolean, conservative and weighted arithmetic (see Glossary) are used in the processes depending on the type of ecosystem service.

Strengths of this method:

- Trade-offs allow decision-makers to explore a range of outcomes and options and can be targeted to specific objectives.
- LUCI's traffic light maps clearly visualise trade-offs and synergies.
- Win-win outcomes can be easily identified and explored.
- Combination of Boolean, conservative and weighted arithmetic provides different interpretations of trade-offs depending on the ecosystem service being analysed, allowing for more accurate analysis.

Limitations of this method

- Trade-off assessments can be skewed by subjective judgements by the user or depending on the objectives set in the tool.
- There is complexity with analysing multiple, often conflicting, objectives and services.
- Potentially a false sense of security with 'win-win' outputs.

3.3.3. Category 2 – Retrospective, post-hoc analysis

Tools in the second category can still be used to prioritise/optimise interventions, locations and benefits but this is left to the user to do via post-hoc comparisons of results from scenario modelling rather than quantitatively identifying 'best' solutions.

Tools in this category are a mixture of those that model ES and those that score land use benefits and cost. Post-hoc analysis by the user can be done in many ways depending on the project objectives, user skillset and the audience. Output information from these tools can be split into two general categories for post-hoc analysis; those that display a spatial pattern of services and those that generate tabulated scoring values. There are overlaps between the tools and in most circumstances, users can take outputs and plug them into other tools or visualisation software for analysis.

The majority of the post-hoc tools in the 13 priority sample prioritise which interventions to do in a given location, based on their expected ability to deliver ES, or trade-offs and synergies. For further details see Section 3.3.5. However, this may not be the case for other post-hoc tools outside of this review.

Tools that can compare outputs within the tool (or the same running software such as Excel) include EBN and the NATURE Tool. InVEST requires outputs to be overlaid in separate GIS software, and ARIES can conduct the post-hoc analysis internally or externally depending on the output. Information is not available for Ciriabest. The ability to conduct post-hoc analysis within the tool is likely preferable and more efficient for the end user, particularly when different intervention/scenario values or maps can be displayed concurrently. The NATURE Tool allows for direct comparison of output values between options in one easy to interpret table interface. The individual tool reviews in Appendix 1 contain additional information on methodologies.

The two-general categories of retrospective, post-hoc analysis tools are:

3.3.3.1. Spatial pattern of services – InVEST, ARIES, EcoservR

These tools primarily help the user visualise the data spatially, however there are differences between them. These outputs can be particularly useful when demonstrating potential interventions and changes to stakeholders, however it is up the user to generate difference scenarios so that these comparisons can be made.

When generating individual scenarios where users are restricted, or where exact interventions that will be implemented have already been determined, these tools are very useful for clear, interpretable, visual mapped outputs. However, for exploring optimal land use post-hoc, further resources are required.

- InVEST requires additional work by the user to overlay map outputs from the different models to allow for comparisons.
- EcoservR generates capacity and demand maps which can be compared to identify opportunities and “pinch points” to plan and deliver interventions.
- ARIES has both spatial visualisation and tabulated outputs, depending on the level of the tool that is being used.

Strengths of this post-hoc analysis method:

- Visualised outputs are very useful for interpretation by the end user and for stakeholder engagement.
- Outputs are potentially more reliable than those that have undergone prioritisation/optimisation through algorithms which have degrees of uncertainty and confidence within the models.
- Comparing multiple scenarios visually can identify areas of interest that may warrant further investigation or analysis.

Limitations of this post-hoc analysis method:

- In most cases the end user is required to process outputs further to conduct the post-hoc analysis, which is more resource intensive.
- Users are required to generate different scenarios; depending on complexity of the project and the tool this can take a long time.
- Post-hoc analysis can be biased by the interventions and scenarios which have been generated, as opposed to algorithms that can generate thousands of iterations.
- The analysis is non-randomised.

- Analysis is dependent on end user expertise.

3.3.3.2. Tabulated scoring values – NATURE Tool, EBN, ARIES, Ciriabest

These tools primarily produce a tabulated output rather than spatially visualised data (there is some uncertainty with Ciriabest due to its recent development and paywall). ARIES has both spatial visualisation and tabulated outputs depending on the level of the tool that is being used. This way of presenting the outputs can be particularly useful when demonstrating numerical values to end users and stakeholders, especially for projects that have certain objectives and targets for ES/benefits such as BNG (NATURE Tool and EBN are particularly relevant for this).

NATURE Tool, EBN and the precursor to Ciriabest (B£ST) use Excel as the tool, delivering tabulated outputs, graphs and pie charts. Ciriabest is now run through its own private software package. Separate editions of the Excel tools will need to be run per scenario and compared by the user. Users are required to combine data outputs themselves for running additional analysis. ARIES has tabulated outputs that can be downloaded and used in other software programmes.

Strengths of this post-hoc analysis method:

- Tabulated outputs and graphs/charts are very useful for interpretation by the end user and for stakeholder engagement - particularly where set targets and goals are in place.
- With Microsoft Excel the outputs and post-hoc analysis is simpler to access and use than GIS or programmes that require programming expertise.
- Comparison of numerical data for BNG and Natural Capital could be particularly useful for planning scenarios.

Limitations of this post-hoc analysis method:

- In most cases, the end user is required to process outputs further to conduct the post-hoc analysis, taking additional resource.
- Users are required to generate different scenarios. Depending on complexity of the project and the tool this can take a long time.
- A lack of mapped outputs can be difficult for interpretation and may require further work to visualise.
- Post-hoc analysis can be biased by what interventions and scenarios have been generated, as opposed to algorithms that can generate thousands of iterations. The analysis is non-randomised. This can be a particular issue if the tool is being used toward targets such as BNG.
- Analysis is dependent on end user expertise.

3.3.4. Category 3 – Tools which present simple mapped priorities

The third category consists of just one tool, ASSIST E-Planner, which focusses on presenting information on priorities through online maps. It does not provide any prioritisation/optimisation but could be interpreted to make land use decisions. The tool is accessible and easy to use. Outputs are maps visualising ES and benefits. There is a traffic light format which assists interpretation. The tool is a particularly good starting point for landowners looking to explore potential ecosystem service opportunities on their land. The tool uses a five metre resolution which is a relevant and usable spatial scale for farmers who may be looking at small scale interventions such as field margins and corners.

Strengths of ASSIST E-Planner:

- Simple to use and access.
- Visual interpretation of ecosystem service opportunities in a traffic light system.
- Heat map outputs for easier interpretation.
- Opportunities are relevant to a range of ELMs within the UK.
- 5m resolution spatial scale makes the tool applicable to projects at a range of spatial scales, from very small to national spatial requirements.

Limitations of ASSIST E-Planner:

- No optimisation or prioritisation capabilities, or post-hoc analysis.
- National data sets within the tool are not always completely accurate at smaller spatial scales and require local knowledge and ground truthing.

3.3.5. Additional sub-categorisation of prioritisation methods

Whilst the tool methods of prioritisation can be split into three main categories, these can be further separated into 'what' is being prioritised rather than 'how' the prioritisation is undertaken.

Within the individual tool reviews in Appendix 1 there are further details on what each tool prioritises, alongside the methods used. These can be split into three sub-categories:

- Prioritising which interventions to do in a given location, based on their expected ability to deliver ES, or trade-offs and synergies. Including tools:
  - NATURE Tool
  - EBN
  - InVEST
  - EcoservR
  - LUCT
- Prioritising where to do a specific intervention based on where ES trade-offs and synergies are, or where there is greatest suitability. Including tools:
  - LUCI
  - Marxan
  - E-Planner

    - ARIES
    - ROOT

- Prioritising which ES to deliver in a location. Including tool:
    - ARIES

Information for HydroloGIS and Ciriabest was unavailable. From the limited accessible methods, it appears that Ciriabest may prioritise based on 'which intervention to do in a location', and HydroloGIS may prioritise 'where to do a specific intervention'.

These sub-categories are important to note when considering what the user is intending to assess or explore when choosing or using a tool. The strengths and limitations of the main prioritisation techniques are discussed above but, for these sub-categories, usability will depend on what questions the end user is assessing.

ARIES can prioritise which ES to deliver in a location, based on objectives, and is particularly useful when looking at the demands from beneficiaries (local communities for example), a feature which most of the other tools lack.

When considering the prioritisation of 'which intervention to do in a location' and 'where to do a specific intervention', it is important to note that the user is still providing the interventions, the tools are not suggesting specific actions. E-Planner is the exception, however as previously discussed, this tool highlights ES interventions but does not carry out any prioritisation methods within the tool.

The tools that prioritise 'which intervention to do in a location' are all examples of post-hoc analysis tools (within our priority 13 sample), where individual ES are valued for a specific area and the user compares which intervention to implement. Tools using analytical methods for prioritisation (and one post-hoc tool, ARIES) fall within the 'where to do a specific intervention' sub-category. This is facilitated by the tools' ability to assess interactions between interventions and ecosystem services within the tool function rather than assessing separately post-hoc.

The choice and usefulness of the tool will depend on the objectives of the end user. Depending on the complexity of the project, the difference between the 'which' and 'where' may not be a large factor in the decision to use the tool. However, for users who are constricted by a specific area, the 'which' intervention tools may be the easiest to use.

3.4. Identification of potential interventions or User defined interventions

Only the E-Planner and HydroloGIS suggest specific interventions to tool users.

HydroloGIS provides a ranked list of interventions that could be used to maximise benefits within a specified spatial area, focussed on addressing water-based problems.

E-Planner requires the user to refer to the guidance documents to find examples of agri-environment interventions relevant to the mapped environmental opportunities, rather than as an output of the tool.

All the other tools require users to specify intended interventions, which are primarily habitat change, creation or restoration based. For example, ROOT starts with the intervention (e.g. forest restoration) and asks where the best places are to restore forest to maximise ecosystem service delivery. Tools then make assumptions regarding the impact of the interventions, either through modelling or scoring (using values and multipliers). Some tools allow users to specify values/impacts of an intervention, with some allowing full customisation of the tool models themselves. These include ARIES, Marxan and InVEST.

Further details can be found in the individual tool reviews in Appendix 1.

3.5. Mapped outputs

Most of the tools generate mapped outputs (Table 1). E-Planner does not, however mapped information is the main component of the tool, and maps are displayed to users to aid spatial decision-making and understanding. NEVO doesn't show any mapped data but does use spatial data to run its models.

Ciriabest and NATURE tools also do not use or produce mapped information, but tool users must input information which is likely to originate from maps.

LUCT provides outputs that can be easily converted to maps within GIS software but does not currently do this within the tool itself.

3.6. Spatial scale

The tools work at a variety of scales. E-Planner works at a slightly finer sub-field scale (5 m resolution) to allow landowners to plan where in a field they may be able to take actions.

HydroloGIS models services at catchment scales at resolutions of 0.5 m to 25 m and can make recommendations for actions at the sub-field level. Many of the other tool's work in a similar way.

Services and potential impacts of interventions are modelled at a broad landscape or catchment scale, but if the data used are at fine resolutions the results are relevant at finer scales. One of the exceptions to this is the NEVO tool which works at the regional scale of 2 km^2. The EBN and NATURE tools work at the site scale to give results for a whole area.

3.7. Relevance to sectors

The tools vary in their scope and relevance to sectors. Some are quite specific in the sector, ecosystem service or policies/objectives they target, whereas others have the ability to function more broadly.

E-Planner is designed for landowners engaging in AES and, as such, is intended to be very simple to use with no additional data requirements: it gives clear results tailored to a specific land holding or field. LUCI is focussed on agricultural landscapes, but it's use requires strong technical skills and as such target audiences are not individuals, but local and regional scale planners, conservation organisations, or academics. LUCI has been used extensively in the Glastir Monitoring and Evaluation Programme (Emmett *et al.* 2017). Both tools should be considered when assessing the needs of farmers and in the development of any future tools that focus on ELMs policies.

Systematic conservation planning and Marxan involve detailed and extensive stakeholder participatory processes and are traditionally used in the conservation sector but, more recently, have been used to generate natural capital land management plans. For example, these methods have recently been used by the consultancy Biodiversity to generate spatial plans for eastern England with a Water Resources East, and mapping products for three of the five pilot Local Nature Recovery Strategy (LNRS) areas. ROOT, LUCI, LUCT, and

InVEST are all intended to be used as part of wider stakeholder participation processes. The outputs from the tools are used as communication and negotiation tools to show how different land use decisions may result in different benefit allocations. They are often intended to be dynamic and iterative with stakeholders exploring a variety of potential land use spatial configurations.

Some tools can also be customised or adapted further to increase their relevance across a larger user base and sectors. The LUCI toolbox for example has been combined with additional models by the United Nations to support their System of Environmental-Economic Accounting (SEEA) framework. Similarly, ARIES also has a SEEA application built on top of their standard tool. ARIES is also open source and allows users to edit the programme for additional functions.

EcoservR has a broad sector base. It is promoted as supporting environmental net gain targets for new builds but has also been used in an ELM test and trial and has been adopted by Liverpool City Region for planning purposes. It does require skills in R to use but provides detailed instructions and data inputs are relatively low. InVEST, ARIES, ROOT, and NEVO aren't promoted towards a particular sector but would be useful for a wide range of users including local and national authorities, private sector organisations, and non-profits. Their application and interpretation require users or teams of users to be highly skilled land use and modelling experts. HydroloGIS also has a broad target user base but it's water focus means it is promoted towards water utilities, agriculture, and planning authorities. As a proprietary tool all the modelling is done in-house by specialists.

Ciriabest, EBN and NATURE are particularly relevant to planners and developers, however EBN and Nature are also useful for land managers and local authorities. The NATURE tool has a greater focus on people's wellbeing and includes mental and physical health benefits, interaction with nature and recreation benefits as well as more common carbon storage, flood regulation, etc. Ciriabest is more directly aimed at planners and developers with focus on NFM and SUDS.

Most tools do not include compatibility with compliance or information on accreditation demands, however there are some tools that take into consideration local and national policy in the UK, such as EBN and NATURE Tool. With other tools the outputs may be able to suggest what interventions could go where for land use decisions, and these could be interpreted alongside ELM stewardship policies, natural capital and BNG.

The Environmental Benefits from Nature tool (EBN) and NATURE Tool are geared towards BNG. The NATURE Tool also includes an 'achievement' score that suggests whether the project meets Net Gain standards. Local policy information can also be used within the NATURE Tool to target specific outcomes for Net Gain.

The Land Use Choices Tool (LUCT) has a particular focus on the wider Defra and UK government policies and objectives and suitable for environmental planners and policymakers.

The tool is also intended for local delivery partners within local government bodies, environmental organisations, and land/estate managers to assist with land use decisions to support practical and deliverable projects and schemes.

With its emphasis on agricultural landscapes, LUCT can support initiatives such as Environmental Land Management (ELM) schemes, nutrient neutrality, carbon markets, and other natural capital approaches. Its outputs and cost-benefit analysis can help identify suitable interventions for specific locations, offering insights to landowners that can be interpreted alongside ELM policy.

3.8. Cost-effectiveness

The majority of the tools reviewed for this report are free to download or access through online interfaces:

- Environmental Benefits from Nature tool (EBN)
- InVEST
- ARIES
- ASSIST E-Planner
- EcoservR
- Natural Environment Valuation Online (NEVO)
- Systematic conservation planning + Marxan
- NATURE Tool (Nature Assessment Tool for Urban and Rural Environments)
- The Restoration Opportunities Optimization Tool (ROOT)

Ciriabest, a tool targeted at practitioners for blue-green infrastructure projects, costs £600 + VAT for a single licence and £2,500 + VAT for a multiple user licence for up to 10 people (prices accurate as per May 2024). It is unclear on the value for money of the product as it was launched recently and there is limited evidence of reviews.

HydroloGIS uses an in-house software package used by Viridian which comes with a fee of £10/km^2 for consultants to carry out the work on behalf of the client. Depending on the existing skills the client or user has, there are other free tools that run analyses on similar ES. However, the tool is tailored to quite specific elements such as sewer flooding which other tools do not provide.

Land Utilisation Capability Indicator (LUCI) is free for not-for-profit organisations, and some elements are freely available online to download from software centres. It is unclear whether the tool is still being supported.

Land Use Choices Tool (LUCT) is a relatively new tool and at present is only accessible through the Environment Agency, who run the assessments in house. All assessments are developed in collaboration with partners/clients and outputs are mapped and shared. Work is underway to explore expanding access to a wider user base. Users will need to contact the Environment Agency to enquire.

3.9. Scale of existing user base

With regard to number of users, where information was provided by developers or through publicly available resources the tools with considerable usage statistics are included in Table 3.

Table 3. Registered users and downloads.

Name of tool	Registered users	Downloads and guidance use
Systematic conservation planning + Marxan	6,000 (across 100 countries)	Unavailable
The Environmental Benefits for Nature tool	40 organisations (user total unavailable)	4,500–5,000
NEVO	1,400	1,900 training video views
InVEST	Unavailable	1,800 downloads on average per month 15,000 support forum page views per month
ARIES	5,000	Unavailable

3.10. Ease of use/usability

Similarly to data requirements, the usability of the tools is highly varied. At its simplest, the tools provide downloadable software with an easy to use interface or are run through well-known existing software such as Microsoft Excel. Some tools require specific programmes such as GIS and Python, which also allows users to adapt the tool. The amount of time and skills required can be split into three broad categories:

- Non-technical users: Tools have an easy to use existing interface or readily available software such as Microsoft Excel, with user guides – Assist E-Planner, NEVO, NATURE Tool.
- Non-technical users: Tools with more advanced software which requires time and resources to learn and implement – Ciriabest (uncertain as tool is new and not freely available), EBN, ARIES.
- Advanced tools for technical users: (includes any programming/GIS skills, even if basic) – InVEST, EcoservR, SCP + Marxan, LUCI and ROOT

HydroloGIS and LUCT do not fit into these broad categories. HydroloGIS is run by an in-house software package by Viridian, where clients provide information on what they want to achieve and the developers run the analysis – clients do not need to supply the data. LUCT is only accessible through the Environment Agency, who run the assessments in-house in collaboration with partners and clients.

Tools which require more advanced skills and technical input may be able to provide more accurate project specific outcomes as inputted data and information is more advanced. However, these tools are less accessible for a larger audience with non-technical skills. A good tool could potentially contain two tiers of user interface, with a simpler, easy to use process for non-technical users, with the ability of additions, edits and customisations for technical users with GIS/coding skills – or even just capacity and resources to learn more technical processes in the tool.

3.11. Data requirements

The requirements for user inputted data vary between tools. The simplest input functionality, where no data is required, is for ASSIST E-Planner, which is a visualisation demonstration tool. Tools that model or score ES range from entering simple spatial data for a project to comprehensive input data requirements. The more data or data handling required for the tool, the less accessible the tool is for nontechnical users. Some models allow the use of simple and complex user data, for example InVEST models contain simple sample data but the user is encouraged to add project specific data. Most tools also require specific project information, which is to be expected if outputs are to be considered accurate and useable. The tools can be split into three broad categories:

- Simple data requirements (including site specific information that should be known to the landowner/project) – Ciriabest, EBN, ASSIST E-Planner and HydroloGIS.

- Simple data requirements supplemented by more advanced data (such as habitat condition, local crop yields) provided by the user – InVEST, ARIES, SCP + Marxan, NATURE Tool, LUCI and LUCT

- High data requirements (a lot of input data is required for the models including additional spatial data. Also includes where data requires pre-processing to be used in the tool) – EcoservR, NEVO and ROOT

3.12. Tool adaptability

Some tools follow specific questions or flows throughout the model, with rigid inputs and outputs. Others allow the user to interact with the calculations/algorithms/ formulas or add in models to create their own toolbox. This potentially allows some tools to support models outside of the ES/benefits they were designed for. For example, the United Nations have created their own toolbox alongside LUCI models to support their SEEA framework. Most of these tools are open source. In terms of adaptability, in this case the ability to edit the tool is considered, not the ability to add in user specific data (see 'data requirements' section).

Defined tools with limited scope for adaptability – Ciriabest (uncertain as tool is new and not freely available), EBN, ASSIST E-Planner, EcoservR, NEVO, NATURE Tool, ROOT and LUCT.

Customisable tools with scope for adaptability – InVEST, ARIES, SCP + Marxan and LUCI.

Adaptability for HydroloGIS is unclear due to the in-house nature of the tool. Adaptability and customisation may allow for wider use of the tool but is not an important factor for the majority of land use decision makers.

3.13. Performance and reliability

Individual tool reviews provide detailed information on performance and reliability. Accurate assessments of performance and reliability were not possible for some tools due to limited access, recent release and limited information within published literature. These include Ciriabest, LUCT and HydroloGIS.

Common themes across the tools included:

- Transparency/reliability within the baseline scores or multiplier scores given to ES/benefits. As a result, the scores or models provided by the tools may not have accurate representation of reality. However, this is to be expected when developing tools to be used across a variety of scales and projects. Tools with user inputted data help increase the reliability for site specific outputs. Tools with these issues include EBN, NATURE Tool, LUCI.

- Calculations for some tools don't take into consideration habitat heterogeneity at wider spatial scales that biodiversity and ES depend on. For example, a score may be given to a certain type of land use/habitat, but this score does not change across the spatial extent of that land use/habitat even if there are significant differences in elevation, slope, temperature, etc which may affect the score in reality. This is the case for LUCI but may also be an issue for other tools that have not specified this limitation in their product information. All models are a simplification of real world processes, but it is not always obvious what the resulting limitations are that may impact the interpretation of outputs.

- Some models take a very long time to run the process depending on the size of the project. The modelling tools take longer than the scoring tools and may be more suitable for academic or large project purposes rather than individual landowners.

- Datasets for base information within the tools can be highly varied within each tool and across tools. Most tools provide information on their datasets, and although some of the data is from sources more than a decade old, most are still relevant (for example hydrology of soil types). There are uncertainties regarding quality of internal and external datasets. For example, the developers of LUCI (UKCEH) state within the tool catalogue that the version control, internal/external model audits, quality assurance, transparency and periodic reviews are currently 'unknown'.

3.14. Ecosystem services/benefits – human wellbeing

Many of the tools take into consideration biodiversity/habitats as well provisioning, regulating and supporting ES. These include water quality, erosion, flood mitigation, agricultural productivity and carbon. Tools also look at some cultural ES and aspects such as public access and recreation. There are some tools that provide a further exploration into human health and wellbeing, combining these with other ES and benefits. This is particularly useful for projects that relate to developments, blue and green infrastructure and open space.

InVEST and NATURE Tool models include human health and wellbeing impacts. InVEST is able to map and value services that include 'fulfilment', 'beauty' and opportunities for recreation. The NATURE Tool provides Natural Capital Score, Cultural and Health, Mental Health and Physical Health scores, however these are experimental aggregations and therefore have a lower confidence level than other individual ES/benefits.

Inclusion of human health and wellbeing as an ecosystem service/benefit is a useful aspect when considering land use change decisions. Elements are more difficult to quantify, and robust, scientifically rigorous data will be required for any analysis.

3.15. Transparency

User satisfaction for individual tools is difficult to quantify without considerable data on user experience. It should be noted that this section is primarily for contextual information on the tools and not an accurate review of transparency.

Some tools were developed alongside governments and key well regarded international bodies and used by these same organisations. The UK government and agencies were involved in the development of EBN, NEVO, LUCI and LUCT with Ciriabest being used by the Welsh Government (who reported the tool as providing an 'objective and clear cost for delivery of projects'). The United Nations has used both ARIES and LUCI, and the International Union for Conservation of Nature (IUCN) helped develop ROOT.

Clearly evidenced and transparent datasets and model calculations/algorithms are important for transparency. The following tools provide evidence of their decision making for data and models, from peer reviewed information or government/international organisation datasets: InVEST, ARIES, EcoservR, NEVO, Marxan, NATURE Tool and ROOT. EBN has evidence for data and calculations but verification of baseline ecosystem service scores is unclear, and questions have been raised in academic literature. Other tools may have evidence of origin for data and models; however, these were not found within publicly available data during the report assessment.

Information on Ciriabest, HydroloGIS and LUCT is currently less available due to the recent release of the tools and limitations on use (cost and private use).

NATURE Tool was Highly Commended by CIEEM in 2022 AWARD, evidence that it has been reviewed positively by users within the environmental/ecological sector.

In terms of user base InVEST, EBN, ARIES and Marxan have clear evidence of high usage which may indicate a level of user satisfaction.

For this report we consider 'performance and reliability' within each individual tool appraisal, assessing evidence of transparency and validation within the data, calculations, formula and models used by the tools. The assessment also considered the origins of datasets and calculations.

Table 4. Summary of priority tool strengths and limitations.

Tool	Strengths	Limitations
EBN	• Allows user inputted data • Does not require GIS or modelling skills • Scope to use the tool for ELM • A wide and varied scope of ES assessed (18)	• Limited scope for adaptation or customisation • Does not account for adjacent factors which may inhibit the potential benefits from ES gains
ARIES	• Ability to focus on human beneficiaries of ES • Allows for customisation • Can be used in data poor conditions • Free to use	• Requires technical skills for some uses of the tool • Can be very time consuming • Complexity of human-natural systems not fully captured
ASSIST E-Planner	• Does not require technical skills such as GIS or modelling • Suggests possible interventions • Fine resolution which aligns to AES options	• Limited scope for adaptation or customisation • Reliability is questioned by the lack of validation • No user inputted data
NEVO	• Has a function to look at change over time, considering climate change impacts • Allows user inputted data • Allows users to define objectives • Free to use	• High data requirements • Requires technical skills and competency • Out of date data at times

Tool	Strengths	Limitations
INVEST	• Provides a monetary value output for some ES • Detailed and transparent limitations and assumptions available • Allows for adaptation and customisation	• Requires basic to intermediate skills in Python • Requires post-hoc analysis for trade-offs • Variable confidence and accuracy of models within the tool
EcoservR	• Extensive documentation on uncertainty (note these were originally written for the former Ecoserv-GIS tool) • Generates mapped outputs • Intervention effects can be detected beyond the site level to local and landscape scales	• Requires competency with R software • Limited scope for adaptation or customisation • Can require quite detailed, complex project specific data
SCP + Marxan	• Allows for adaptation and customisation • Can theoretically be used for any land use change intervention • Generates mapped outputs • Can find the 'global optimum' through simulated annealing (see Section 3.3)	• Requires technical skills and competencies • Can be very time consuming
NATURE	• Does not require technical skills such as GIS or modelling • Can be used in data scarce conditions • Makes complex data easy to interpret • Highly relevant and targeted to Natural Capital and BNG	• Does not account for the wider landscape • Post-hoc analysis is required • Limited scope for adaptation or customisation
LUCI	• Considers trade-offs and synergies • Tool is adaptable and customisable • The model allows mapping of ES at fine (sub-field) to landscape spatial scales	• Requires basic GIS skills and access to software • Requires high resolution data which can be limiting • Some limitations noted for models
ROOT	• Provides mapped outputs • Well supported methodology • Useful for large scale projects	• Requires technical skills including GIS and statistical analysis • High data requirements • Requires high performing computers

Tool	Strengths	Limitations
LUCT	• Spatial resolution is fine and suitable for sub-field assessments (0.41 ha) • Cost-benefit analysis • Allows user input data to replace or supplement national data	• Does not generate mapped outputs directly • Tool currently only available through the EA
HydroloGIS	• Specialisation for NFM and water flow/quality projects • Does not require technical skills • Broad application regarding strength and benefits	• Lack of publicly available data/guidance • Reliability and validation information is unavailable • Requires a fee
Ciriabest	• Specialisation for NFM and BGI projects • Cost-benefit analysis • User inputted data	• Lack of publicly available data/guidance • Reliability and validation information is unavailable • Requires a fee

4. Other tool reviews

During the review of the 13 priority tools, other tools related to land use decision making or ES/benefits were collated and rapidly assessed. The full list of other tools considered is given in Appendix 2. These tools did not meet the criteria for a full review as they were limited to less than three ES/benefits or they did not conduct prioritisation/optimisation, however, there are notable elements from some of these other tools that should be considered for any future tool development. In some circumstances tools appeared to meet the threshold but had very limited publicly available information so were not considered for a full review.

4.1. Agricultural relevance

With the development of ELMs and the high percentage of land under agriculture, tailoring a tool toward the agricultural sector may be key to delivering national climate and biodiversity goals. Within the individual tool reviews, ASSIST, E-Planner, LUCT and LUCI allow the user to assess ES broadly focussed on the agricultural landscape. Other tools with good examples of agriculture focussed elements include:

- **Agricultural Land Environmental Risk Tool (ALERT):** An internal tool available to Natural England and Environment Agency staff. This web-based GIS tool primarily holds data from remote sensing that can be used to help farmers reduce environmental pollution from their business. ALERT has been utilised by the Catchment Sensitive Farming partnership to target on-farm mitigation measures for run-off, soil erosion, deposition, etc. The remote sensing data may be a useful element for any potential tools.

- **Agrimetrics Tool:** An agri-food data marketplace where users can find, manage and monetise food and farming data. This includes crop analytics, satellite data, climate data, yield forecasts and ecological indicators. Potentially a useful data catalogue for tools involving agricultural assessments.

- **The Cool Farm Tool:** An online assessment tool (free for first 5 uses) that allows farmers across the globe to quantify and track environmental impacts and improvements over time for greenhouse gases, water and biodiversity. User data is required but should be data known to the landowner/manager. The tool creates 'what-if' scenarios and gap analysis to develop tailored reduction strategies. Membership is extensive and multinational, including academic partners such as the University of Oxford, Cambridge and Aberdeen. Heavily geared to farm businesses and appears to be very popular.

- **Farmscoper V5:** A Defra and Environment Agency funded decision support tool with ADAS focussed on assessing cost and effectiveness of agricultural mitigation methods on multiple pollutants. The database has over 100 mitigation methods. The tool assesses what could or should be done to reduce farm pollution. Currently the tool's pollutant model uses a 1 km^2 resolution for soil, climate and other data so is potentially too coarse to be used on a field or holding level. However, it is free and Microsoft Excel based so fairly accessible and useful for looking into local mitigation opportunities. A cost effectiveness assessment is particularly helpful to landowners.

- **AgLand**: A tool quite similar to ASSIST E-Planner, providing maps of services and benefits. The tool maps ecosystem service supply and demand and is a starting point to help landowners identify suitable areas to apply interventions for ecosystem service provision, synergies and trade-offs. These include food production, pollination, carbon storage and flood prevention. The 1 km^2 resolution is potentially too coarse to use at a field or holding level but could still provide information on local opportunities. The tool is a free map viewer and is a clear, quick and easy way for landowners to gain an overview of what ES opportunities are on their land.

In terms of tool functionality, usability and relevance, the Cool Farm Tool could be considered as having useful elements for the agriculturally focussed end user. AgLand, alongside ASSIST E-Planner, is a good starting off point for landowners looking for an initial exploration into possible land use decisions with some scope to provide suggestions, but it is limited in resolution. The data from ALERT and the Agrimetrics Tool may be of particular interest to any future tools with a focus on agricultural land use changes.

4.2. Popularity and awareness

There is a plethora of existing land use decision making tools, mapping systems, website interfaces and guides. To implement a novel tool successfully, the user base needs to be aware of the product. How this is achieved would differ between different hypothetical sectors, for example advertising in the private sector. Some tools and mapping systems are frequently used and well known due to their links with government policies and existing mandatory systems used by landowners (such as the Rural Payments portal and the internal Land Management System within the Rural Payments Agency (RPA) within England).

Launching a new tool amongst an already busy market may be difficult. In regard to the agricultural sector in the UK, numerous farming specific tools and consultancies exist, therefore a targeted tool may benefit from being integrated into ELMs guidance or existing interfaces. For example, MAGIC Map is signposted for applicants of ELMs in order to assess existing elements of their land including designations, historical assets or nutrient vulnerability.

There may be some merit into exploring how a new tool could be incorporated within the existing process of how landowners manage their holdings through the relevant devolved governments rural payments service (e.g. the Rural Payments Agency in England). This would bring the tool to the forefront of the UK landowner user base and could also be incorporated with land management stewardship schemes.

4.3. Mapping

Mapping of ES and benefits is a good way to visualise and interpret information and is broadly more accessible to a wider audience than data expressed just though tables and numerical outputs. It may also be more useful when presenting information to stakeholder groups and decision makers.

Digitisation of data that can be accessed across government bodies and the land managers will be crucial for efficient delivery of positive ELMs.

Many of the priority tools reviewed contain either mapping interfaces or mapped outputs. Two other tools worth mentioning are MAGIC Map and the Land App.

- MAGIC map is an online, Defra supported interactive map viewer that is widely used by landowners, planners, government bodies and local authorities. This includes countryside stewardship targeting layers which are particularly useful for landowners applying for schemes. The map holds updated information on designations that is key to landowners and planners. There are issues with the data accuracy and age of other datasets.

- The Land App is a private tool that is becoming more frequently used, particularly in the UK, for the agricultural and conservation sectors. It can provide easily generated reports of what a specific spatial area contains (including information contained in MAGIC Map). The developers are also looking into land management algorithms which aim to give land managers a more instant direct understanding of market prioritisation for land use interventions potentially with pricing for features contained within their holding. This could be particularly relevant to land use decision making tools in the future. The tool is already being used by private landowners and agents when mapping applications for Countryside Stewardship and may be worth exploring further in the future.

With the rising interest in the Land App, it may be worth considering how any future tools can make use of existing mapping interfaces or at least keep in mind compatibility of outputs/inputs between existing well used and trusted systems.

4.4. Monetary value and funding opportunities

Providing monetary estimates of interventions or cost-benefit analyses is particularly useful for landowners when considering land use decision making. For many individuals and businesses, the economic outcomes of interventions will be one of the most important factors. Tools that can provide accurate estimates of costs and/or monetary benefits may be more appealing to users and for exploring decisions with stakeholders.

Some of the priority tools provide monetary values to ES/benefits and cost-benefit/cost effectiveness analyses on land use interventions. These include Ciriabest, InVEST, ARIES, NEVO and Marxan. The most common monetary value output relates to carbon, where there are already existing markets. Alongside estimates of monetary values, compatibility with funding opportunities would be a helpful component of tools. These could include private green finance markets, BNG and environmental stewardship/grants. Additional tools with elements to consider include:

- ReThink Carbon. A recently released tool developed initially for Scotland with support from the Scottish government and John Muir Trust. The tool looks at the financial, biodiversity and ecosystem service benefits of land use change, estimating greenhouse gas emissions as well. The tool integrates funding opportunities including the Woodland Carbon Code and the Peatland Code, looking at financial returns under different scenarios. The tool takes into account 65 grants that could be applied depending on the site locality.

- Farmscoper V5. A Defra and Environment Agency funded decision support tool with ADAS focussed on assessing cost and effectiveness of agricultural mitigation methods on multiple pollutants. The tool provides cost estimates for interventions using cost coefficients. These include excreta (costs associated with livestock waste), manure, area to be managed, and fertiliser costs. These costs may help inform land use intervention decisions and overall affordability and financial planning.

Including monetary values within tool outputs would be a positive element of any future land use decision making tool. Whether these are cost-benefit/effectiveness estimates or values based on current markets, an economical steer on interventions would be useful for landowners/land managers to assess the financial stability of future decisions. Incorporating funding opportunities, particularly government funded stewardship/grant schemes would be a key element to any agriculturally focussed tool or user base. Again, this could be incorporated within existing systems and guidance from Defra and devolved governments rural payment services.

4.5. Socio-economic

Many of the priority tools reviewed covered a wide range of ES/benefits, with most of these focussing on provisioning, regulating and support ES. A few included elements of cultural ES such as recreational and aesthetic values. These aspects of land use interventions are important to include in tools, but they can be less objective in terms of value outputs.

The ORVal (Outdoor Recreation Valuation Tool) has been developed by the University of Exeter, with funding from Defra. The tool allows users to examine the recreational value of existing green space and test how the number of visits and the value of these visits may change if land cover was altered or if new green spaces are created. The results can be grouped by local authority area or catchment and can be split by socio-economic group.

These elements may be particularly useful for tools looking at BGI, local planning or for any land use interventions that have (or could have) public access. Whilst some cultural service aspects are difficult to quantify (the value of views or tranquillity for example), they are an aspect that should be considered for land use decision support tools.

4.6. Artificial intelligence (AI)

Artificial intelligence (AI) and machine learning algorithms are being used more frequently across a huge range of sectors. Within the environmental sector, AI can aid in numerous applications including establishing nutrient cycling and crop productivity models (Elahi *et al.* 2019; Zhang *et al.* 2021) and implementing sustainable forest management practices (Liu *et al.* 2021). AI can also be used to increase speeds and efficiency of complex modelling.

ARIES (see individual tool review) uses AI to pair ecosystem service models with spatial data to quantify the ecosystem service flows.

ReThink Carbon utilises AI powered ‘discovery’ although this is a very new tool and publicly available information on the method of AI application is not evident. With advancements in technology, it may be worth considering the functions of AI in any future tool.

5. Technical recommendations

There are a large number of land use decision tools available, targeting a plethora of ES and benefits. This report has reviewed 13 tools that prioritise or optimise three or more ES/benefits, but there are many more tools available to decision makers that focus on specific services or provide valuable information that can help inform land use interventions. Through the review of these 13 tools, it is clear that there is no single tool that can inform all aspects of land use decision making in the UK or at other national levels. Tools that are focused on more specific targets and goals (BNG or agricultural land use) provide more accurate, specific information than those looking at general ES. However, these tools tend to miss out on some fundamental services and may mask important benefits that are not being considered and therefore limit assessment of the full range of trade-offs or synergies.

When designing a tool or selecting a tool the target user and objectives need to be considered. Is the tool for general land use change decisions? Or for BNG, ELMs or carbon offsetting? The technical skills of the end user also need to be considered. Is the tool for any individual landowner or land manager or is it targeted at planners, policy makers, or advisers to land managers? All these questions will steer and potentially limit the scope of the theoretical tool.

5.1. Recommendations regarding tool methods

5.1.1. Modelling of ecosystem services vs relative scoring of benefits

The need for a tool that either models ecosystem services (ES) or scores them will depend on what the project that the end user is delivering. Whilst modelling tools can model ES provision, looking at interrelationships between them and dynamic assessments, scoring tools may be much more appropriate for projects looking at meeting specific values for certain ES, such as BNG.

Modelling tools however allow for integration of various data sources within the model process, enabling the simulation of how these variables may impact ES supply, demand and flows across a spatial area.

One of the main concerns is the scientific robustness behind the scoring or modelling process. Whilst ES modelling tools undertake more complex ES provisioning, some of the scoring tools undertake relatively complicated calculations (such as ROOT). The reliability of the models, formulas and calculations cannot be easily categorised between modelling or scoring tools, there is a spectrum across all of them.

A number of tools provide peer reviewed evidence of calculations and data, with calculations and models detailed within user guidance. However, there are questions surrounding baseline values for ES for some tools, and for the multipliers for some of the scoring models. However, when compared with the modelling limitations and uncertainty, it can be argued that the accuracy and reliability of modelling and scoring tools as a general concept is difficult to distinguish between.

5.1.2. Method of prioritisation or optimisation

Inclusion of prioritisation/optimisation through analytical methods within the tool is preferred and will assist end users with limited time and resources with decision making. This may be particularly useful for individual landowners looking to undertake interventions who do not necessarily have the resources to run multiple scenarios and run ad-hoc analysis. ROOT, LUCI, LUCT, NEVO, SCP + Marxan and HydroloGIS conduct prioritisation/optimisation analysis within the tool.

Post-hoc analysis is still useful and draws valuable conclusions on ES provision. In particular, EBN and NATURE Tool provide clear values for ES, which are relevant to BNG and natural capital. The issue for prioritisation and optimisation for post-hoc analysis tools is the additional resources needed to generate different scenarios to interpret what is best for the spatial area.

Of the prioritisation/optimisation analytical methods within the tools themselves, the four broad categories for the priority tools consists of

- Linear programme algorithms
- Simulated annealing algorithms
- Cost-benefit analysis
- Trade-offs & synergies

Each have their own strengths and limitations. Simulated annealing algorithms potentially have an advantage over linear programme algorithms as they are not limited to linear assumptions between variables and can interpret more complex relationships (ecosystem service interactions are complex and not always linear). Simulated annealing algorithms are also better at finding the global optimum (potentially better prioritisation than linear programme algorithms). SCP + Marxan utilises simulated annealing algorithms, is a customisable tool and can target any land use change and ES where data can be provided.

Cost-benefit analysis may be particularly useful to landowners who are looking into land use change as part of their business. LUCT utilises a prioritisation/optimisation method within the tool, providing cost-benefit and total benefit outputs. The cost-benefit assessments are subject to a changing landscape of economic costs so there is a risk of inaccuracy in results. However, input data can be updated by the user to increase accuracy and reliability.

LUCI provides trade-off analysis to identify win-win outcomes, this could also be particularly useful for visualising potential options and informing land use change decisions.

Currently there is not a one size fits all tool, however for future tools it may be worth exploring combining methods of simulated annealing algorithms with a cost-benefit analysis then incorporated into it. Potentially combining aspects of SCP + Marxan and LUCT.

5.1.3. Identification of potential interventions or user defined interventions

Only the E-Planner and HydroloGIS suggest specific interventions to the tool user. HydroloGIS provides a ranked list of interventions relative to the highlighted spatial area, whereas E-Planner has a list of interventions within the user guidance not the tool outputs themselves.

All other tools require the user to input what interventions they will enact, land use change, habitat creation, etc.

A theoretical tool that could model potential interventions against ES provision and optimise these spatially would be incredibly complex and require a large amount of resources and computational power. Therefore, it is likely that tools will need to rely on user defined interventions until advancements have been made. With the development of machine learning this may be possible, and ARIES has already embedded AI within the tool.

The HydroloGIS method of ranking potential interventions within a spatial area for specific ES benefits could be useful for other tools and could be particularly relevant for ELMs.

5.1.4. Mapped outputs

The ability to visualise ES provision through maps is an advantage to the end user and to any additional stakeholder engagement that user may undertake for land use decisions. A number of tools provide maps within the tool, or outputs that can readily be converted in GIS software (for example, LUCT). To increase usability, maps should be generated within the tool and through a user face that does not require technical GIS skills or software to access them.

It is worth noting that EBN and NATURE Tool do not produce mapped outputs but have tabulated/graphed information on ES values. This is still very useful and, in some circumstances, is more relevant to the user. For example, if a project requires BNG, the tabulated simple values and graphs allow the user to clearly see if targets are being met.

In an ideal tool it would be beneficial to have both mapped outputs and tabulated summaries.

The compatibility of data outputs with data requirements from government departments (for example the Rural Payments Agency) will be vital for efficiency and reduction of double handling of data. This will benefit multiple parties:

- funding applicants, who would use the initial outputs as a decision-making tool to seek the best finance opportunities, whether under ELMs or thorough other stacked or bundled opportunities,
- Defra, Natural England and the RPA for scheme support, compliance, monitoring, evaluation and learning,
- third parties such as private finance providers or consultants engaged by Defra for accurate and complete spatial data for eligibility checking or scheme evaluation.

5.1.5. Scale

For tool accuracy, reliability and relevancy, the finer the spatial scale the better. This will depend on the project and the end user, however for a typical land manager a sub-field level of detail would be useful for prioritising land use decisions. The NEVO tool works at a regional scale of 2 km^2 which may be relevant to regional or national projects, planning and policy design but not necessarily an individual landowner. A five metre resolution similar to E-Planner would be a good spatial scale for the average landowner.

Finer resolutions can require more processing power and time to assess, and there are issues with datasets not being at that resolution and therefore not being as reliable for the modelling/scoring tool. For example, if concerned about carbon sequestration for a 0.25 km^2 project area and the dataset is at 2 km^2, the average value across the 2 km^2 may not be relevant at the project scale. These potential data limitations need to be transparent within any tool.

5.1.6. Relevance to sectors

Depending on the end user and project, the scope of relevant ES and benefits will vary. Ciriabest is able assess 19 ES and benefits, with InVEST targeting 22. Marxan has no limits on ES/benefits depending on what the user can input into the tool. Not all of these services and benefits will be relevant to each project and area, however if the tool is modelling ES, it will be important to include as many of these as possible so that the interrelationships of ES are modelled more accurately. If certain services are left out of the tool, certain ES flows may be modelled incorrectly or miss out on ES that could potentially be negatively impacted by an intervention.

Both LUCT and LUCI have a focus on the agricultural landscape, however the ES assessed in the tools have a wider remit than just agriculture. These may be particularly useful to consider for any future agriculture related tools.

5.1.7. Data requirements

Considering the end user, the data requirements for the tool should allow for relatively minimal input with the scope of adding in additional information for users with more available data. ASSIST E-Planner requires no data input but does not provide any modelling or scoring of ES. EBN is a scoring tool that has simple data requirements that should be known or readily accessible to the landowner.

Similarly to the user interface, a two-tiered approach would be beneficial, where the tool can function with quite minimal spatial data relevant to the project – with the opportunity to add in more advanced details. InVEST, ARIES, SCP + Marxan, NATURE Tool, LUCI and LUCT are good examples where basic data is provided within the tool, but the user can improve the accuracy and robustness with project specific data.

Importantly, any data embedded within the tool needs to be sourced from scientifically robust data, with publicly available evidence of data sources. Many of the tools use recognised national datasets and list their sources but is unclear on when these are updated (if at all). Combining tools with up-to-date data is key, and the agri-food data marketplace within the Agrimetrics Tool may be a good source alongside government datasets.

5.1.8. Tool adaptability

The requirements and benefits of tool adaptability are largely dictated by the target audience, sector and projects. For example, tools designed for BNG or NFM may be quite rigid in how customisable the tool is (NATURE Tool for example). On the other hand, where tools have been designed to work across a broad spectrum of ES and/or countries, there may be scope for users to add in their own models, customise models and create toolboxes that include the original tool. InVEST, LUCI and ARIES are good examples of such tools. With LUCI, the United Nations have created their own toolbox that utilises LUCI models to support their SEEA framework.

Customising and adapting tools tends to require technical skills in GIS or programming and may not be possible for many typical landowners or projects. However, incorporating adaptability into the model may allow academics, conservation bodies, non-government organisations and governments both nationally and internationally to adapt tools and use them for region/project specific outcomes. Making the tool open access may allow this customisation, above and beyond what the targeted general user might require it for.

5.2. Recommendations regarding end user tool interface and usability

For land use decision making, there is a highly variable scale of end user from an individual landowner to government policy makers. To enact change and ensure accessibility by individual landowners who are making decisions on their land, it is recommended that the tool is suitable for non-technical users and most importantly, free.

NATURE Tool is a good example of a tool for nontechnical users, who only need use Microsoft Excel and who can follow a user guide for inputting data and running the tool. However, it may be useful for the tool to have a downloadable easy to follow programme (or web portal) with a simple user interface. The InVEST tool workbench is a good example but does require some GIS skills to run. The NATURE Tool 2.0 is currently in development and seeks to improve the interface for users. This may be worth considering as the tool provides clear scoring outputs for a number of ES.

A two-tier tool is recommended to allow expanded use by technical users. This could allow users with GIS/coding skills to create additions or edits within the tool for more project specific focussed outcomes. Again, the InVEST tool workbench is a good example, and potentially LUCI which has been combined with other toolboxes for wider purposes. ARIES is a good example of how a tool can be split into an easy-to-use simpler interface with the option of those with skills going in to input their own data as well as own codes for models.

A new model that allows this would encompass most user groups, but the focus should be on the easy to use ‘assume no technical skills’ end user. This may particularly be the case if the tool is focussing on ELMs users where individual farmers are unlikely to have coding/GIS skills or the time to learn these.

5.3. Agricultural sector specific recommendations

One solution would be to consider the tools identified in this report that most closely deliver Defra’s requirements to identify any opportunities for greater alignment.

Of the priority tools reviewed, the Land Utilisation Capability Indicator (LUCI) and Land Use Choices Tool (LUCT) have a focus on agricultural land and potential impacts of land use change on ES within these landscapes.

A tool could be developed further taking account of the key recommendations set out earlier in this report. Co-design with farmers and land managers – the key end users – who will be critical to its success. Previous co-design work on this has indicated a very strong desire from this audience for mapped outputs.

A two-tier system of data input requirements would also be beneficial to farmers and land managers. This could allow an exploration of possibilities with relatively limited data that could be expanded upon depending on what information the user has access to. This would increase the inclusivity of the tool but allow for more technical application.

To help with uptake and use of any tool aimed at ELM, it will need to be well advertised and located in an easily accessible format. A tool could potentially be incorporated within the devolved governments rural payment service portals, and/or be connected to government portals where applications for schemes such as the sustainable farming incentive (SFI) take place.

5.4. Summary of key considerations for future tool development

Through the review there are a number of aspects that could be implemented within a future tool for spatial prioritisation and optimisation of land use decisions. The review has highlighted the benefits of spatial prioritisation, and the benefits from conducting the process within the tool itself rather than relying on post-hoc analysis which the user may not have the time or resources for. Simulated annealing algorithms combined with cost-benefit analysis may be methodologies to explore further, particularly considering SCP + Marxan and LUCT (although elements of other tools such as the ‘traffic light’ system in LUCI could be useful for future tools).

The following points should also be considered for any tool development:

- The tool needs to be accessible and free. Combining the tool with existing landowner government interfaces and platforms, including base data such as RPA field numbers would be beneficial.

- Modelling speed and computational requirements will differ depending on how complex the tool is. For general use by landowners there will need to be a limit to software requirements.

- Data sets for any tool need to be transparent, updated and from a trusted source. There will need to be capacity and resources put into managing the tool, including keeping up to date with new datasets and refreshing the tool.

- The tool must address habitat heterogeneity, a common issue amongst datasets. This is where the same value is given for the same habitat across a spatial area even if there are differences in elevation, slope, condition, etc. EBN and NATURE Tool are good examples which overcome this issue using indicators for habitat condition.

- The tool should have relevance to ELMs, through the ability to select inputs with clear interventions (options), ideally from a menu, that the user can input at the appropriate scale and with a choice of point, linear or polygon data inputs, appropriate to the intervention.

- Compatibility of outputs and digitisation of spatial data within Defra will be vital for efficiency and future collaboration. Giving land managers the tools they need to put the right thing in the right place and access funding for ELMs alongside other funding opportunities will enable delivery of ES - public goods - for less, and more efficient monitoring and evaluation. This will ensure scheme outcomes can be properly measured and impactful outcomes that are good value for money are prioritised.

- For prioritisation and optimisation, models should overlay and combine individual ES to highlight win-win scenarios, trade-offs and negative impacts. An easy to interpret traffic light system, such as LUCI, would be beneficial to the end user.

- Optimisation must be considered as limited within the tool and not a real word optimal solution – further context and considerations must always be taken into account.

- To assess and prioritise a wide range of ES or actions, a tool may need a nested modelling framework. This could combine multiple single ES models with additional processing models to conduct prioritisation.

6. References

6.1. Individual tools

Ciriabest

Ciriabest (CIRIA'S Benefits Estimation Tool), Susdrain website, accessed 11 March 2024, available at https://www.susdrain.org/resources/best.html

The Environmental Benefits from Nature Tool (EBN)

Cianchi, B., Everard, M., Gething, B., Cook, R. & Ginepro, M. (2023) 'The efficacy of biodiversity and ecosystem assessment approaches for informing a regenerative approach to built development', *Environmental Policy and Development*, 20 (1), pp. 248-262.

Smith, A.C., Baker, J., Berry, P., M., Butterworth, T., Chapman, A., Harle, T., Heaver, M., Hölzinger, O., Howard, B., Norton, L., R., Rice, P., Scott, A., Thompson, A., Warburton, C. & Webb, J. (2021) Environmental Benefits from Nature (EBN) Tool – Beta Release Data Catalogue, accessed 12 March 2024, available at https://publications.naturalengland.org.uk/file/6185579690328064

Smith, A.C., Baker, J., Berry, P.M., Butterworth, T., Chapman, A., Harle, T., Heaver, M., Hölzinger, O., Howard, B., Norton, L.R., Rice, P., Scott, A., Thompson, A., Warburton, C. & Webb, J. (2021) EBN User Guide, Natural England Access to Evidence, accessed 12 March 2024, available at https://publications.naturalengland.org.uk/publication/6414097 026646016

Integrated valuation of Ecosystem Services and Trade-Offs (InVEST)

Bagstad *et al.* (2013) 'A comparative assessment of decision-support tools for ecosystem services quantification and valuation', *Ecosystem services*, 5, pp. 27-39.

Caro *et al.* (2020) 'Ecosystem services as a resilience descriptor in habitat risk assessment using the InVEST model', *Ecological Indicators*, 115, 106426.

Hamel, P., Guerry, A., D., Polasky, S., Han, B., Douglass, J., A., Hamann, M., Janke, B., Kuiper, J., J., Levrel, H., Liu, H., Lonsdorf, E., McDonald, R., I., Nootenboom, C., Ouyang, Z., Remme, R., P., Sharp, R., P., Tardieu. L., Viguié, V., Xu, D., Zheng, H. & Daily, G.C. (2021) 'Mapping the benefits of nature in cities with the InVEST software', npj *Urban Sustainability*, 1(25).

InVEST User Guide (2024) Natural Capital Project, 2024. InVEST 3.14.1. Stanford University, University of Minnesota, Chinese Academy of Sciences, The Nature Conservancy, World Wildlife Fund, Stockholm Resilience Centre and the Royal Swedish Academy of Sciences. Available at: http://releases.naturalcapitalproject.org/investuserguide/latest/en/index.html#invest-models

Kumar, S., Raj, A.D. & Kalambukkattu, J.G. (2023) 'Geospatial modelling for sustainability of soil ecosystem services in hilly and mountainous landscapes', in *Water, Land, and Forest Susceptibility and Sustainability*, Volume 2: Insight Towards Management, Conservation and Ecosystem Services. Elsevier pp. 331-359.

Meraj *et al.* (2022) 'Modelling on comparison of ecosystem services concepts, tools, methods and their ecological-economic implications: A review', *Modelling Earth Systems and Environment*, 8(1), pp. 15-34.

Mueller *et al.* (2012) 'Closing yield gaps through nutrient and water management', *Nature*, 11 490(7419), pp. 254-7.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., Chan, K.M., Daily, G.C., Goldstein, J., Kareiva, P.M. & Lonsdorf, E., (2009) Modelling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment*, 7(1), pp.4-11.

Nelson, E.J. & Daily, G.C. (2010) Modelling ecosystem services in terrestrial systems. F1000 biology reports, 2.

Sharps, K. *et al.* (2017) 'Comparing strengths and weaknesses of three ecosystem services modelling tools in a diverse UK river catchment', *Science of The Total Environmen*t, 584–585, pp. 118–130.

Artificial Intelligence for Environment and Sustainability (ARIES)

Bagstad, K., Villa, F., Johnson, G.W. & Voight, B. (2011) A guide to models and data. The ARIES Consortium. Available at: https://seea.un.org/sites/seea.un.org/files/7_11.pdf

Bagstad, K., Semmens, D., J. & Winthrop, R. (2013) 'Comparing approaches to spatially explicit ecosystem service modelling: A case study from the San Pedro River, Arizona', *Ecosystem Services*, 5, 40-50.

Bagstad, K, J., Semmens, D., J., Waage, S. & Winthrop, R. (2013a) 'A comparative assessment of decision-support tools for ecosystem services quantification and valuation', *Ecosystem Services*, 5, pp. 27-39.

Sharps. K., Masante, D., Thomas, A., Jackson, B., Redhead, J., May, L., Prosser, H., Cosby, B., Emmett, B. & Jones, L. (2017) 'Comparing strengths and weaknesses of three ecosystem services modelling tools in a diverse UK river catchment', *Science of the Total Environment*, 584-585, pp. 118-130

Villa, F., Bagstad K., J., Voigt B., Johnson G., W., Portela R., Honzák M. & Batker, D. (2014) A Methodology for Adaptable and Robust Ecosystem Services Assessment. *PLoS ONE* 9(3): e91001.

Willcock, S., Martínez-López, J., Hooftman, D.A., Bagstad, K.J., Balbi, S., Marzo, A., Prato, C., Sciandrello, S., Signorello, G., Voigt, B. & Villa, F. (2018) Machine learning for ecosystem services. *Ecosystem services*, 33, pp.165-174.

ASSIST E-Planner

Redhead, J., W., Burkmar, R., Brown, M. & Pywell, R. F. (2022) 'E-Planner: A web-based tool for planning environmental enhancement on British agricultural land', *Environmental Modelling and Software*, 155.

Urguhart, J., Goodenough, A. & Micha, N. (2023) Decision support tools for sustainable landscapes: Enhancing farmer engagement. Report to Landscape Decisions Programme. Countryside and Community Research Institution: Cheltenham.

EcoservR

Angers-Blondin, S., Pimblett, J., Bellamy, C., Rouquette, J., Holt, A., Varley, M. & Bowe, C. (2020) EcoservR: a natural capital mapping tool for measuring public goods. ELM Test and Trial 074. Final report presented to Defra, September 2020.

Holt, A., Rouquette, J., Bowe, C., Busieker, K. & Angers-Blondin, S. (2020) Baseline natural capital assessment for the Liverpool City Region. Nature Capital Solutions Ltd.

Holt, A., Zini, D. & Ashby, M. (2021) South Yorkshire natural capital and biodiversity mapping. Natural Capital Solutions Ltd.

Southgate, F. (2016) An analysis of Ecoserv-GIS Ecosystem Service mapping outputs for the ARC Project Areas, using Horsham as a case study. Sussex Wildlife Trust.

Natural Environment Valuation Online (NEVO)

Binner, A., Ferrini, S., Day, B., Owen, N.E., Bateman, I.J., Smith, G., Liuzzo, L., Haddrell, L. & Collings, P. (2019). Natural Environment Valuation Online Tool. Technical Documentation, version 1.0, June 2019. Chapter 2: Forestry Model

Day, B., Owen, N., Binner, A., Batemen, I., Cho, F., De-Gol, A., Ferguson-Gow, H., Ferrini, S., Fezzi, C., Harwood, A., Lee, C., Luizzio, L., Mancini, M. & Pearson, R. (2020) The Natural Environmental Valuation (NEV) Modelling Suite: A Summary Technical Report. Available at: https://www.exeter.ac.uk/media/universityofexeter/collegeofsocialsciencesandinternationalstudies/leep/documents/workingpapers/LEEP_Working_Paper_01-2020_-_The_NEV_Modelling_Suite_v2.pdf (Accessed: 20/03/2024)

Impact summary by SWEEP available here: https://sweep.ac.uk/wp-content/uploads/2023/05/017-ImpactSummary.pdf (Accessed: 20/03/2024)

NEVO Team & Lidgard, K. (2019) NEVO Case Study – Reconnecting and improving the River Wey. Accessed 12 March 2024, available at https://sweep.ac.uk/wpcontent/uploads/2023/01/017-NEVO-River-Wey.pdf

Tool Information by SWEEP available here: https://sweep.ac.uk/wp-content/uploads/2023/01/017-NEVOTool-Information.pdf (Accessed:20/03/2024)

Systematic Conservation Planning + Marxan

Beger, M., McGowan, J., Treml, E.A., Green, A.L., White, A.T., Wolff, N.H., Klein, C.J., Mumby, P.J. & Possingham, H.P. (2015) Integrating regional conservation priorities for multiple objectives into national policy. *Nature communications*, 6(1), p.8208.

Janßen, H., Göke, C. & Luttmann, A. (2019) ‘Knowledge integration in Marine Spatial Planning: A practitioners’ view on decision support tools with special focus on Marxan’, *Ocean and Coastal Management*, 168, pp. 130-138.

Smith, R.J., Cartwright, S.J., Fairbairn, A.C., Lewis, D.C., Gibbon, G.E.M., Stewart, C.L., Sykes, R.E. & Addison, P.F.E. (2021) 'Developing a nature recovery network using systematic conservation planning', *Conservation Science and Practice*, 4(1), e578.

Water Resources East (2022) The Water Resources East Natural Capital Plan. Available at: https://wre.org.uk/projects/systematic-conservation-planning/ (Accessed: 25/03/2024)

Watts, M., Ball, I., Stewart, R., Klein, C., Wilson, K., Steinback, C., Lourival, R., Kircher, L. & Possingham, H., P. (2009) 'Marxan with Zones: Software for optimal conservation-based land- and sea-use zoning', *Environmental Modelling & Software*, 24(12), pp. 1513-1521.

HydroloGIS

Viridian. (2023) H20: Source2Sea – Manual for Nature-based Solutions. Report to Kent Wildlife Trust. Available at: https://www.kentwildlifetrust.org.uk/sites/default/files/2023-10/H2O_Source2Sea_Manual_v1.2.pdf (Accessed 27/03/2024)

Nature Assessment Tool for Urban and Rural Environments (NATURE)

Cianchi, B., Everard, M., Gething, B., Cooke, R. & Ginepro, M. (2024) The efficacy of biodiversity and ecosystem assessment approaches for informing a regenerative approach to built development. *Integrated Environmental Assessment and Management*, 20(1), 248-262.

Hölzinger, O., Morris, J., Kirby, M. & Chavan, R. (2022) Introduction, user guide & methods for NATURE Tool Version 1.1 BETA.

Hölzinger, O. (2024) E-mail to Jamie Neaves, 1 March 2024.

Hölzinger, O. (2025) Case Study A. Provided via email communication by tool developer, 18 June 2025.

NATURE Tool (2024) NATURE Tool Resources. Available at: https://nature-tool.com/?page_id=49 (Accessed 20 March 2024).

Scott, A., Stevenson, U., Kirby, M., Kreule, J. & Hölzinger, O. (2021) The NATURE Tool - UK Planning Review Desk Study and Planning Workshop Summary 26th - 29th January 2021. WSP, Ecosystems Knowledge Network, Northumbria University. https://nature-tool.com/?page_id=224

Land Utilisation Capability Indicator (LUCI)

Bagstad, K. J., Semmens, D. J., Waage, S. & Winthrop, R. (2013). A comparative assessment of decision-support tools for ecosystem services quantification and valuation. *Ecosystem Services*, 5, 27-39.

Emmett, B. *et al.* (2014) Glastir Monitoring & Evaluation Programme. First year annual report. Bangor, NERC/Centre for Ecology & Hydrology, 242pp. (CEH Project no. NEC04780)

Jackson, B., Pagella, T., Sinclair, F., Orellana, B., Henshaw, A., Reynolds, B., Mcintyre, N., Wheater, H., & Eycott, A. (2013) Polyscape: A GIS mapping framework providing efficient and spatially explicit landscape-scale valuation of multiple ecosystem services. *Landscape and urban planning*, 112, pp.74-88.

Pereira, F. C., Charters, S., Smith, C. M., Maxwell, T. M. & Gregorini, P. (2023) A geospatial modelling approach to assess the capability of high-country stations in delivering ecosystem services. *Land*, 12(6), 1243.

Sharps, K., Masante, D., Thomas, A., Jackson, B., Redhead, J., May, L., Prosser, H., Cosby, B., Emmett, B. & Jones, L. (2017) Comparing strengths and weaknesses of three ecosystem services modelling tools in a diverse UK river catchment. *Science of the total environment*, 584, pp.118-130.

United Nations System of Environmental-Economic Accounting (SEEA) (date unknown) Land Utilisation and Capability Indicator (LUCI) [PowerPoint presentation]. Available at https://seea.un.org/sites/seea.un.org/files/luci_presentation_se ea-eea.pdf (Accessed: 26 March 2024).

Veerkamp, C.J., Loreti, M., Benavidez, R., Jackson, B. & Schipper, A.M. (2023). Comparing three spatial modelling tools for assessing urban ecosystem services. *Ecosystem Services*, 59, 101500.

The Restoration Opportunities Optimization Tool (ROOT)

Beatty, C.R., Raes, L., Vogl, A.L., Hawthorne, P.L., Moraes, M., Saborio, J.L. & Meza Prado, K. (2018) Landscapes, at your service: Applications of the Restoration Opportunities Optimization Tool (ROOT). Gland, Switzerland: IUCN.

Currie, J., Merritt, W., Liang, C., Sothe, C., Beatty, C.R., Shackelford, N., Hirsh-Pearson, K., Gonsamo, A. & Snider, J. (2023) 'Prioritizing ecological restoration of converted lands in Canada by spatially integrating organic carbon storage and biodiversity benefits', *Conservation Science and Practice*, 5(6), e12924.

Li, J., Merten, J., Burke, G. & Mumford, E.C. (eds.) (2018) Application of Restoration Opportunities Assessment Methodology (ROAM) in Asia. Summary of findings from the first Asia regional ROAM learning exchange. Bangkok, Thailand: IUCN.

Li, R., Li, R., Zheng, H., Yang, Y. & Ouyang, Z. (2020) 'Quantifying Ecosystem Service Trade-Offs to Inform Spatial Identification of Forest Restoration', *Forests*, 11(5), pp 563578.

Land Use Choices Tool (LUCT)

ADAS (2023) The Land Use Choices Tool (LUCT) [PowerPoint Presentation]

Wilson, L., Hobley, D. & Skirvin, D. (2021) ADAS Land use change scenario evaluation using the Land Use Choices Tool (LUCT) [PowerPoint Presentation]

6.2. Other references

Elahi, E., Weijun, C., Zhang, H. & Nazeer, M. (2019). Agricultural intensification and damages to human health in relation to agrochemicals: Application of artificial intelligence. *Land use policy*, 83, pp 461-474.

Liu, T., Sun, Y., Wang, C., Zhang, Y., Qiu, Z., Gong, W., Lei, S., Tong, X. & Duan, X. (2021) Unmanned aerial vehicle and artificial intelligence revolutionizing efficient and precision sustainable forest management. *Journal of Cleaner Production*, 311, p.127546.

Rose, D.C., Sutherland, W.J., Parker, C., Lobley, C., Winter, M., Morris, C., Twining, S., Ffoulkes, C., Amano, T. & Dicks, L.V. (2016) ‘Decision support tools for agriculture: Towards effective design and delivery’, *Agricultural Systems*, 149, pp 165-174.

Zhang, P., Guo, Z., Ullah, S., Melagraki, G., Afantitis, A. & Lynch, I. (2021) Nanotechnology and artificial intelligence to enable sustainable and precision agriculture. *Nature Plants*, 7(7), pp 864-876.

7. Glossary

Term	Description	Reference
Bayesian model	A probabilistic method which uses Bayes' theorem to update probability of a hypothesis based on new evidence. It provides a framework for incorporating prior knowledge and beliefs into statistical models, allowing for the estimation of unknown parameters and making predictions with uncertainty.	Höfer, S., Ziemba, A. & Serafy, G.E. (2019) 'A Bayesian approach to ecosystem service trade-off analysis utilizing expert knowledge', *Environmental systems and Decisions*, 40, pp. 67-83. Doi: https://doi.org/10.1007/s10669-019-09742-2
Biodiversity Net Gain	Biodiversity Net Gain (BNG) is an approach to development and/or management which ensures biodiversity is left in a measurably advantageous state following development. In England, BNG is mandatory under Schedule 7A of the Town and Country Planning Act 1990 (as inserted by Schedule 14 of the Environment Act 2021), requiring developers to deliver net gain of 10% for any development.	-
Boolean arithmetic	Boolean arithmetic or Boolean algebra is an area of mathematics which operates in binary values which are 1 = true and 0 = false.	Attenborough, M. (2003) Mathematics for Electrical Engineering and Computing. Oxford: Newnes.
Cell-based model	A cell-based model, also known as cellular automation, mimics complex systems by using a grid-like structure where each cell follows a specific rule based on its own state and the state of adjacent cells which are predefined. The model evolves over time and the behaviour of the cells create dynamic patterns and interactions in the data.	-
Conservative arithmetic	Also known as interval arithmetic or conservative numerical analysis, it is a mathematical approach to handling uncertainty by working with intervals instead of single-point values. Intervals represent the possible range of value for each quantity.	-

Term	Description	Reference
Ecosystem service(s) ES	The direct and indirect contributions of ecosystems to societal functioning, ultimately having an impact on our survival and quality of life. There are four types of ES: provisioning, regulating, cultural and supporting services, and may include pollination, pest control, recreation, or water purification as examples. ES in the report may be expressed as: • Ecosystem service supply: the quantity and quality of ES available within a given ecosystem or area. • Ecosystem service demand: the human or societal need or desire for ES, reflecting the extent that humans rely on or value the services. • Ecosystem service flow: the transfer of ES from the natural environment to human beneficiaries, representing the actual utilisation and consumption of the service.	Wolff, S., Schulp, C.J.E. & Verburg, P.H. (2015) 'Mapping ecosystem services demand: A review of current research and future perspectives', *Ecological Indicators*, 55, pp. 159-171. Doi: https://doi.org/10.1016/j.ecolind.2015.03.016
Ecosystem serviceshed	Ecosystem servicesheds are the geographical areas which provide a range of ES, often attributed to political or administrative boundaries. For the application of ROOT, ecosystem servicesheds are the spatial data (polygons) that capture which areas of the landscape are more or less important for providing services.	-
Environmental Land Management	Environmental Land Management (ELM) is a package of AES in England aimed at enhancing biodiversity, soil health, climate change and natural resource protection. It has been designed to support the 25 Year Environment Plan and carbon net zero commitments.	-
GIS	A Geographical Information System (GIS) is a computer system (hardware or software) which analyses and displays geographically referenced information including spatial and geographical data. It enables the visualisation and interpretation of a variety of layers of information and their geographical pattern.	-

Term	Description	Reference
Blue-green infrastructure	Blue-green infrastructure (BGI) encompasses the natural and semi-natural features, interventions, and structures which can be designed and managed to deliver a wide range of ES. Green elements include trees, fields or parks, whilst blue elements include canals, water treatment facilities or ponds. Some companies and groups refer to it as blue and green infrastructure.	-
Linear programming algorithm	A mathematical optimisation technique used to maximise or minimise a linear objective function subject to a set of linear equality and inequality constraints. The algorithm used to solve linear programming problems is known as the simplex algorithm. Put simply, a method to achieve the best outcome in a mathematical model whose requirements and objectives are represented by linear relationships.	Ahmad, M., Azam, M., Naeem, M., Iqbal, M., Anpalagan, A. & Haneef, M. (2017) 'Resource management in D2D communication: An optimization perspective', *Journal of Network and Computer Applications*, 93, pp. 51-75. Doi: https://doi.org/10.1016/j.jnca.2017.03.017
Model wrapping	The process of embedding a machine learning model into another to improve its performance by incorporating its additional functionality. This allows for a modular approach to building complex machine learning systems which integrate seamlessly to achieve a desired outcome.	-
Monte Carlo simulation	A computational technique used to understand the impact of uncertainty and variability in a system by generating many random samples or scenarios. Named after the famous Monte Carlo Casino.	Mooney, C.Z. (1997) Monte Carlo Simulation. Thousand Oaks: SAGE Publications Inc
Multi-criteria decision analysis (MCDA)	Multi-criteria decision analysis (MCDA) is a decision-making methodology used to evaluate and prioritise alternatives or options based on multiple criteria or objectives. It involves systematically assessing various options against a set of criteria or attributes that are important for decision-making.	Taherdoost, H. & Madanchian, M. (2023) 'Multi-Criteria Decision Making (MCDM) Methods and Concepts', *Encyclopaedia*, 3(1), pp. 77-87. Doi: https://doi.org/10.3390/encyclopedia3010006
Natural Capital	Refers to Earth's natural stock of resources which have an economic value attached to them, including but not limited to, habitats, soils, or water. It is from these natural resources that ES can be derived.	-

Term	Description	Reference
Natural Flood Management	Natural Flood Management (NFM) uses natural processes to reduce the frequency and severity of floods through techniques such as afforestation, wetland restoration and natural riverbank management.	-
Post-hoc analysis	A statistical procedure undertaken after the primary analysis of a dataset has taken place. It typically aims to explore relationships between variables, or to make further comparisons between groups or conditions that were not focused on in the initial analysis.	-
Probabilistic methods	Methods which utilise probability theory to quantify uncertainty and randomness, and make predictions or decisions based on probabilistic reasoning, therefore incorporating the likelihood of different outcomes occurring in the calculation. They allow the user to account for uncertainty in their models and make quantitative predictions with that in mind.	Spencer, J.H. & Alon, N. (2016) The Probabilistic Method. 4th ed. Hoboken: John Wiley & Sons
R	R is both a language and environment (software) for statistical computing and graphics.	-
Rasters	Raster data is stored into grids of equally sized cells. Each cell contains a value which represents a specific attribute or characteristic of a geographical area being analysed.	-
Resource Investment Optimisation System (RIOS)	RIOS is an open-source software tool that supports the design of cost-effective investments in watershed services for clean and reliable water. It has been field tested throughout Latin America but does not appear to be currently supported by a developer.	-
Service Path Attribution Networks	This is a network flow approach to ecosystem service assessment. It provides a spatial framework for determining the topology and strength of ecosystem flows and identifies the human and ecological features which give rise to them.	

Term	Description	Reference
Simulated annealing algorithm	The simulated annealing process starts with an initial solution and then iteratively improves the current solution by randomly perturbing it and accepting the perturbation with a certain probability. The probability of accepting a worse solution is initially high and gradually decreases as the number of iterations increases.	Laarhoven, P.J. & Aarts, E.H.L. (1987) Simulated Annealing: Theory and Applications. Dordrecht: Springer
Sustainable Drainage Systems	Sustainable Drainage Systems (SUDS) are designed to manage water as close to the source as possible to mimic natural drainage and move away from conventional drainage such as pipes and sewers. SUDS may include green roofs, swales, or permeable paving.	-
Systematic Conservation Planning (SCP)	The process of planning in a way which considers multiple elements of natural capital at the same time, rather than in a piecemeal approach. SCP looks at the bigger picture, using spatial prioritisation to identify synergies which can highlight areas that will lead to multiple benefits being managed simultaneously. Objectives, actions, and targets are stakeholder led, meaning that outcomes are also supported by a wider variety of people.	-

Term	Description	Reference
The Bonn Challenge	The Bonn Challenge was launched in 2011 and aims to restore 350 million hectares of degraded and deforested land by 2030. The commitments typically involve specific targets for restoring degraded landscapes, such as forests, wetlands, and grasslands, as well as actions to support sustainable land management practices, biodiversity conservation, and climate change mitigation and adaptation. User defined interventions Within tools users can specific what the changes will consist of in regard to ecosystem service provision and benefits. This could include: • land cover/habitat change (e.g. species-poor grassland to woodland) • land use change (e.g. changes in arable farming methods, from pesticides to organic) • change/creation of a natural or man-made feature (e.g. a pond or sustainable drainage system).	-
Weighted arithmetic	Weighted arithmetic, or weighted mean, calculates the average of a dataset by assigning weights to each value. The weighted mean is obtained by multiplying each value by its weight, summing these products, and then dividing by the sum of the weights. This method allows prioritization of values based on their importance, commonly used in statistics, finance, and economics to account for variations in significance among data points when calculating averages.	Dodge, Y. (2008) The Concise Encyclopaedia of Statistics. New York: Springer-Verlag

8. List of Acronyms

Acronym	Meaning
AES	Agri-environment scheme
AI	Artificial Intelligence
ARIES	Artificial Intelligence for Environment and Sustainability
BN	Bayesian Network
BNG	Biodiversity Net Gain
CSV	Comma-separated values
EBN	Environmental Benefits from Nature tool
EIA	Environmental Impact Assessment
ELM	Environmental Land Management
ES	Ecosystem Service
BGI	Blue-Green Infrastructure
GIS	Geographical Information System
INVEST	Integrated Valuation of Ecosystem Services and Trade-offs
JNCC	Joint Nature Conservation Committee
LNRS	Local Nature Recovery Strategy
LUCI	Land Utilisation Capability Indicator
LUCT	Land Use Choices Tool
NATURE	Nature Assessment Tool for Urban and Rural Environments
NEVO	Natural Environment Valuation Online
NFM	Natural Flood management
NGO	Non-governmental organisation
RIOS	Resource Investment Optimisation System
ROOT	Restoration Opportunities Optimization Tool
SBI	Single Business Identifier
SCP	Systematic Conservation Planning
SEEA	System of Environmental-Economic Accounting
SUDS	Sustainable Drainage System

9. Appendix 1: Individual tool reviews

9.1. The Environmental Benefits from Nature tool (EBN)

9.1.1. Developer(s)

Natural England, University of Oxford, in partnership with Defra, Forestry Commission, and Environment Agency (also on project team - Balfour Beatty, WSP, Ecosystems Knowledge Network, UK Centre for Ecology & Hydrology).

9.1.2. Interventions and/or services that the tool is designed to assess

Habitat and land use changes, particularly in conjunction with BNG interventions.

9.1.3. Benefits targeted

18 ES comprising flood regulation, water supply, erosion protection, water quality regulation, air quality regulation, recreation, aesthetic value, education and knowledge, interaction with nature, sense of place, pollination, pest control, carbon storage, local climate regulation, noise reduction, food production, wood production, fish production.

9.1.4. Purpose of tool

A voluntary decision-support tool developed to work alongside BNG (and in conjunction with Biodiversity Metric 3.0) and enable wider benefits for people and nature from habitat change. It is designed to be used at a variety of scales and settings to help achieve improved environmental outcomes through better consideration of the services that nature provides. Its intended purpose is to act as an exploratory scoping tool to be used in conjunction with BNG and EIA to compare alternative options for site design, whilst strengthening business cases and decision making.

9.1.5. Audience

The tool has been designed for environmental consultants, house builders and infrastructure developers, local authorities working on Green Infrastructure, providers of off-site biodiversity units, and stakeholders in other habitat led projects who are looking to consider wider benefits. The tool is suitable for use at all stages of project delivery, from initial scoping to optioneering, application and post application assessment. However, it has also been used by land managers including Wildlife Trusts and farmers.

9.1.6. Tool details

- The key categorisations of the tool for this report are:
- Scoring of land use benefits and costs – allows user inputted data
- Does not generate mapped outputs
- The user defines the interventions
- Prioritises/optimises interventions by allowing post-hoc exploration of tabulated scoring value results by the user. Post-hoc analysis can be conducted within the tool or Microsoft Excel

  - Prioritises which intervention to action in a location

- Spatial scale: tabulated format, no defined resolution

The tool lightly models ES by providing an indication of an increase, continuation or decrease in ES over a 30-year period, with indication of results broken into 10-year sections.

The EBN tool functions in Excel, utilising a model based on scores which range from 1–10. The tool models the function of various land types to deliver 18 ES and allows for the user to quantify the ability for different interventions to deliver services by defining project specific variables such as land use type, condition, and extent. Scores are adjusted by using multipliers based on 40 indicators that assess the condition and location of a habitat, giving each land type a weighting on their ability to deliver ES. These modified scores are then multiplied by the area of habitats, along with additional multipliers to account for the risk involved in implementation and the time taken for new habitats to reach their target condition. This is called the impact score. The condition indicators or spatial factors have been grouped into Basic, Standard and Advanced. This is based on the scale of the project, the complexity of the outputs (i.e. if mapping is also required), and the likely level of biodiversity impact.

The tool also generates pie charts which show total change in habitat area before and after development, alongside whether the BNG targets have been met. The results indicate how the provision of ES has changed from the baseline to the post-development situation.

9.1.7. Tool appraisal

At a glance: Key strengths and limitations

Strengths

- Allows user inputted data
- Does not require GIS or modelling skills
- Scope to use the tool for ELM
- A wide and varied scope of ES assessed (18)

Limitations

- Limited scope for adaptation or customisation
- Does not account for adjacent factors which may inhibit the potential benefits from ES gains

9.1.8. Relevance to sectors

The EBN tool is suitable for developers, planners and other interested parties to enable wider ecosystem benefits for nature and people, supporting BNG and the government's 25 Year Environmental Plan (as updated by the Environmental Improvement Plan 2023). The tool was initially designed for developers and planners; however, it has also been adopted by consultancies and land managers including Wildlife Trusts and farmers. It has been used consistently by 40 organisations and there have been around 4,500–5,000 downloads.

The EBN tool provides a common and consistent means of considering the direct impact of land use change across the full range of services that nature delivers. The tool indicates relative change in ES provision associated with habitat change and is intended to 'start a conversation' around wider benefits to people and enable better consideration of changes in ES as a result of development. Once BNG has been demonstrated using the Biodiversity Metric, the EBN tool identifies opportunities to enhance ES provision and to minimise negative impacts. It can inform better project design by indicating potential gains or losses in the supply of ES and can help to make negotiation over land use change more transparent for stakeholders.

Following a four-year developmental period with input from Government and industry stakeholders, the tool has been developed alongside several tests and pilots. The tool is currently in its Beta release stage, with Natural England currently engaged in evaluating its use to understand its effectiveness, and to determine where its works best and to ultimately guide this. At present the tool has been developed to work alongside other approaches such as EIA as a scoping tool, but mainly to support the BNG metric 3.0. However, sources suggest it has been used alongside more recent iterations of this. As the matrix includes land use, there is also potential scope to use the tool in ELM contexts.

9.1.9. Cost-effectiveness

The tool is free to use and is easily accessible to download. Due to its relative ease of use, the time and resources needed for projects is likely comparatively low compared to other tools that require GIS or programming inputs.

9.1.10. Ease of use/usability

The tool has been carefully developed, and attention has been made to its launch, ensuring sufficient information is readily available. A comprehensive user guide, with a set of principles, accompanied by a detailed catalogue of available data is provided, and the reliability of such data sources has been scrutinised by the developer. The tool requires minimal software expertise when using it for small projects, though as projects develop and become more complex, a greater level of understanding may be necessary. However, the EBN tool is praised for its usability and ease of instruction.

9.1.11. Data requirements

Data requirements are outlined in the catalogue provided by the developer. Fortunately, the user can note when data may be less reliable by using the guide, as is the case for soil compaction or peat quality (Smith *et al.* 2021). Importantly, the tool does allow for the user to input site specific data where this is available.

9.1.12. Tool adaptability

EBN is a defined tool with limited scope for adaptability or customisation.

9.1.13. Performance and reliability

The scoring matrix (how impact scores are defined through multipliers and weighting factors for habitats) has been developed alongside published evidence, expert consultation and extensive reviews. The scores have been reviewed against 30 existing tools and data sources, with over 700 pieces of literature to support this. However, reviewers and users have raised questions on the reliability of such sources, finding difficulty in verifying the baseline scores given to ES. Equally, it has been noted that consultations have been less transparent. Verification issues and discrepancies were found by Cianchi *et al.* (2023)

whereby they found inconsistencies with habitat scores given to bracken when compared to other tools.

Issues with the tool are seen when measuring ES related to cultural aspects. This is because a level of subjectivity is introduced as, for most values, opinion and personal preferences are associated. Furthermore, cultural analysis is limited as the tool does not provide a detailed assessment of factors such as environmental justice or community impact and therefore does not associate gains or losses in ES with individual groups of people.

Further limitations to the tool are noted in how it uses changes in habitat extent, condition, and location as proxies for changes in ES but does not consider factors such as topography or hydrology. In the same regard, the tool does not consider for adjacent factors which may inhibit the potential benefits from ES gains. The tool is spatially agnostic and uses a crude, simple matrix that links habitats to a certain quantity of ES delivery without taking into consideration other linked variables that may have an impact on ES delivery. For example, the benefits of tree planting in an urban environment may be inhibited/reduced by adjacent traffic. Furthermore, the tool does not account for the cumulative impact of losses over time, as losses calculated in the first 10-year period will not be included in the 30-year estimate.

9.1.14. Comparisons with similar tools

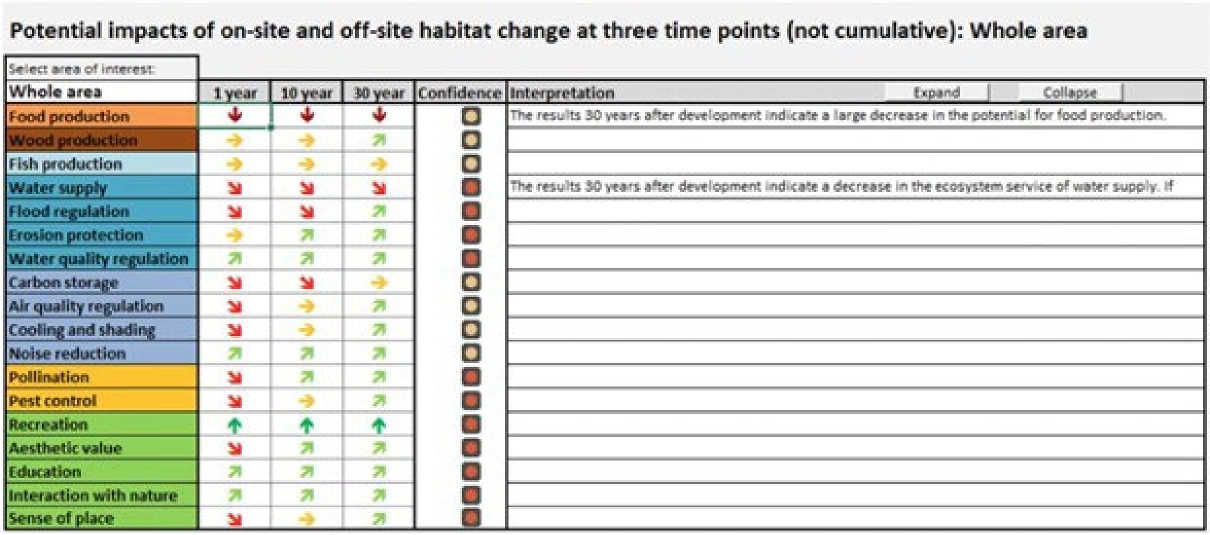
The tool was reviewed by Cianchi *et al.* (2023) alongside a similar tool which also uses Excel, the Nature Assessment Tool for Urban and Rural Environments (NATURE). EBN is largely praised for its ease of use and user guide, however in comparison to NATURE it is limited by its inability to account for trade-offs in ES across wider spatial scales, and limits with its customisation, as NATURE was advantageous for being more adaptable to local or project specific priorities.

9.1.15. Examples of use

Minimal documentation exists regarding the usage of the EBN tool within the industry, however Cianchi *et al.* (2023) demonstrate the tool on a 2.2 ha greenfield site located in Rutland, England. The site was described as a uniform grassland habitat, with development expected to include the construction of an ecological training centre, grassland enhancement, the introduction of bat boxes and hibernacula and hedge improvements.

9.1.16. The Environmental Benefits from Nature tool (EBN) output example

Example of tool outputs from Smith *et al.* (2021) EBN User Guide. Accessed 12 February 2024.

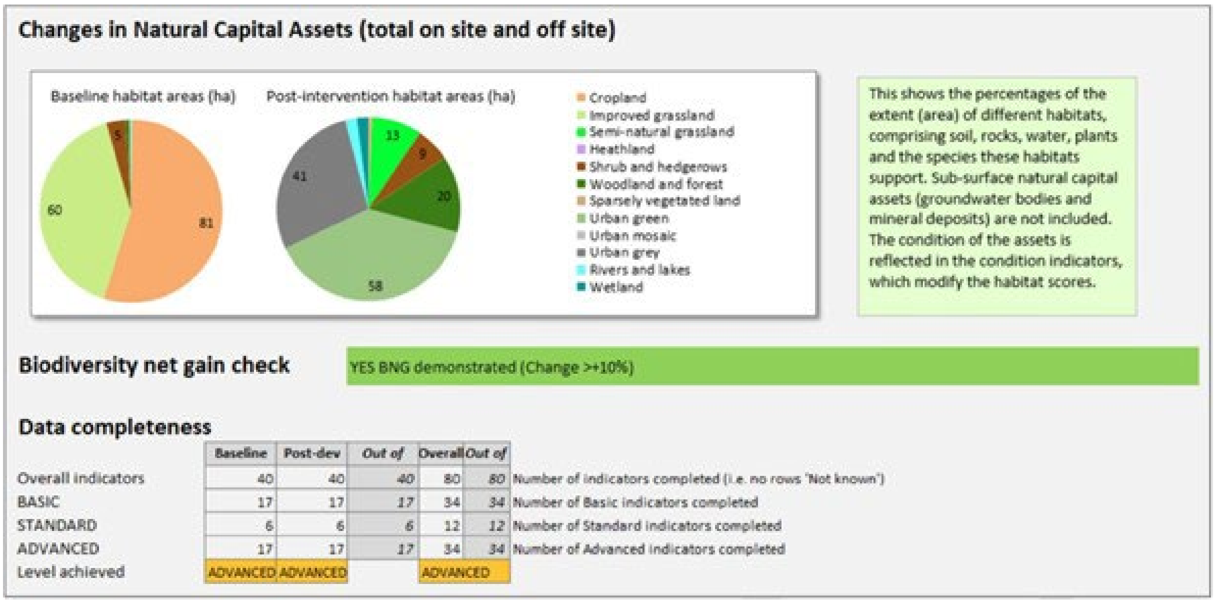


Potential impacts of on-site and off-site habitat change at three time points (not cumulative): Whole area

Select area of interest:

Whole area	1 year	10 year	30 year	Confidence	Interpretation (Expand / Collapse)
Food production	↓	↓	↓		The results 30 years after development indicate a large decrease in the potential for food production.
Wood production	→	→	↗		
Fish production	→	→	→		
Water supply	↘	↘	↘		The results 30 years after development indicate a decrease in the ecosystem service of water supply. If
Flood regulation	↘	↘	↗		
Erosion protection	→	↗	↗		
Water quality regulation	↗	↗	↗		
Carbon storage	↘	↘	→		
Air quality regulation	↘	→	↗		
Cooling and shading	↘	→	↗		
Noise reduction	↗	↗	↗		
Pollination	↘	↗	↗		
Pest control	↘	→	↗		
Recreation	↑	↑	↑		
Aesthetic value	↘	↗	↗		
Education	↗	↗	↗		
Interaction with nature	↗	↗	↗		
Sense of place	↘	→	↗		

Figure 1. EBN tabulated output showing potential changes in ES and benefits over time following habitat change interventions. Source: Smith *et al.* (2021). EBN User Guide.



	Baseline	Post-dev	*Out of*	Overall	*Out of*	
Overall indicators	40	40	*40*	80	*80*	Number of indicators completed (i.e. no rows 'Not known')
BASIC	17	17	*17*	34	*34*	Number of Basic indicators completed
STANDARD	6	6	*6*	12	*12*	Number of Standard indicators completed
ADVANCED	17	17	*17*	34	*34*	Number of Advanced indicators completed
Level achieved	ADVANCED	ADVANCED		ADVANCED		

Figure 2. EBN chart and tabulated outputs showing changes in Natural Capital Assets at the baseline and post development. Source: Smith *et al.* (2021). EBN User Guide.

9.2. ARIES (Artificial Intelligence for Environment and Sustainability)

9.2.1. Developer(s)

Hosted by the Basque Centre for Climate Change, with support and funding from the National Science Foundation for Ecoinformatics, University of Vermont and Earth Economics and Conservation International.

The development of ARIES was originally funded by the US National Science Foundation and receives support from the ASSETS project funded by ESPA/NERC. UNEP-WCMC and Conservation International also provided support for the development of specific components.

9.2.2. Interventions and/or services that the tool is designed to assess

Land use and land cover changes using spatial data, which can be combined with socioeconomic factors.

9.2.3. Benefits targeted

Flood regulation, coastal flood regulation, sediment regulation, water supply, outdoor recreation, aesthetic views, open space proximity, crop pollination, subsistence fisheries, and carbon sequestration. The user is also able to create models for additional ES.

9.2.4. Purpose of the tool

ARIES aims to allow non-technical users, policy designers and other interested parties to use sophisticated modelling capabilities. It uses multiple platforms to rapidly estimate and forecast ES and their correspondent range of economic and spatial values. Its purpose is to provide a suite of models that can support science-based decision making, and can also tackle investigations into natural capital accounting, food security, marine spatial planning and renewable energy.

9.2.5. Audience

The ARIES suite has a broad audience and has been designed to be used by policymakers, NGOs, consultants, companies, conservationists, research institutions and the public sector.

9.2.6. Tool details

The key categorisations of the tool for this report are:

- Modelling of ES – allows user inputted data
- Generates mapped outputs
- The user defines the interventions (through customisation of the model)
- Prioritises/optimises interventions by allowing post-hoc exploration of spatial pattern of services and tabulated scoring value results by the user. Post-hoc analysis can be conducted within the tool or requires external software depending on the outputs.
    - Prioritises where to do one specific intervention
- Spatial scale: varies according to input data, can be fine to national scale.

ARIES is an open-source AI and digital software which maps ES. It functions using two applications; a general ‘blank canvas’ programme using kExplorer and the United Nations System of Environmental Economic Accounting (UN SEEA) application, which is built on top of kExplorer. It provides a post-hoc examination of the spatial patterns of service provision across the landscape under a variety of scenarios, which can demonstrate trade-offs across multiple services.

ARIES modelling pioneered three innovative approaches:

- adaptive modelling – using the best knowledge for the specific problems being considered. This includes the use of expert opinion collected by the ARIES modellers.
- end-user simplification – striking the balance between an effective tool and the desire to 'keep it simple'.
- independent extensibility – allows for flexibility and for models to be created for either broad or very specific ideas and that each model can provide information and tools for any idea.

ARIES uses AI to pair ES models with spatial data to quantify ES flows for a spatial area. The ES models are a variety of open-source physical process models (for example the CAESAR-LISFLOOD flooding and erosion model). It is based on the k.LAB technology which allows researchers to contribute models and scientific data that simulate and integrate environmental and socioeconomic systems. Collaborative information is hosted on a network and when provided with a user query, ARIES automatically builds all the agents involved in the nature/society interaction, connects them into a flow network and creates the best models for each agent and connection.

ARIES quantifies these flows using network flow propagation models known as Service Path Attribution Networks (SPAN's). During assembly of the model, the appropriate SPAN models are selected and linked, driven by the ES benefits being considered.

ARIES has been developed as an online platform, with two main applications, kExplorer and ARIES for SEEA Explorer. SEEA Explorer supplies ES outputs for a geographical area and can be simply used to look at natural capital accounting. The outputs are mapped and can be downloaded in table formats. kExplorer allows for more advanced use with the opportunity to add user data specific to the area/ES and to edit the models within the programme.

ARIES allows for the building and integration of various kinds of models. To properly match models to contexts, k.LAB uses a sophisticated, multiple criteria ranking algorithm that can mix objective criteria (such as spatio-temporal resolution or currency) with user-provided rankings of data or model reliability and quality. ARIES focuses on beneficiaries, probabilistic analysis, and spatio-temporal dynamics of flows and scale, aiming to distinguish between supply and demand. ARIES, in addition to standard modelling approaches incorporated by model wrapping, can also use probabilistic methods (Bayesian Networks) if there are insufficient local data available.

The SPAN algorithms incorporate these Bayesian Network (BN) models into the flow models using methods that include Monte Carlo simulation and variance propagation.

The model algorithms in ARIES ensure that any BN modelling used takes account of available local knowledge. BN models can be very helpful during the model development phase as their intuitive visual outputs can be readily interpreted by decision-makers who may not possess a detailed technical background in modelling.

Methodology: https://journals.plos.org/plosone/article?id=10.1371/journal.po ne.0091001.

9.2.7. Tool appraisal

At a glance: Key strengths and limitations

Strengths

- Ability to focus on human beneficiaries of ES
- Allows for customisation
- Can be used in data poor conditions
- Free to use

Limitations

- Requires technical skills for some uses of the tool
- Can be very time consuming
- Complexity of human-natural systems not fully captured

9.2.8. Relevance to sectors

The ARIES tool has been under development since 2007 and has benefited significantly from guidance, support and developmental input from research sectors and charities. It is the first spatial prioritisation tool of its kind which uses AI. Due to its history and degree of support, the tool has been repeatedly reviewed through scientific literature making it a robust and trustworthy user experience that allows users to be able to explore and readily understand its limitations. There are currently around 5,000 registered users including policymakers, NGOs and consultants, however the developers behind ARIES are interested in increasing its use in the public sector.

9.2.9. Cost-effectiveness

The tool is free to use and is easily accessible to download. Depending on the project and spatial scale there may be implications on time and resources required for the tool.

9.2.10. Ease of use/usability

The ARIES website has an extensive set of documentation which can guide the user through the process of modelling and tool usage. A benefit of ARIES is that once defined and composed, ARIES models are accessible through any web browser with calculations handled on a separate server. This means that the user is not required to purchase or gain proficiency with modelling or GIS software (Bagstad *et al.* (2011). Sharps *et al.* (2017) highlights the intention of the online ARIES tool to be simple for new users; however it also highlights the need for technical skills when using the k.LAB technology.

9.2.11. Data requirements

Data requirements vary with the scope of the tool's usage. For example, when exploring a water yield model, the user would be required to input data on average annual precipitation, average evapotranspiration, land use type proportions and any known measurements of water amount which can be accessed from gauging stations. Some data can be user collected; however national datasets are equally important. When modelling carbon in topsoil, the user would be required to provide data on precipitation, land cover, elevation, soil group, slope, aspect, and growing degree days.

9.2.12. Tool adaptability

ARIES is a customisable tool with scope for adaptability, customisation and combination with other tools/models.

9.2.13. Performance and reliability

Most tools use deterministic models, which can be limiting where data is scarce. ARIES however uses probabilistic models (e.g. Bayesian), which can run with minimal data input. Importantly these models can convey uncertainly about their inputs and outputs and can be parametrised directly by the modeller or automatically trained to extract quantitative relationships between their inputs using AI (Bagstad *et al.* (2011). This benefit has been supported by Sharps *et al.* (2017) when comparing ARIES against InVEST and LUCI. The limitations of Bayesian usage are highlighted by Villa *et al.* (2014). They note that probabilistic models help to communicate and measure uncertainty, but their linear nature makes it difficult to incorporate feedback processes that influence natural and social systems. ARIES addresses this by using Bayesian models to quantify initial conditions for dynamic flow models, which helps with understanding ES flows to some extent. However, it doesn't fully capture the complexity of human-natural systems. Moreover, the usefulness of Bayesian models relies on having accurate training data, which can be challenging when data are at different resolutions and reliability levels.

Overall use of ARIES can be time consuming, which is expected when model customisation is introduced. Though it is difficult to provide a general 'rule of thumb' to how long an assessment will take, Bagstad *et al.* (2013) found that in comparison to InVEST, data input, modelling and model customisation took 800 hours, compared to 275 hours when examining the same area of land in InVEST. The paper does highlight however that preparation and time can be reduced where access to global data layers is available. Bagstad *et al.* (2013a) supports this when highlighting that time requirements can be significantly reduced when the data archive is improved, and an example provided suggested a significant reduction from 800 to 80 hours. Wilcock *et al.* (2018) highlights the need to convert decision variables into categorical (nominal) data, ultimately adding to the time required for processing.

Users can edit the models within the tool which may impact robustness. Depending on the project and user skill this could create issues in the accuracy of the tool.

9.2.14. Examples of use

- ARIES has been used by United States Geological Survey (USGS) scientists to map and explore the hydrological and ecological model integration in the Colorado River basin to address drought and climate change in the study area. They are exploring what models are available, when it is appropriate to couple/integrate models, and lastly to see how they can apply technology to support an appropriate approach.

- Sharps *et al.* (2017) used ARIES to model water supply, carbon storage and nutrient retention in a temperate catchment in North Wales. Models were parametrised for the UK and then applied to the study area. A 50 m^2 resolution was used.

- Bagstad *et al.* (2013) used the tool in comparison with InVEST using the San Pedro River, Arizona as a case study. Here they were able to apply scenarios for urban growth and mesquite (small shrub native to the Americas) management to quantify ES change for carbon, water and scenic viewsheds.

- Willcock *et al.* (2018) used ARIES to model firewood use in Africa and biodiversity use in Sicily.

9.2.15. ARIES (Artificial Intelligence for Environment and Sustainability) output example

Example of tool outputs from Villa *et al.* (2014) A Methodology for Adaptable and Robust Ecosystem Services Assessment. *PLoS ONE* 9(3): e91001. Accessed 12 March 2024.

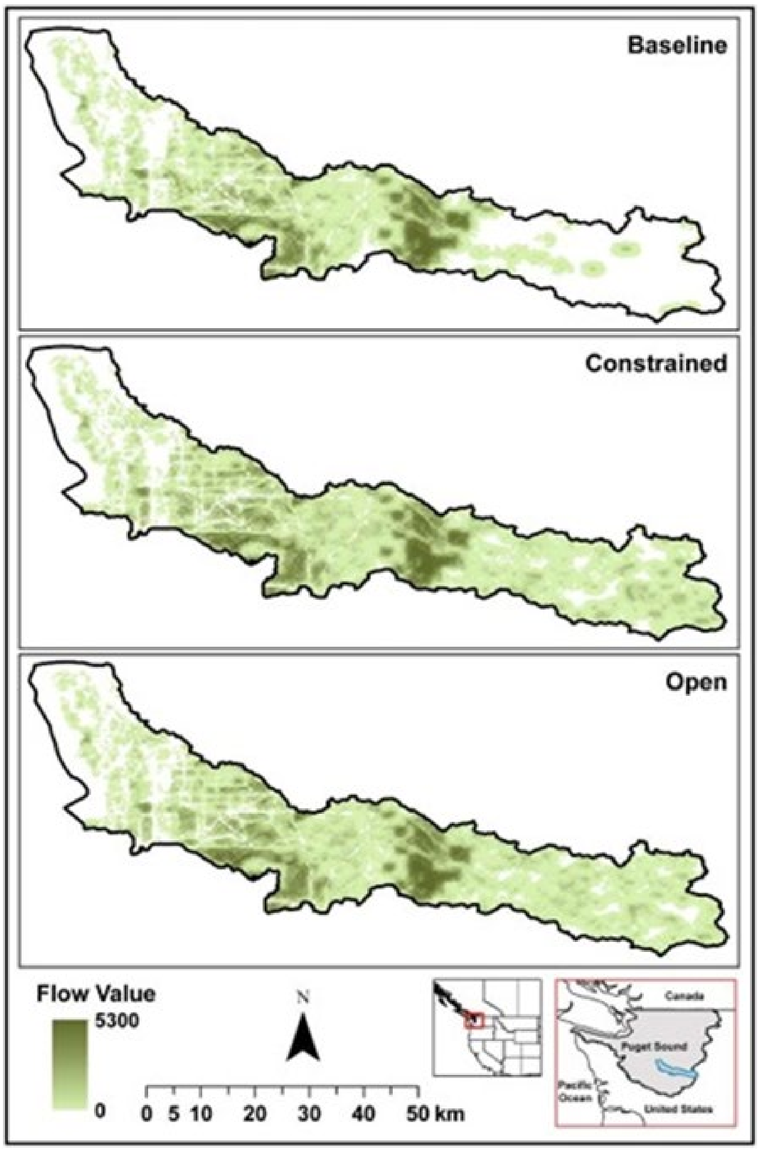


Figure 3. ARIES spatial output showing ES flow of proximity to open space under baseline conditions and constrained and open urban-growth scenarios. Source: Villa *et al.* (2014). A Methodology for Adaptable and Robust Ecosystem Services Assessment. *PLoS ONE* 9(3): e91001.

9.3. ASSIST E-Planner

9.3.1. Developer(s)

UK Centre for Ecology & Hydrology – John Redhead, Richard Pywell, *et al.*

9.3.2. Interventions and/or services that the tool is designed to assess

Agri-environment actions:

- Sown pollen and nectar mixes, perennial wildflower areas, restoration of species rich grassland
- Sown wild bird seed mixes, supplementary feeding
- Grass buffer strips, cover crops, water storage features, reduced agrochemical use
- Reseeding, drainage management, mowing/grazing
- Planting of trees, protection of existing trees, agroforestry

9.3.3. Benefits targeted

Flower-rich pollinator habitat, winter bird food, water resource protection, wet grassland restoration, woodland creation.

9.3.4. Purpose of the tool

The tool provides farmers and land managers with an easy to use and free web-based tool with which to identify the most suitable places for different environmental management options. The aim is to support farmers' decisions by presenting complex environmental data in an easy to interpret format, which can supplement their local knowledge and ultimately inform decisions.

9.3.5. Audience

The tool is primarily targeted at farmers and land managers in the agricultural and conservation sectors. However, it is seeing increasing usage beyond this core audience and application with reference to green finance. This includes carbon and peatland markets, with financing from private investment groups.

9.3.6. Tool details

The key categorisations of the tool for this report are:

- Generates mapped outputs
- Prioritises where to do one specific intervention
- Identifies potential interventions
- Presents simple mapped priorities to users
- Spatial scale: 5 m^2 resolution

E-Planner provides freely accessible and easy-to-interpret maps in a traffic light format. Variables are scaled to a range of 0–1, with 0 as least suitable and 1 at most suitable. Suitability maps are presented at a five metre resolution which is in line with other agricultural decision support systems (ADSS). Maps are constructed of relative suitability assessed from a combination of biophysical variables including the likelihood that a given opportunity can be implemented; increase its potential for delivery or decrease in the change of unintended detrimental effects. Environmental opportunities include flower-rich pollinator habitat, winter bird food, water resource protection, wet grassland restoration, and woodland creation. Their suitability is calculated based on variables such as aspect, soil texture, topographic wetness, and soil erodibility to name a few, with suitability then considered highest based on variables such as whether an area of land is south facing, in the context of flower rich pollinator habitat, or at high risk of flooding, in the context of wet grassland restoration. The values of these variables are pre-defined within set databases including government sources. Possible implementation actions are subsequently provided.

Environmental opportunities are defined as suites of potential actions which aim to deliver environmentally beneficial outcomes based on changes to management or by taking land out of production. Each opportunity has a range of ways in which it could be implemented, (i.e. through AES), depending on the farming system or local context. The tool does not model specific outcomes from environmental opportunities, (i.e. ES), as these are highly dependent on local context, quality of implementation, and other factors which are difficult to quantify at fine resolution across national extents.

The tool functions solely on a web-based platform. It begins with the user defining their holding, either through the SBI feature or by uploading shapefiles including information on field parcels. The user then selects the opportunities which they are interested in. The tool does not compare the opportunities against each other; the user must make decisions themselves.

E-Planner uses readily available national information from OpenStreetMap, NEXTMap Britain Digital Terrain Model, National Soil Map of England and Wales, IH 30 Digital Flood Risk Map, Land Cover Map 2015, and Natural England Priority Habitat Inventory, amongst data sets from published literature on watercourse networks and hydrology of soil types.

Handling and processing of spatial datasets was programmed in R, using the Raster, sp, insol, fastersize, nabor and whitebox packages. JASMIN, a national data computing facility for the environmental sciences community was used to process each job on a 10km tile. The web application was written in JavaScript with the main architecture built by Reach framework. Ionic GUI provided the responsive interface; mapping functionality was implemented by the Leaflet framework with basemaps provided by OpenStreetMap. More information can be found in Redhead *et al.* (2022).

9.3.7. Tool appraisal

At a glance: Key strengths and limitations

Strengths

- Does not require technical skill such as GIS or modelling
- Suggests possible interventions
- Fine resolution which aligns with AES options

Limitations

- Limited scope for adaptation or customisation
- Reliability is questioned by the lack of validation
- No user inputted data

9.3.8. Relevance to sectors

Recent reports support the tool's claimed reach in the agricultural setting, and anecdotal evidence suggests that farmer clusters of 10–20 individuals use the tool to support their decision processes (Urquhart *et al.* 2023).

E-Planner links mapped output information to potential implementation opportunities that include ELMs. Mapped data is highly relevant and compatible with ELMs (such as priority habitat data).

9.3.9. Cost-effectiveness

The tool is free to use and is easily accessible online. Due to its relative ease of use, the time and resources needed for projects is likely comparatively low compared to other tools.

9.3.10. Ease of use/usability

The tool is supported by a well presented and easy to navigate web page which includes sections on a user guide and next steps. The map itself is easy to navigate, and the user guide is easy to follow. Subsequent outputs of the tool are presented simply in a heat map, with a traffic light colour system to highlight the opportunities next to national priorities. Colours can be changed at the user's preference.

Importantly maps are presented at a five metre resolution. This is important as the outputs which are suggested by the tool include agri-environment actions which are of similar resolutions. This includes buffer strips of 6–12 m width. This allows land managers to pinpoint with high accuracy the best areas to focus on. Importantly E-Planner is regularly updated. Since its launch, user feedback has been accounted for and used to steer the progress of the tool with the software currently on version 3.0 (Urquhart, Goodenough & Micha 2023).

9.3.11. Data requirements

Simple data requirements which can just include the landowners SBI or their holding information.

9.3.12. Tool adaptability

E-Planner is a defined tool with limited scope for adaptability or customisation.

9.3.13. Performance and reliability

The data used for variables and suitability is robust and reliable. For data which has been cited from the 1990s, at a glance this would appear outdated. However, the information from the papers and datasets is unlikely to change with time as they include information on hydrology of soil types and areas which are at risk from flooding. Both areas of research may have changed over time or resolutions may have become more accurate, but the likelihood of this information to skew the output of the tool is unlikely. Other datasets used for E-Planner are relatively stable and unlikely to drastically change over time, and emphasis is placed on the user's local knowledge of the site to counteract any discrepancies. This includes the Land Cover Map and Natural England's Priority Habitat Inventory. It is important to reflect on the validation undertaken by Redhead *et al.* (2022) which found that agreement between field-based scores from an expert surveyor with E-Planner scores was generally high, particularly for areas which were least suitable and those most suitable. However, the papers notes that agreement was weaker for winter bird food, whilst stronger for wet grassland creation. Some would argue however that using one survey on two farm examples limits the reliability as this does not present a high degree of replication.

9.3.14. Examples of use

- The tool was used in a validation exercise on a mixed dairy and an arable enterprise in the south of England. All five benefits were targeted in the exercise (Redhead *et al.* 2022).
- A number of farm cluster groups have used the tool to help identify the optimal locations for targeted landscape scale interventions across a suite of land holdings/farms.
- The tool has links to the Land App which brings E-planner to a potential audience of over 21,000 Land App registered users, covering over 9.5 million hectares.
- Network Rail, alongside Forest Research, have used the tool to help identify solutions for woodland and tree planting along the rail network to help mitigate for delays due to fallen trees and leaves on the line.

9.3.15. Assist E-Planner output example

Example of tool output from UK Centre for Ecology & Hydrology (2024) E-planner tool webpage. Accessed 15 March 2024.

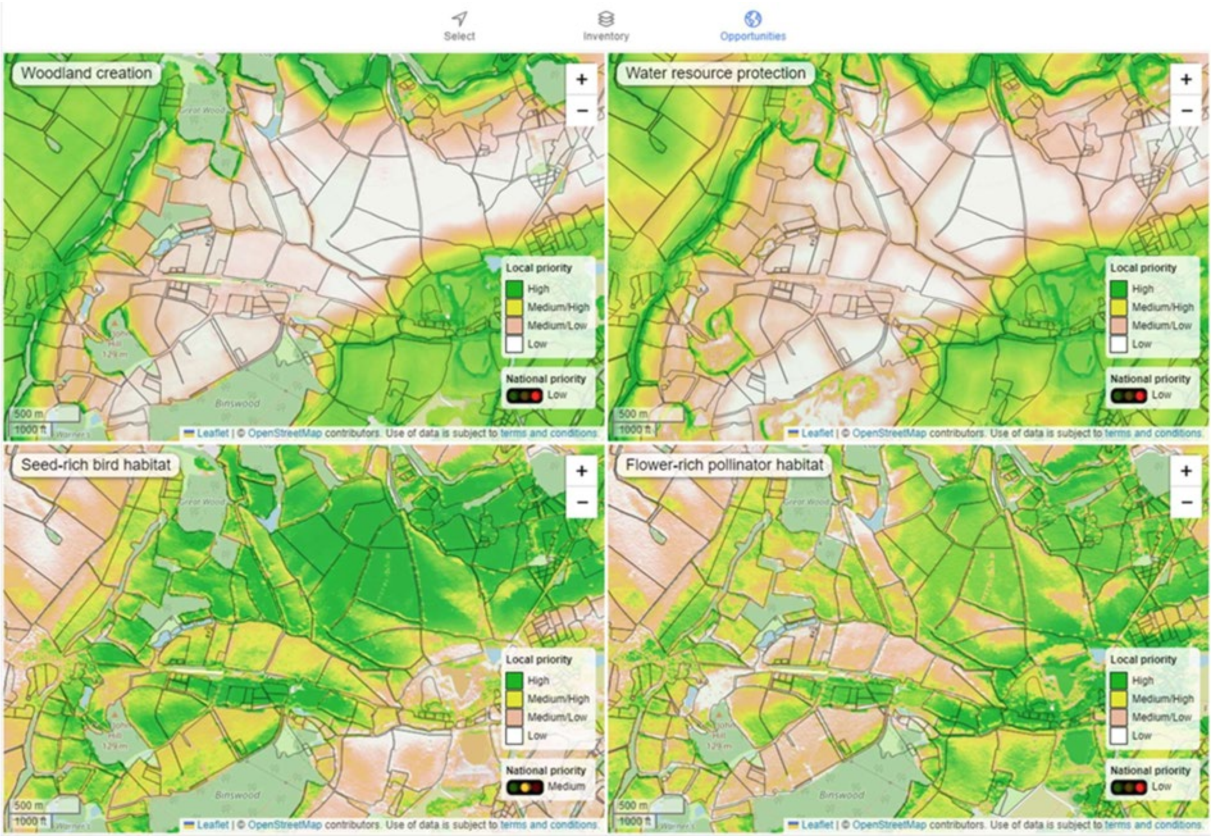


Figure 4. ASSIST E-Planner spatial results showing the priority locations for potential implementation of four interventions (woodland creation, water resource protection, seed-rich bird habitat creation and flower-rich pollinator habitat creation). Source: UK Centre for Ecology & Hydrology (2024) E-planner tool webpage.

9.4. Natural Environment Valuation Online (NEVO)

9.4.1. Developer/s

University of Exeter Land, Environment, Economics and Policy Institute (LEEP), with support from Defra and NERC.

9.4.2. Interventions and/or services that the tool is designed to assess

The tool allows the user to alter the price and quantity of agricultural, timber and carbon products, alongside land cover options including woodland, agriculture, semi-natural habitats, urban and water.

9.4.3. Benefits targeted

Water quantity and quality, recreation, biodiversity, greenhouse gas (GHG) emissions, agricultural production, woodlands, and timber production.

9.4.4. Purpose of tool

The NEVO Tool is a web application to help users explore, quantify, and make predictions about the benefits that are derived from existing and altered land uses across England and Wales. The tool is freely available to anyone and is designed to be easy to use, making it accessible to a wide range of users.

The NEVO Tool is a powerful, open-access, web application designed for regional spatial planning. It can be used to explore the integrated relationships between climate change, land use change, ecosystem service flows and economic values.

9.4.5. Audience

The tool has been designed for the agricultural, conservation, environmental and public sector, aimed at landowners and land managers, councils, local authorities, National Park Authorities, National Landscapes, charities, trusts, private sector organisations and academia.

9.4.6. Tool details

The key categorisations of the tool for this report are:

- Modelling of ES
- Does not generate mapped outputs (outputs compatible with GIS software but will need to be generated separately)
- The user defines the interventions
- Prioritises/optimises interventions by analytical methods within the tool: trade-offs & synergies
    - Prioritises where to do one specific intervention
- Spatial scale: quite coarse, landscape scale at 2 km^2 or at the sub-catchment scale (variable areas)

The NEVO tool is a web-based platform which allows the user to explore, alter and optimise land use as well as the resulting ecosystem and financial benefits. The ‘Explore’ feature provides summary information about land use in the defined area for the decade 2020–2030. Users can move through time to see how land use and ES are predicted to change, considering climate change. Outputs can be downloaded as csv files or maps.

The ‘Alter’ feature allows the user to alter landscape characteristics by asking a ‘what if?’ question. Once users have selected an area, they are able to consider how the flow of ES would change over time if they were to alter the land use or agricultural prices in the area. Lastly the ‘Optimise’ feature allows the user to consider ‘what’s best?’ relating to finding the best locations to change land use to achieve a particular objective with combined outputs from multiple models (only available at the sub-catchment scale). Users can specify the type of land use intervention and the total amount of hectares to be changed, as well as the overall objective, which can be to maximise particular quantity outputs (e.g. biodiversity richness) or value outputs (e.g. timber and agricultural profits). Information on how this optimisation works is limited within the developer guidance and publicly available resources.

Users can specify the type of land use change (from what, to what), the total area (ha) to be changed, and the overall objective, which can be to maximise quantity outputs (e.g. biodiversity richness) or value outputs (e.g. timber and agricultural profits). The tool runs on a suite of individual models which have been selected and modified by LEEP to provide real-time results to the user. These are as follows:

- For modelling agricultural outputs, profits, and input use, LEEP have designed a UK Farm Model which works in three stages. Firstly, it separates all available agricultural land into grassland or arable. Next, arable land is allocated to a crop, grassland is split into temporary, permanent, and rough, and livestock is split into dairy cattle, beef cattle, and sheep. The third step calculates gross margin.

- To calculate timber outputs and profits the Forestry Commission's (FC) Timber Yield model has been used to show profitability on a decadal basis, whilst considering climate change and spatial suitability. The user can define a land use change, with three planting regimes, broadleaf, conifer, or a 60–40 broadleaf and conifer split. This model is a combination of the CARBINE model which predicts tree growth and the FC Forest Investment Appraisal Package which provides accurate profits for timber production.

- Carbon sequestration and GHGs can be explored for both agricultural and forestry settings. For the agricultural setting, NEVO uses a tailored version of the Cool Farm Tool which sits in between simple emission factor approaches and more complex process-based models. It requires information on agricultural land use, alongside detailed soil characteristics to provide insight into key greenhouse gases and pollutants based on assumptions from Binner *et al.* (2019). For forestry, the CARBINE tool is used again in a similar way to calculate tree growth, however the tool uses sub-models to provide information on: Carbon sequestered in and GHG emitted from livewood; from harvested wood products and from deadwood (litter); and GHG associated with a range of soil types.

- Recreational demand is supported by the ORVal Recreational Demand model (Outdoor Recreation Valuation tool), also developed by LEEP. Again, for use in NEVO, this tool is scaled back and is based on aggregations of the quantities for each greenspace at 2 km^2 grid cells. NEVO allows for three different assumptions for how land use change will impact recreation: Alter current paths; Provide new paths; Provide new parks. ORVal predicts the number of adult visits made to different green spaces, with influential factors including socio economic characteristics, day of the week, month of the year, attributes of a greenspace, and the availability and qualities of alternative greenspaces. The model is estimated from data collected in the Monitor of Engagement with the Natural Environment (MENE) survey.

- The JNCC species distribution model implements a modelling framework for 100 priority species in Great Britain. However, due to the size of the dataset, the authors of NEVO have created a statistical emulator. This is an average of the ensemble of the seven models used within the JNCC modelling framework, using generalised linear models. The JNCC modelling framework uses Bioclim, boosted regression trees, generalised linear model, generalised additive model, kernel support vector machine, Maxent, and random forest. It takes 75% of data for training and 25% for validation and models 100 times, with the final model an ensemble of the average of the 100 predictions.

- The LEEP UK SWAT (Soil and Water Assessment Tool) was developed by the United States Department of Agriculture – Agricultural Research Service, however the NEVO authors have calibrated it to England and Wales. The SWAT tool is the result and extension of the combination of previously developed tools including SWRRB model (Simulator for Water Resources in Rural Basins), CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) and EPIC (Erosion–Productivity Impact Calculator). The model simulates water movement through infiltration, surface runoff, return flow, lateral flow, evapotranspiration and canopy storage, and models nutrient and pesticide transport.

9.4.7. Tool appraisal

At a glance: Key strengths and limitations

Strengths

- Has a function to look at change over time, considering climate change impacts
- Allows user inputted data
- Allows users to define objectives
- Free to use

Limitations

- High data requirements
- Requires technical skills and competency
- Out of date data at times

9.4.8. Relevance to sectors

NEVO allows the user to explore at various land scales, including administrative scales such as local authorities, terrain-based scales such as river network sub-basins, and up to country scales. Data is mapped to a 2 km^2 resolution. This large-scale resolution is both a limitation and a strength. For large-scale restoration, such as landscape recovery projects, this tool is excellent for highlighting changes to ES alongside financial benefits which ultimately underpin land management. However, the tool has been designed for land managers and landowners, of which those operating on smaller holdings may be unable to reap the benefits of the tool's features.

Research by South West Partnership for Environment & Economic Prosperity (SWEEP), a collaboration between the University of Plymouth, University of Exeter and Plymouth Marine Laboratory found that there are over 1,400 registered users of the tool, with 1,900 views of their training videos. They found that 27% of registered users were returning, with major consultancies such as Mott MacDonald and Arup acting as core users. The tool is also used by land managers such the Rivers Trust and National Parks.

9.4.9. Cost-effectiveness

The tool is free to use and is easily accessible to download. Due to more complicated skill and input needs, the resources required for projects may be higher than more simple tools.

9.4.10. Ease of use/usability

The tool is easily accessed from web browsers with a clear layout. The developers have provided a series of short videos to help guide the user through the various sections and uses of the tool. This is supported by an information sheet developed by SWEEP, though this is not linked to the NEVO page.

9.4.11. Data requirements

Requirements vary based on the scope of the study, though are typically extensive. For example the UK Farm model requires the user to input data on land use (in hectares), livestock numbers, soil data, average annual rainfall, autumn machinery working days (a measure of the suitability of the soil for arable cultivation), mean potential evapotranspiration, median duration of field capacity, total number of degree days in the growing season (from April to September), and mean elevation (altitude), share of agricultural land with slope higher than 6 degrees, and lastly agricultural input and output prices.

The data underpinning the models are robust but could be considered out of date at times. For example, the tool uses the Land Cover Map 2007, though the latest version of this was in 2021. On the other hand, the Farm model uses agricultural census data from 1976 to present for estimations.

9.4.12. Tool adaptability

NEVO is a defined tool with limited scope for adaptability or customisation (but does use other models and tools within NEVO).

9.4.13. Performance and reliability

LEEP have scaled back and simplified many of the models which underpin NEVO. This has meant that the user can receive responsive reports on their workings. For example, the statistical emulator used for species distribution, has significantly reduced the typical computational speed of two hours for one years' worth of modelling. However, the simplification of the model has meant that, at times, the probability of species occurrence is over or underestimated. This is a trade-off with the reduction in time that the model takes to run, making it more cost effective.

Overall, the models underpinning NEVO have been selected due to their known scientific rigour and repeated use. For example, the Forestry Commissions Ecological Site Classification model works on both soil, moisture, elevation, and temperature, as well as expert judgement for assigning characteristics to macro-classes. However, there are some limitations to these tools for the use in NEVO. For example, the Cool Farm Tool does not include additional impacts associated with converting from the existing land cover to agriculture or vice versa. Similarly, limited spatial distribution of weather datasets in the UK increases uncertainty in the UK iteration of the SWAT model.

9.4.14. Examples of use

- In collaboration with the Environment Agency, the team behind NEVO used the tool to add value and reconnect the River Wey. The tool was used to assess land cover within the catchment, highlighting the economic values of recreation alongside agriculture. The tool was also used to assess the effect of NFM on water quantity and quality, alongside species richness and GHG sequestration.

- Wood Group UK Ltd consultants used NEVO to review nutrient impacts of diffuse pollution sources in freshwater catchments draining into the Solent European Protected Sites as well as the Itchen Special Area of Conservation.

9.4.15. Natural Environment Valuation Online (NEVO) output example

Example output from NEVO Team and Lidgard K. (2019) NEVO Case Study – Reconnecting and improving the River Wey. Accessed 12 March 2024.

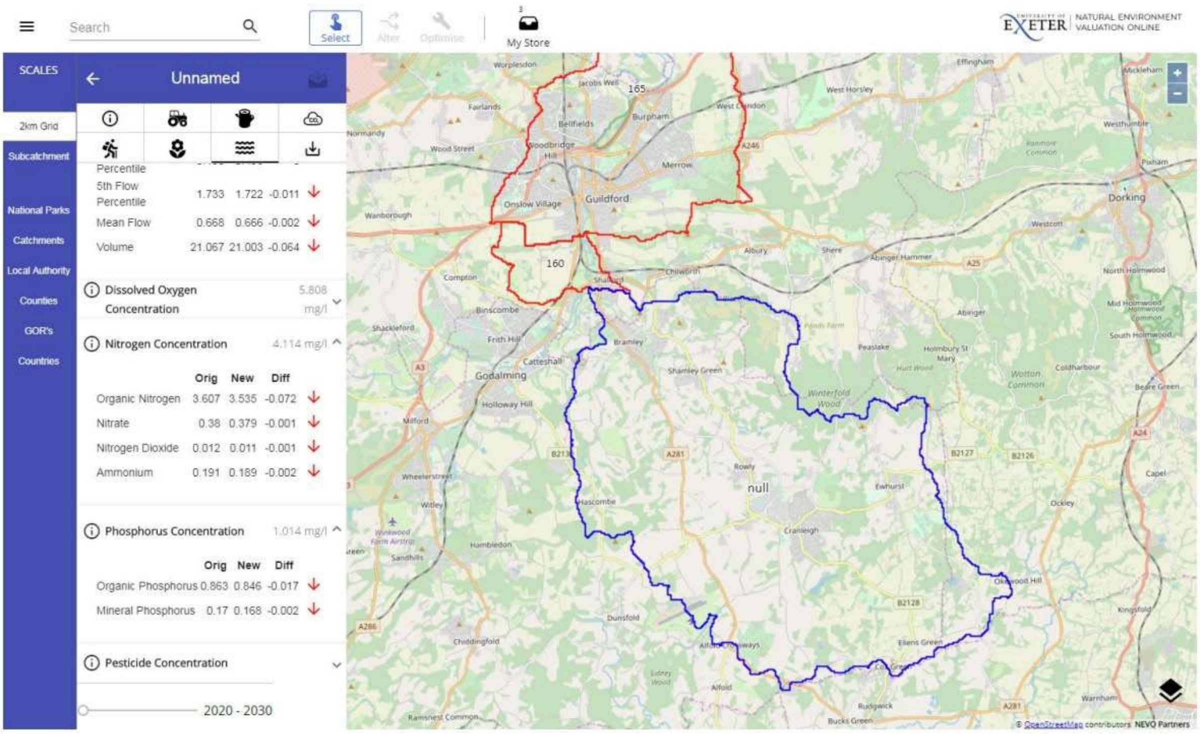


Figure 5. NEVO tool output showing the impact of woodland planting on water quantity and quality for a sub water catchment area. Source: NEVO Team and Lidgard K. (2019) NEVO Case Study – Reconnecting and improving the River Wey.

9.5. InVEST (Integrated Valuation of Ecosystem Services and Trade-offs)

9.5.1. Developer(s)

The Natural Capital Project. A partnership based at Stanford University that includes WWF, The Nature Conservancy, the University of Minnesota, Stockholm Resilience Centre and the Chinese Academy of Sciences.

9.5.2. Interventions and/or services that the tool is designed to assess

Any change in land use that can be mapped and supplied to the models.

9.5.3. Benefits targeted

Habitat Risk Assessment, Habitat Quality, Pollinator Abundance: Crop Pollination, Forest Carbon Edge Effect, Carbon Storage and Sequestration, Coastal Blue Carbon, Annual Water Yield, Nutrient Delivery Ratio, Sediment Delivery Ratio, Unobstructed Views: Scenic

Quality Provision, Visitation: Recreation and Tourism, Wave Energy Production, Offshore Wind Energy Production, Crop Production, Seasonal Water Yield.

9.5.4. Purpose of tool

InVEST is a spatially explicit ES modelling tool that provides quantitative outputs, which can be applied in different contexts, and can work at local or national scale depending on available data. Designed to inform decisions about natural resource management, it provides information about how changes in ecosystems are likely to lead to changes in flows of ES to people and conservation. It seeks to enable decision makers to assess quantified trade-offs associated with alternative interventions, management choices and climate scenarios. This analysis of trade-offs can be used to balance environmental and economic goals of different decision makers across specific geographical locations. For example, conservation organisations could use the tool to align conservation activities with improved human livelihoods.

Alongside more typical quantifiable ES and benefits, InVEST is able to map and value services for human wellbeing and 'fulfilment' including 'beauty' and opportunities for recreation. It can also analyse impacts of climate change and population growth on ecosystem service supply, where ES originate and where they are consumed. The tool includes ecosystem service models for terrestrial, freshwater, marine and coastal ecosystems. The tool is best suited for analyses of multiple services and multiple objectives.

9.5.5. Audience

The intended users of InVEST are extensive across the public, private and non-profit sectors and include government bodies, NGOs, environmental organisations, researchers, conservationists, international lending institutions (such as international green finance organisations) and corporations.

The developers of InVEST endeavour to monitor publications involving the tool, and the uses generally align with the intended uses. Users of InVEST (and of information generated from InVEST) often include researchers, NGOs/non-profits focused on conservation and sustainable development, government and multilateral development banks (for example the World Bank), and to some extent private companies.

User numbers are not tracked, however the InVEST desktop software is downloaded on average 1,800 times a month, with the online user guide reporting around 3000 monthly users. The support forum sees an average of 15,000 monthly pageviews, confirmed as human and not bots. The software has been downloaded in more than 185 countries and InVEST estimate that there are a few thousand active users of the tool worldwide.

9.5.6. Tool details

The key categorisations of the tool for this report are:

- Models ES – allows user inputted data
- Generates mapped outputs
- The user defines the interventions
- Prioritises/optimises interventions by allowing post-hoc exploration of spatial pattern of service results by the user. Outputs need to be assessed outside of the tool in another programme

  - Prioritises which intervention to action in a location

- Spatial scale: local to national scale, data resolution varies from 10 m^2 to 300 m^2 depending on dataset

InVEST is a suite of open-source software models run through graphical user interface, Workbench (downloadable desktop software), or directly in Python.

The tool consists of 22 software models for mapping and valuing ES which can be applied at multiple scales from local site-specific boundaries to country-wide assessments. It combines land use and land cover data with information on the supply (biophysical processes) and demand of ES from the literature to provide an output value for individual services expressed in biophysical or economic terms. Biophysical output values are given as absolute quantities or relative magnitudes (e.g. tons of sediment retained or percent change in sediment retention) (Sharps *et al.* 2017).

The 22 models for mapping and valuing ES are supported by additional tools for preparing, processing and visualising data which are included in the desktop interface for users. These include preprocessors for hydrological models and watershed delineation which feed into the 22 ecosystem service models. All InVEST models are available as standalone software. Users require mapping software such as ArcGIS or QGIS to prepare certain inputs for the models and to perform any further analysis with the mapped outputs (for example overlays). No specific data is required to view.

Models can be run through a graphical user interface (the InVEST Workbench) or directly in Python, for users with coding skills. Users require basic to intermediate GIS skills. No specific software is needed to view TIFF image outputs for simple visualisation of the models.

Most models use a ‘production functions’ approach, where models account for both ecosystem service/benefit supply and demand (in this case the location and activities of people who benefit from the services). For example, a model might account for living habitats such as mangrove forests and reefs as buffers to storm waves, and the locations of people and infrastructure that may be affected by coastal storms. This allows a more targeted approach to where ecosystem supply is most important, and potentially where interventions are most cost-effective.

Post-hoc examination by the user of the spatial pattern of service provision across the landscape under a variety of future scenarios can highlight trade-offs across multiple services. Additional work is required by the user to overlay map outputs from the different models.

An example of model methodology is for ‘crop production’ ecosystem service. The InVEST model uses a percentile-based yield model which covers 175 crops worldwide, and a regression-based model that uses fertiliser application rates for ten crops. When the model is run, all results are paired with observed (ground truth) results from the same region for quality control and to provide additional nutrition information for the crops. The percentile yields are useful for exploring a range of intensification levels within each of the crop’s climate zones. The regression model can provide estimates of yields under different fertiliser inputs for a range of crops including barley, maize, potato, rice and wheat. Additional user input data on fertiliser inputs is required for the regression model.

The percentile and regression model algorithms use data tables and maps from global Monfreda datasets from varying years, including some relatively old datasets (2000 and 2012). Interpolation and calculations are run through the model algorithms (detailed steps can be found in the InVEST User Guide for each model) and the crop regression model follows the algorithm equations from Mueller *et al.* (2012). Results are provided as csv files and rasters.

9.5.7. Tool appraisal

At a glance: Key strengths and limitations

Strengths

- Allows user inputted data
- Detailed and transparent limitations and assumptions available
- Allows for adaptation and customisation
- A wide and varied scope of ES assessed (22)

Limitations

- Requires basic to intermediate skills in Python
- Requires post-hoc analysis for trade-offs
- Variable confidence and accuracy of models within the tool

9.5.8. Relevance to sectors

The models are useful for anyone looking to make decisions related to the ES/benefits InVEST models, including human health and wellbeing. The reported users are mostly researchers, NGOs, non-profits, and development banks concerned with the environment and sustainable livelihoods.

9.5.9. Cost-effectiveness

The tool is free to use and is easily accessible. Due to its relative ease of use, the time and resources needed for projects is likely comparatively low compared to other tools that require GIS or programming inputs.

9.5.10. Ease of use/usability

The tool is free to use, and data within the models is available to any user. The tool is easily accessible to download, either as a desktop ‘Workbench’ or directly through Python. The developers report thousands of interactions on user forums each month, with feedback from users indicating that the tool is widely used.

Basic to intermediate skills in Python/GIS are required to use and interpret results, however there are detailed instructions. Depending on the project there will be varying levels of input and pre-model processing required. The larger the spatial scale and ES required, the longer the estimated time required. Because of the required skills, the tool is likely not appropriate for non-technical users and in the context of Defra ELMs is likely unsuitable for most landowners/land managers.

The models use a wide range of datasets and algorithms depending on the ecosystem service/benefit. There are comprehensive user guides which explain the approaches taken by the models step by step (peer reviewed methods), as well as providing open and transparent information on the data sources. There are many examples of uses in the scientific literature as well as examples provided by InVEST. The models have been extensively vetted in the peer-reviewed literature (Bagstad *et al.* 2013).

9.5.11. Data requirements

Limitations and assumptions of each individual model are clearly explained in the user guide. As an example, for ‘crop production’ the model is not able to capture variation in productivity that occurs across diverse landscapes as the model is quite coarse and mostly driven by climate. For example, a rocky hill slope and a fertile river valley in the same climatic zone would be assigned the same yield (InVEST User Guide 2024). This limitation of spatial allocation of ecosystem service/benefit demand is common across the models, with one value given to each land/climate class where this could vary greatly in reality (Sharps *et al.* 2017). This limitation could be mitigated by adding additional categories (e.g. inputting specific crop data for different topographies) into the tool (which can be done as InVEST is customisable). This would require additional inputs and an understanding to be able to quantify differing attribute values to capture expected differences in outputs.

The tool also has limited modelling of feedback between the different ES and cannot effectively handle complex trade-offs. This would require further post-hoc analysis by the user.

Sample data is provided for all models, but this is mainly intended to provide users with examples of how the data should look and to understand the inputs and outputs of models. Users can input data if they have the coding/GIS skills required to edit the models. Alongside user-specific inputted data, the tool has the flexibility to adapt in terms of scale and targets. For example, researchers looking at vulnerability of coastal ecosystems and relationships between stressors and ecosystem service supply potential incorporated ES abundance into the InVEST habitat risk assessment (HRA) tool. Results showed significant differences between user customised models, which incorporated other variables than those in the original model (Caro *et al.* 2020).

The ability to express economic valuation outputs is very useful and may be of interest to users exploring natural capital options. Expressing the market value of ES can help motivate stakeholders in undertaking conservation plans and help explain the value of protecting/enhancing areas which provide these benefits (Meraj *et al.* 2021). The ES assessed in the models are relevant to a number of both public and private finance opportunities in the UK, such as carbon storage and sequestration, but do not directly link to funding opportunities, so further post-hoc analysis would need to be undertaken.

9.5.12. Tool adaptability

InVEST is a customisable tool with scope for adaptability through programming.

9.5.13. Performance and reliability

InVEST tools are largely easy to use, simple, and have readily available data. However, the limitations and simplifications of these is highlighted in literature. For example, when looking at urban planning, Hamel *et al.* (2021) highlights the requirement to use InVEST in combination with other models, as it was only able to provide one element of the ecosystem knowledge required. Further investigation into model performance is highlighted throughout the in-depth guidance provided by the developer. Regarding the urban environment, the developer has noted limitations for the Urban Flood Risk Mitigation Model. Largely these are centred around the simple approaches used, which ultimately reduces confidence in the model outputs.

9.5.14. Examples of use

- Stakeholder engagement - InVEST was used to alongside other tools to demonstrate market values of ES in the context of conservation plans for stakeholders in Hawaii. The monetary estimate outputs from the tool helped motivate the stakeholders as they could tangibly see the value of the services (Nelson *et al.* 2010).

- Soil erosion & sediment export estimation – InVEST was used to simulate the ES provided by the seasonal water yield and sediment retention models within the mountainous landscape of the Himalayas. The models identified where soil erosion rates and soil loss could be avoided by land use, land cover and conservation interventions (Kumar *et al.* 2023).

- Payment for Ecosystem Servies – InVEST modelling can help prioritise where funds should be allocated to conservation and restoration projects to provide the best ecosystem service/benefits outcomes and value for money.

9.5.15. InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) output example

Example output from Nelson *et al.* (2009) Modelling multiple ecosystem services, biodiversity conservation, commodity production, and trade-offs at landscape scales. Frontiers in Ecology and the Environment, 7(1), pp.4-11.

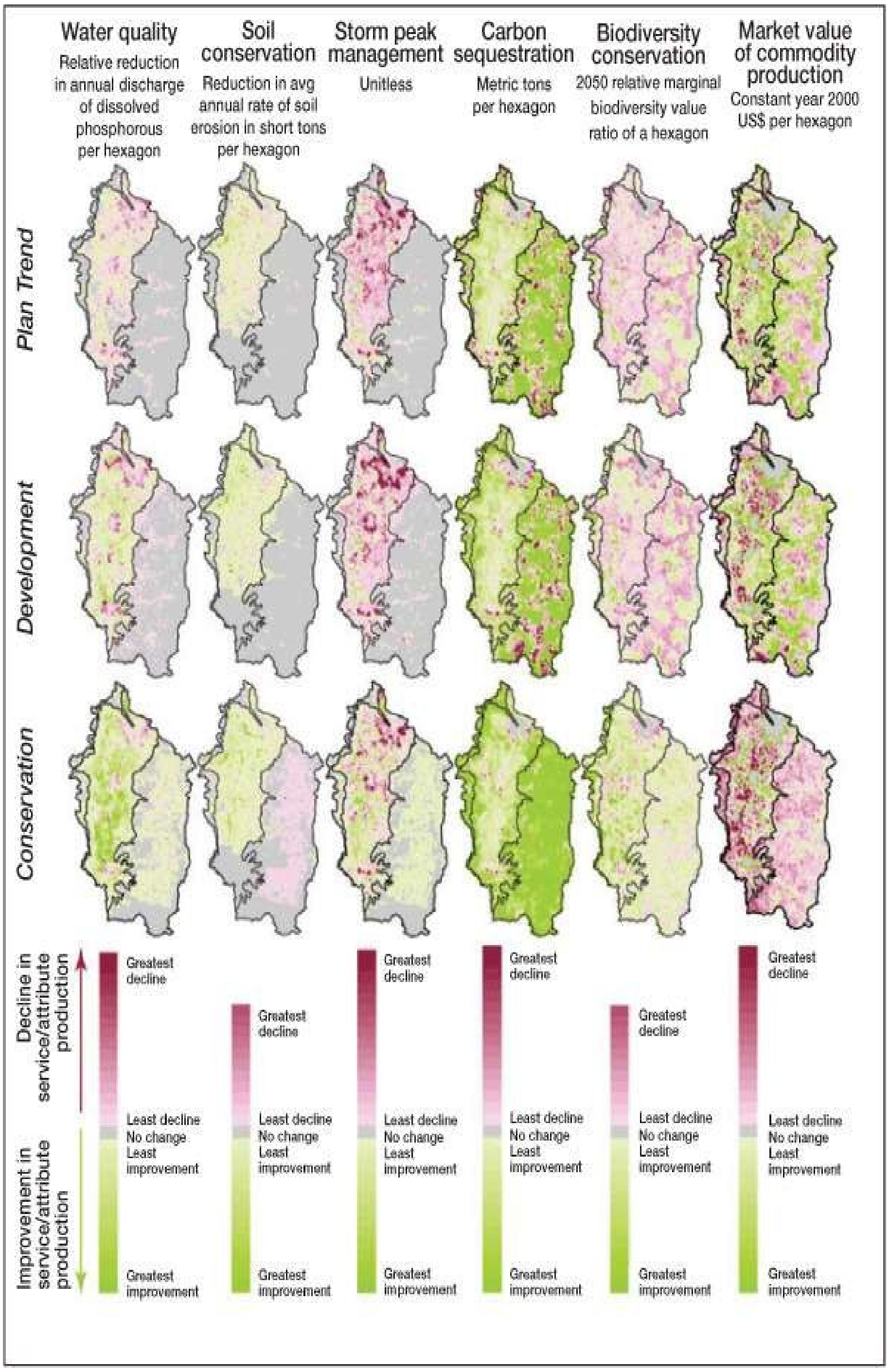


Figure 6. InVEST spatial outputs depicting maps of change in ecosystem services, biodiversity conservation, and market value of commodity production from 1990 to 2050 for three land use change scenarios. Depicting greatest improvements (green) to greatest decline (red). Source: Nelson *et al.* (2009) Modelling multiple ecosystem services, biodiversity conservation, commodity production, and trade-offs at landscape scales. *Frontiers in Ecology and the Environment*, 7(1), pp.4-11.

9.6. EcoservR

9.6.1. Developer(s)

Liverpool John Moores University, Natural Capital Solutions, Forest Research, Cheshire Wildlife Trust.

9.6.2. Interventions and/or services that the tool is designed to assess

Habitat restoration, habitat change, and differences in accessibility for the public.

9.6.3. Benefits targeted

Carbon storage, air purification, water purification, pollination, local climate regulation, noise regulation and accessible nature.

9.6.4. Purpose of tool

EcoservR is an updated version of Ecoserv-GIS, a toolkit originally developed by Durham Wildlife Trust for mapping habitats and ES in the UK using widely available national datasets. The toolkit generates an environmental baseline classifying over 200 habitat types and uses spatial models to map their capacity to provide a range of ES, as well as the demand for them. Its intended purpose is to map ES via RStudio producing robust, evidence-based figures to support individual assessments.

9.6.5. Audience

The tool has been designed predominantly for people working in the planning, development, conservation, or agricultural industries, including roles such as land managers, conservationists and consultants.

9.6.6. Tool details

The key categorisations of the tool for this report are:

- Modelling of ES – allows user inputted data
- Generates mapped outputs
- The user defines the interventions
- Prioritises/optimises interventions by allowing post-hoc exploration of spatial pattern of service results by the user. Post-hoc analysis can be conducted within the tool
    - Prioritises which intervention to action in a location
- Spatial scale: local to regional scale, limited information from developers

The tool models ES in RStudio by providing projected changes (gains or losses) arising from a given intervention. The tool works by firstly establishing an environmental baseline. EcoservR produces a detailed habitat map based on a range of nationally available and mostly free datasets (or licensed for public sector) datasets such as OS MasterMap Topography, Priority Habitat Inventory, National Forest Inventory, OS Open Greenspace, CORINE Landcover and more. This ensures that methods are transferrable. EcoservR then measures a range of ES. Capacity and demand maps can be analysed to identify opportunities and “pinch points”, to plan and deliver interventions where they are best suited and most needed. “Pinch points” refer to where multiple ES and benefits are bottlenecked or concentrated in one area, highlighting its importance and value. Capacity maps refer to supply of ES and demand maps refer to where ES is ‘needed’ (usually referring to human population size or proximity depending on the ES being measured).

Measured changes in deviation from the baseline for a given intervention are dependent on spatial models. The models are very sensitive, meaning that effects can be detected beyond site level to local and landscape scales. Areas can be reassessed with new or updated data for sensitivity analysis or scenario modelling. The tool outputs indicate deviation from the baseline which can be mapped in RStudio (or any GIS software), showing where ES occur and indicating relatively high demand for a service, or high capacity to deliver services.

EcoservR is a rewrite of an existing tool, Ecoserv-GIS, into the R language. Ecoserv-GIS was re-written in R to eliminate dependency on proprietary software and workflows that were no longer supported. Updated technical documentation is yet to be released, however the models have remained the same. At present however, only 7/9 models are still available in the EcoservR package. The workings behind the individual ES tools are as follows (Southgate 2016):

- **Air purification:** This is mapped by assigned air purification scores to broad habitat types based on their ability to trap pollutants, whilst also identifying areas around the vegetation where air pollution may be reduced. The societal demand (specifically regarding impacts on individuals) for air purification is mapped via calculating population density in urban areas. The regulatory demand (government targets and objectives on air pollution) for air purification is mapped via estimating traffic-based air pollution levels which are calculated using reverse distance from roads, road type, and the assumption that there is higher traffic use on higher category roads.

- **Carbon:** Carbon storage, both above and below ground, is mapped by assigned potential carbon storage values for habitat types based on peer-reviewed literature. Values map typical habitat storage levels and levels within the upper 30 cm of soils. The demand for carbon is considered to be constant across the entire study area.

- **Water purification:** The ability of the natural environment to purify water is assessed by determining surface resistance through considerations of vegetation type and slope gradient. Regulatory requirements are determined by evaluating fine-scale erosion risk, which indicates the likelihood of contributing pollutants, and by examining the proportion of the watershed occupied by agricultural or urban land use, which are sources of pollution.

- **Pollination:** This is mapped based on the likelihood of pollinator visitation, calculated using likely travel distance from pollinator habitat. The demand for pollination is mapped by identifying areas where crops may benefit/require pollination such as allotments, orchards, and areas of agricultural land.

- **Local climate regulation:** This is mapped based on the presence of various blue and green infrastructure. The regulatory demand for local climate regulation is mapped via the calculation of the proportion of urban land cover within the local environment. The societal demand for local climate regulation is then mapped based on population density, and the population’s vulnerability to raised temperatures and heatwaves based on age.

- **Noise regulation:** A noise regulation score is assigned to vegetation types based on height, density, permeability, and year-round cover. The demand for noise regulation is mapped via the estimation of noise volume levels, and the potential societal impacts which may arise from noise. Potential noise volumes are then calculated based on Euclidean distance (shortest straight-line distance) from roads, railways, and airports. Volume is estimated based on distance from the noise source which is weighted to source type. The societal demand is then mapped based on population density and Index of Multiple Deprivation (IMD) health scores.

- **Accessible nature:** This is mapped by identifying public accessibility and scoring areas by their level of perceived naturalness. The demand for accessible nature is mapped by estimating the proportion of households without accessible greenspaces within 500 m and their relative need for the related health benefits, based on IMD health scores.

9.6.7. Tool Appraisal

At a glance: Key strengths and limitations

Strengths

- Extensive documentation on uncertainty
- Generates mapped outputs
- Intervention effects can be detected beyond the site level to local and landscape scales

Limitations

- Requires competency with R
- Limited scope for adaptation and customisation
- Can require quite detailed, complex project specific data

9.6.8. Relevance to sectors

Ecoserv-GIS, the predecessor to EcoservR was designed for land managers, conservationists and consultants. Case study examples provide some evidence that these groups are indeed the main users. EcoservR has been developed by the Natural Capital Hub at LJMU. To date, case studies suggest it has largely been used by this organisation alongside Liverpool John Moores University, particularly for the use of quantifying natural capital in the Liverpool and South Yorkshire areas.

9.6.9. Cost-effectiveness

The tool is free to use and is easily accessible. Due to skill requirements for the software, resources and time for projects would depend on the user.

9.6.10. Ease of use/usability

At present the tool is in its beta version and has not been fully released to the public with appropriate guidance. Due to its design in R, as a minimum the user would be expected to have a proficiency in R alongside other mapping software.

9.6.11. Data requirements

The models used in EcoservR are data intensive and include a lot of GIS processing, however the need for user input is limited as the processes are automated and use built-in data where possible.

9.6.12. Tool adaptability

EcoservR is a defined tool with limited scope for adaptability or customisation.

9.6.13. Performance and reliability

Underpinning much of the modelling, including the method for designing a baseline map, are national datasets which are verified and reliable. Importantly, the data requirements set out for each tool are backed up by extensive literature. To ensure robustness and trust in the model's outputs, the developers have undertaken a full literature review to define inputs and highlight uncertainties. Each review and breakdown of the tool is available here: NatureScot Research Report 954 - EcoServ-GIS v.3.3: A toolkit for mapping ecosystem services (GB scale) | NatureScot. Interestingly however, modified versions of the EcoservR tools were used for the analysis of natural capital in South Yorkshire. Only the existing models for nature capacity, air purification and climate regulation were used, the rest were noted to be modified or built on.

9.6.14. Examples of use

- EcoservR was used to model before and after assessments of natural assets and ES for The Health Business and Technical Park in Runcorn, Cheshire, involving nature-based solutions such as woodland creation and water management through SUDS.

- Individual models of the EcoservR package were used to define natural capital and biodiversity in South Yorkshire.

- EcoservR was used to assess net loss or gain in ES based on developments within the Liverpool City region.

- EcoservR was used to baseline natural capital assessment for the Liverpool City region.

9.6.15. EcoservR output example

Example output from Angers-Blondin *et al.* (2020) EcoservR: a natural capital mapping tool for measuring public goods. ELM Test and Trial 074. Final report presented to Defra, September 2020.

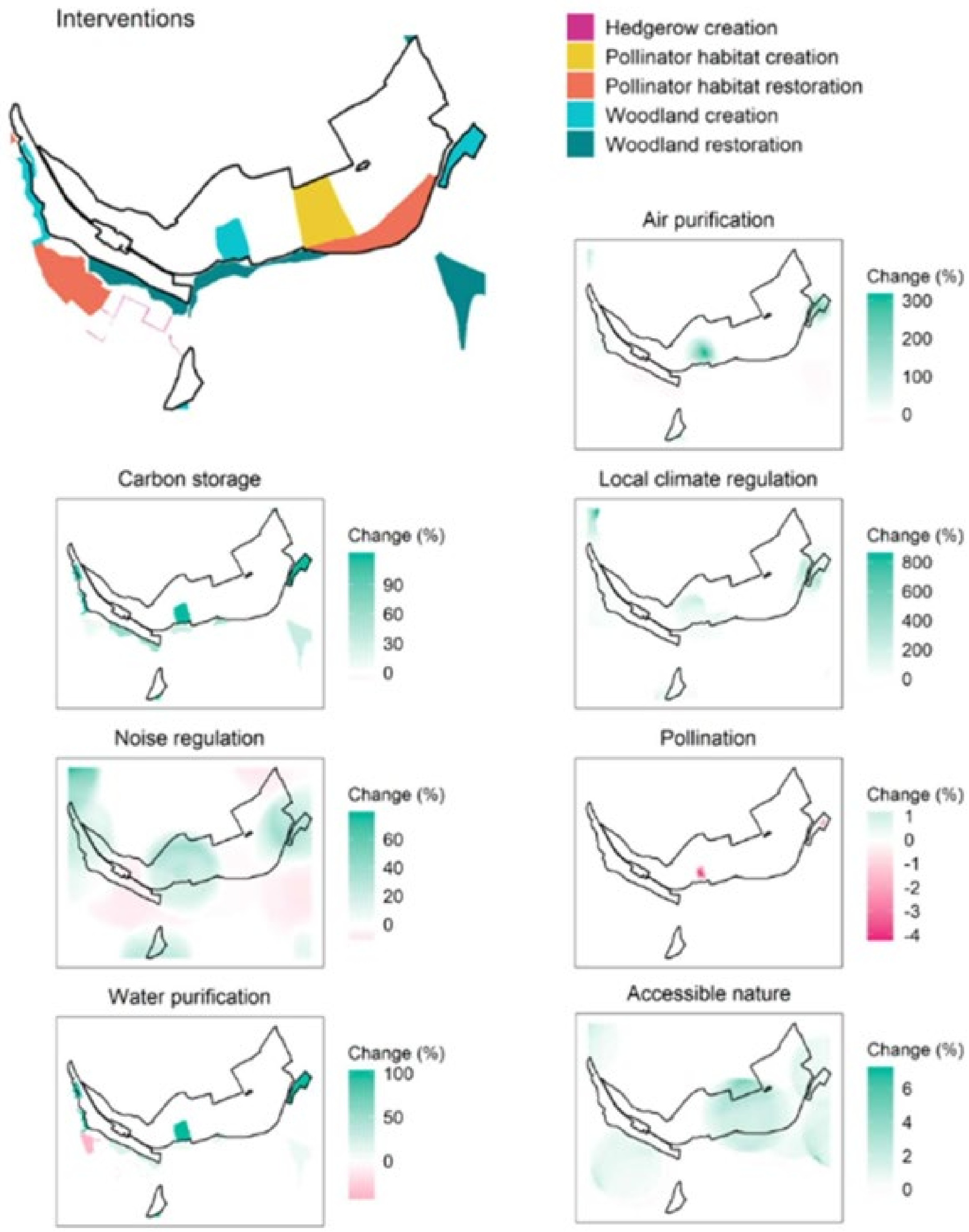


Figure 7. EcoservR spatial outputs depicting the change in ES and benefits following five different interventions. Source: Angers-Blondin *et al.* (2020) EcoservR: a natural capital mapping tool for measuring public goods. ELM Test and Trial 074. Final report presented to Defra, September 2020.

9.7. Systematic Conservation Planning + Marxan

9.7.1. Developer/s

Marxan – a collaboration of academics, funded by many organisations over the years as it expanded its scope - including the Great Barrier Reef Marine Park Authority.

9.7.2. Interventions and/or services that the tool is designed to assess

Any land use change.

9.7.3. Benefits targeted

Any environmental or social benefits.

9.7.4. Purpose of tool

The tool's overarching aim is to provide a suite of opensource tools which can help structure, design, and evaluate spatial planning projects for land, freshwater and ocean conservation, by balancing ecology and economics. More specifically, Marxan aims to minimise costs subject to the constraints of meeting biodiversity targets.

9.7.5. Audience

The tool has been designed for anyone requiring a spatial prioritisation tool to support conservation efforts. Marxan prides itself on inclusion and access.

9.7.6. Tool details

The key categorisations of the tool for this report are:

- Scoring of land use benefits and costs – user inputted data
- Generates mapped outputs
- The user defines the interventions
- Prioritises/optimises interventions by analytical methods within the tool: simulated annealing algorithms
    - Prioritises where to do one specific intervention
- Spatial scale: user can define scale, fine scale to national

SCP Systematic serves as a collaborative framework for guiding conservation efforts when working with stakeholders. It integrates both social and analytical components, aimed at identifying the most cost-effective strategies for enhancing natural capital. This method has been adopted and driven by the Marxan software, which uses an optimisation algorithm to provide solutions that meet conservation objectives cost effectively. It efficiently achieves this by using simulated annealing to select a set of potential conservation areas that meet a set of user-defined targets and costs. Simulated annealing makes use of randomness as part of the search process, meaning that it is suitable for complex systems and real-world scenarios where other local search algorithms do not operate well. The process begins with an initial solution, which is improved by randomly running the process until an optimal solution with a certain probability is found.

Marxan has several key steps. Firstly, the user is required to identify goals and objectives for the project. For example, setting the extent of restoration within a planning area to 30% to align with Defra's 30by30 goal (Smith *et al.* 2021). This is quite often undertaken with stakeholder engagement before engaging with the tool. Then, features relevant to the research/project aims are mapped using the best available data, for example PHI polygons. Next, the study/project area is divided into planning units. Planning units are manageable subsections of the study/project area which contain information on cost and condition. Marxan then identifies sets of areas that meet conservation targets for minimal "cost," and can be used to explore trade-offs between conservation and socioeconomic objectives. In addition, it highlights sites that occur in many solutions, which can help identify priority areas for conservation action.

Marxan is supported by a range of software to assist in the visualisation and interpretation of results. The standard output however is an output file saved to .dat, .txt. or .csv in tabulated form. Marxan MaPP allows user to generate mapped outputs.

9.7.7. Tool appraisal

At a glance: Key strengths and limitations

Strengths

- Allows for adaptation and customisation
- Can theoretically be used for any land use change intervention
- Generates mapped outputs
- Can find the 'global optimum' through simulated annealing

Limitations

- Requires technical skills and competency
- Can be very time consuming

9.7.8. Relevance to sectors

The extensive catalogue of case studies supporting the use of Marxan highlights its importance in the conservation and environmental planning sectors, by providing a robust package of tools for decision making. The Marxan website states that the software is currently used by over 6,000 users across 100 countries. Marxan has been used by The Wildlife Trusts for Buckinghamshire, Berkshire and Oxfordshire to develop a nature recovery network, highlighting its application to a UK based setting (Smith *et al.* 2021).

9.7.9. Cost-effectiveness

The tool is free to use and is easily accessible. Due to skill requirements for the software, resources and time for projects would depend on the user.

9.7.10. Ease of use

Janßen, Göke, and Luttmann (2019) state that there are strict data and expertise requirements for the use of Marxan, but also parameterisation is difficult, and calibration is demanding. They found that responses to a questionnaire investigating the use of Decision Support Tools (DSTs) found that most users had a higher education qualification, and experienced experts are required to make full use of the tool, particularly to interpret results and data. However, where proficiencies in statistical analysis, mapping, and associated software are acquired, users and potential users can benefit from extensive support and guidance provided by Marxan. They host training courses on systematic conservation planning with Marxan, alongside providing a learning library, with resources such as manuals and tutorials, and planning exercises.

9.7.11. Data requirements

Due to the broad application of Marxan, data requirements are near limitless depending on the questions being asked in the project. Therefore, time commitments can range from days to years depending on the scale of the project. When developing the nature recovery network for Buckinghamshire, Berkshire and Oxfordshire, data was used from the NE PHI polygon dataset, supplemented by additional NE datasets for traditional orchards, wood pasture and parkland, the ancient woodland map, QSM data set for ponds and OS open river database for rivers. Habitats were parametrised through amount of habitat within designated sites, within the proposed nature recovery network, the amount in the planning region, and the target amount.

9.7.12. Tool adaptability

Marxan is a customisable tool and has scope for adaptability.

9.7.13. Performance and reliability

Research efforts have focused on developing computer software to solve the minimum-set problem, or set cover problem, and numerous algorithms have been developed to find solutions. The set cover problem is a classical question seeking to find the largest possible set from a given collection of subsets. The large number of possible solutions makes some iterative and optimizing algorithms unsuitable for conservation planning problems as they often slow to find solutions, find inefficient solutions, or find only single solutions. This is summarised in Section 3.3.2 with the difference between a tool finding the local or global optimum. Marxan, the most widely used software for conservation planning however, uses simulated annealing algorithms (Watts *et al.* 2009). An advantage of simulated annealing algorithms is their ability to find many near-optimal solutions to large problems in a reasonable amount of time.

9.7.14. Examples of use

- Used to identify gaps in the Coral Triangle Marine Protected area to identify areas of conservation priority to meet the initiative's goals for establishing and expanding effective marine protected areas.

- Used to develop a new method to help land managers manage expectations by constructing production possibility frontiers in East Kalimantan.

- Used to create a regional planning framework for the Gobi Desert which led to the creation of 68,800 km^2 of protected areas.

9.7.15. Systematic Conservation Planning + Marxan output example

Example output from Beger *et al.* (2015) Integrating regional conservation priorities for multiple objectives into national policy. *Nature communications*, 6(1), p.8208.

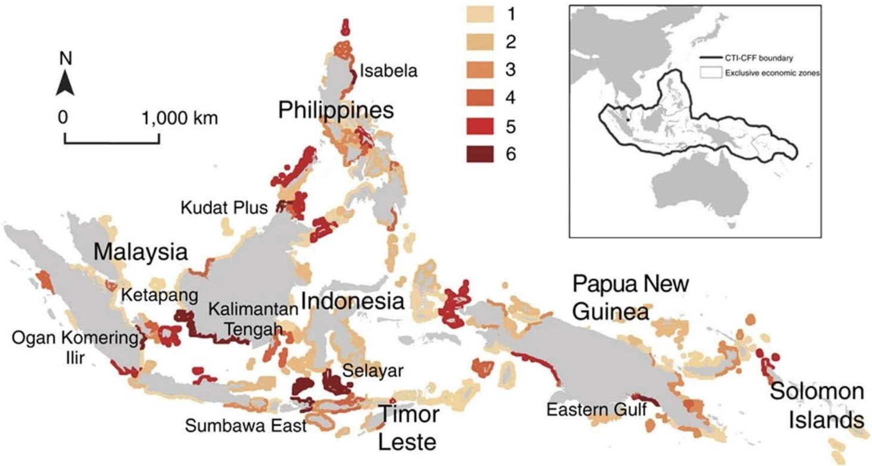


Figure 8. Marxan spatial output depicting the outcomes of objective-driven spatial conservation planning for 6 distinct conservation objectives. Areas with benefit for each objective are depicted in red, with graduated colours showing areas that achieve benefits for 5 down to 1 objectives. Source: Beger *et al.* (2015) Integrating regional conservation priorities for multiple objectives into national policy. *Nature communications*, 6(1), p.8208.

9.8. NATURE Tool (Nature Assessment Tool for Urban and Rural Environments)

9.8.1. Developer/s

WSP, Ecosystems Knowledge Network - in collaboration with Northumbria University. Co-funded by Innovate UK, WSP and the Ministry of Justice.

9.8.2. Interventions and/or services that the tool is designed to assess

Housing and infrastructure development, changes in habitats.

9.8.3. Benefits targeted

Flood regulation, erosion protection, water quality regulation, water availability, air quality regulation, aesthetic values, mental health, physical health, education and knowledge, interaction with nature, recreation, sense of place, biodiversity - habitat / hedgerows / rivers, pollination, carbon storage, cooling and shading, pest control, food and fish commercial / community, wood production, photovoltaic carbon impact.

9.8.4. Purpose of tool

NATURE Tool is an Excel based scoring tool used to quantitatively assess and manage the impact and benefits of natural capital and Nature-Based Solutions on ES and human wellbeing. The tool is designed to be used in the early planning design phases of development projects to assess the impacts of the project and potential offsetting requirements. NATURE has a more targeted approach for development projects and takes local policy within the UK's devolved governments into consideration. The tool can also be used for baseline assessments and to inform opportunity mapping. NATURE quantifies the benefits of nature-based interventions, reveals trade-offs and enables the tool user to objectively demonstrate environmental Net Gain and sustainable action through development.

The NATURE Tool enables the user to assess up to 17 ES as well as physical and mental health benefits through a scoring system indicating both the direction and magnitude of project impacts. These scores are aggregated, added and multiplied (these are experimental aggregations, see tool details) based on policy priorities resulting in an overall 'Natural Capital Score' for the project.

The primary focus of the tool is for planning and development; however, it can be used more broadly depending on the user's objectives. For example, a conservation focussed community group could use the tool to assess potential benefits of interventions in a nature reserve, farm or as small a spatial scale as a garden. Other opportunities for NATURE Tool include community health impact assessments, planning for climate emergencies and promoting placemaking (focusing on how communities use space). The tool is free and relatively easy to use, making it more accessible to wider audiences and functions.

9.8.5. Audience

The tool has primarily been designed for anyone involved in infrastructure developments that need to assess natural capital, Net Gain and offsetting requirements. This includes housing and infrastructure developers, local planning authorities and water and energy authorities. The tool can be specified for use across the UK's four devolved planning systems (Scott *et al.* 2021). However, the tool can also be used to assess ecosystem service impacts for habitat changes and can be used for a more conservation focussed audience such as NGOs, private land managers, charities and local groups.

The developers of NATURE Tool do not monitor the number of users and cannot confirm the sectors that utilise the tool. NATURE Tool have heard that other sectors outside of planning and development are using the tool for similar purposes, (i.e. Net Gain impacts from land use interventions).

9.8.6. Tool details

The key categorisations of the tool for this report are:

- Scoring of land use benefits and costs – allows user inputted data
- Does not generate mapped outputs (but mapped outputs can be produced using the same model, as a paid service)
- The user defines the interventions
- Prioritises/optimises interventions by allowing post-hoc exploration of tabulated scoring value results by the user. Post-hoc analysis can be conducted within the tool or Excel
    - Prioritises which intervention to action in a location
- Spatial scale: tabulated information, does not use spatial resolutions

NATURE Tool is a freely available Excel spreadsheet tool. Algorithms and multipliers within the Excel spreadsheet then calculate natural capital performance and impacts. The tool is a relatively simple data in, scores out process.

The user enters the habitat areas before and after an intervention as well as the level of accessibility of the site. The tool then automatically calculates natural capital performance and impact using six key indicators for each of the ES and benefits of interest. The calculations can be reviewed in the tool and consist of multipliers. The multipliers impact the scoring of each ecosystem service based on peer reviewed information where available, or by expert knowledge where data was limited. Habitat delivery risk multipliers are also used for assessing confidence in the scores. The user then needs to interpret these scores for each ecosystem service and can make post-hoc comparison among different scenarios to optimise ecosystem service gains. The tool results are summarised in two overall indicators, biodiversity (impacts on wildlife and species resilience) and natural capital (the impact of the project on people with regard to ES and health benefits).

The six key indicators used in the calculations for natural capital performance and impact are:

- **Change Score:** how will a project impact on the natural capital performance in relation to the baseline (predevelopment)? This is the main indicator for measuring project success with regard to biodiversity impacts. The higher the score, the greater the positive change in the ecosystem service supply.

- **Potential Score:** to what extent has the maximum site potential for natural capital been achieved? This score takes into consideration the level of the baseline and the potential for change, and how much of the maximum benefit potential for the site has/would be achieved. This score indicates how valuable a site is in terms of natural capital and its potential for additional improvement; however, it is theoretical.

- **Completeness Score:** how complete is the assessment? This is defined as a measure of how detailed the entered habitat categories are and to what extent optional indicators were used. This score is displayed for transparency, it indicates how accurate the assessment is. If the user has inputted data into advanced indicators, the accuracy of the assessment should be higher.

- **Policy Priority:** high, medium or low based on national policy or as defined by the ‘objective setter’. Policy priorities determine how ES and benefits are weighted when aggregated to an overall score. This scoring is mainly displayed for reference and transparency but is useful when projects are focussed on planning within specific policy areas. ES with high policy priority scores weigh more strongly in the aggregated Natural Capital Score.

- **All Objectives Met?:** will the project achieve the natural capital objectives as defined by the ‘objective setter’? For specific defined projects the user can set objectives that the tool can include within the scoring. An 'objective setter' can be used to create an adapted version of the tool for a specific area or local authority. This allows the user to decide what ES need to be assessed for the project, the objectives for the project (improvement scores) and policy weighting (based on local or corporate policies specific to the project). This 'objective setter' helps steer the precision of the model toward the required prioritisations for the specific project.

- **Achievements:** does the project achieve Net Gain? Achievements are awarded to the scores depending on the level of ‘change score’, ‘potential score’ and ‘completeness score’, providing a quick reference to if/how the project is delivering Net Gain.

The NATURE Tool can also be used to assess the natural capital baseline of a site. In this case, the tool calculates (per ha) baseline scores as well as the potential scores only.

The tool calculates scores for the 17 ES as well as aggregated Natural Capital, physical and mental health benefits, and abated carbon emissions from solar installations. The ES include air quality regulation, pest control, pollination, wood production, recreation, carbon storage and flood regulation. The calculations use the six key indicators described above, and users add in site specific details for each benefit. These details can simply be the area of the habitat/benefit or can include advanced details on what the intervention will entail. These are different for each benefit but usually consist of selecting a pre-defined option from a list. For example, woodland management categories for interventions are ‘primarily managed for wood production’, ‘minimum intervention management for woodland production’ and ‘not managed for wood production’. These categories will impact the resulting score for associated benefits.

The base scores are then adjusted based on multipliers in relation to indicators for the ecosystem service/benefit location and condition. The multipliers are specific to each ecosystem service/benefit. For example for air quality, the score is based on a habitat base score and multipliers including a) population density/external visitor numbers (multiplier higher in areas with higher density/visitors), b) air quality management area (multiplier higher if within one of these areas), c) habitat maturity (multiplier higher for mature habitats), and d) delivery risk (penalties for newly created habitats with risk of implementation failure).

For each ecosystem service/benefit the tool provides a sheet that shows the calculations of the base score and the multipliers. The basis and evidence for the multipliers is different for each ecosystem service/benefit. The origins of the baseline ecosystem service score are not on the developer website.

Each benefit has a confidence rating rationale but does not necessarily explain origins of some of the multiplier values. The Natural Capital Score, Cultural & Health, Mental Health and Physical Health scores are experimental aggregations and therefore have a lower confidence level than individual ES/benefits.

The outputs from the calculations are displayed in Excel with summary results for each benefit, and detailed results which breakdown each benefit by the six key indicators and multipliers. For comparisons between scenarios, users need to run separate editions of the Excel tool and conduct post-hoc analysis of the results.

9.8.7. Tool appraisal

At a glance: Key strengths and limitations

Strengths

- Does not require technical skills such as GIS or modelling
- Can be used in data scarce conditions
- Makes complex data easy to interpret
- Highly relevant and targeted to Natural Capital and BNG

Limitations

- Does not account for the wider landscape
- Post-hoc analysis is required

- Limited scope for adaptation or customisation

9.8.8. Relevance to sectors

The tool is relevant to anyone looking to make decisions specifically regarding developments and their impacts on natural capital. The tool provides clear, easy to understand scores on a variety of benefits and should help steer projects to achieve Net Gain. Other users can use the tool to assess impacts of land use change interventions, and it is relevant across conservation practice as well as development planning. Policy scores are relevant for the UK, but the tool is relevant for development planning in other parts of Europe.

The tool developers have not been tracking use of the tool; however, a large number of stakeholders have been involved in development and NATURE Tool 2.0 is also currently under development. The tool was Highly Commended at the 2022 CIEEM Awards and is widely used by developers, planners, water/energy providers and local authorities. The project includes 38 partners who have engaged in the development of the NATURE Tool and results will be fed back into the development of upcoming iterations.

9.8.9. Cost-effectiveness

The tool is free to use and is easily accessible to download. Due to its relative ease of use, the time and resources needed for projects is likely comparatively low compared to other tools that require GIS or programming inputs.

9.8.10. Ease of use/usability

The tool is marketed as an easy to use, accessible system. Microsoft Excel is required to run the tool, but no other software is required. Basic skills in Excel are required to use the tool, and users will need to import their own GIS information regarding the site. NATURE Tool has been purposefully designed to be applied quickly with minimum data requirements and non-specialist skills. Depending on assessment scope, project scale and complexity, most NATURE Tool assessments can be completed within one to five days which means that time requirements are also marginal in the context of most projects. For small projects, scores can be generated in a matter of hours.

Project specific knowledge is required, as is the case for all the tools, and there is considerable guidance both within the tool itself and the user guide. Outputs are provided within the Excel tool, and no further software or processing skills are required – unless comparing multiple interventions in which case post-hoc comparisons of scores will need to be done manually or with additional skills on Excel. There are no mapped outputs, so the tool is unable to ‘suggest’ spatial locations of benefits from interventions.

9.8.11. Data requirements

Site/project specific data are required; at a minimum these are a defined site boundary, existing habitat data and data on the accessibility of the greenspaces on site. There are additional ‘advanced’ questions within the tool that can be answered to increase the accuracy of the calculations. It is assumed that for most projects where the user has site specific information that these additional inputs can be added.

However, the calculations can still be run with the minimum information, and this may be particularly useful for projects where specific details are unknown or where general score estimates are required.

9.8.12. Tool adaptability

NATURE Tool is a defined tool with limited scope for adaptability or customisation.

9.8.13. Performance and reliability

The tool attempts to deal with the complexity of natural capital and ES in a simple and easy to interpret way with limited resources.

The scoring approach is comparable with the Environmental Benefits from Nature Tool and employs a similar confidence rating in the scoring. The tool considers risk and habitat age and maturity (takes into account values for one year woodland are different to five years).

There are no spatial limits to the data, and it can be used on a very small scale. The tool results are easily communicated and at a glance the achievements, objectives and completeness scores allow the user to assess whether the proposed project is providing positive impacts. Monetary impacts are provided for carbon related impacts.

There is a data checklist spreadsheet that assists with user data collection to input into the tool. Some of the datasets appear to be quite old, however others have been updated suggesting that some datasets have not been changed since their original (albeit old) iteration. The tool has undergone testing through the project partnership and a new tool, NATURE Tool 2.0, is under development. There are some concerns with accuracy regarding some of the multiplier scores where these have come from expert knowledge and not necessarily from clear peer reviewed data. Each benefit does include a confidence rating rationale even if there is not necessarily an explain regarding the origins of some of the multiplier values. Risk and confidence levels in the scores are transparent within the results, and experimental and low confidence levels are clear. The lack of clear source information for some of the values is balanced with the overall user-friendly experience of the tool (Cianchi *et al.* 2024).

The tool results are indicative and do not provide a definitive answer, and post-hoc analysis is required if users want to compare different scenarios, which can add a considerable amount of resource to the project if at a large scale.

The tool is relatively rigid when compared to some of the other scoring/modelling tools. For some benefit calculations additional information can be added, however this is often limited to a selection from a pre-determined list of options. The amount of flexibility is a limitation, as the process of scoring relies on fixed Excel calculations. There are no opportunities to edit the calculations, a limitation when compared to tools that allow users to edit programming and input specific datasets. However, this is balanced with the relative simplicity and accessibility for a higher number of nontechnical users.

The user can focus project-specific objectives into the tool, for the ‘objectives met’ score. This can allow for a more project specific tailored experience with outputs more relevant to the user, however some of the ES/benefits can be removed from the assessment altogether. Depending on the user this could lead to assessment bias and siloed thinking, where local or project priorities are weighted differently to other (potentially equal in value) ES/benefits (Cianchi *et al.* 2024). This may obscure losses to what the user may consider lower priority services.

It is worth noting that the development of NATURE Tool 2.0 seeks to improve the current version of the tool by:

- Streamlining the importing GIS data into the tool

- Better reflection of local context and stakeholder views and easier adaptation of the model
- Inclusion of more monetary valuations

9.8.14. Examples of use

- The Ministry of Justice used the NATURE Tool to assess the natural capital impact of greenspace improvements interventions within the estate on inmates and the local community. A specific tool tailored for the Ministry was developed (Hölzinger, pers comm 2024).
- Royal Seaport in Stockholm, Sweden, was a large 250+ hectare brownfield development site with plans to deliver 12,000 homes and 35,000 workplaces. Sustainability was central to the development of the plans, including the creation of an ecological corridor. The NATURE Tool allowed for a holistic and wide assessment of the ES/benefits the interventions could provide. The tool was deployed retrospectively to the plans and reflected more outcomes than other tools had previously suggested (NATURE Tool 2024).

9.8.15. NATURE Tool output example

Example output from Hölzinger, O. (2025). Case Study A.

Services & Benefits	Baseline Units/ Score	Project Units/ Score	Unit/ Score Change	Change Score	Confidence Rating	Policy Priority	Achievements
Natural Capital Score	249	286	+37	+15%			
Cultural & Health	196	204	+8	+4%			
Mental Health	129	132	+3	+2%		L	
Physical Health	96	119	+23	+24%		L	
Aesthetic Values	123	126	+2	+2%		H	
Education & Knowledge	0	0	0	0%		L	
Interaction with Nature	180	181	+1	+1%		L	
Recreation	0	0	0	0%		L	
Sense of Place	460	478	+18	+4%		H	
Regulating & Supporting	300	369	+70	+23%			
Air Quality Regulation	24	56	+32	>100%		M	
Carbon Storage	58	174	+116	>100%		H	
Cooling & Shading	12	24	+12	>100%		L	
Erosion Protection	621	678	+58	+9%		H	
Flood Regulation	377	524	+147	+39%		M	
Water Quality Regulation	306	411	+105	+34%		H	
Pest Control	516	463	-53	-10%		L	
Pollination	404	421	+17	+4%		M	
Provisioning	115	83	-32	-28%			
Food & Fish | Commercial	0	0	0	0%		L	
Food & Fish | Community	0	0	0	0%		L	
Water Availability	459	331	-128	-28%		L	
Wood Production	0	0	0	0%		L	
Abiotic Services							
Photovoltaic Carbon Impact	0	0	0	0%			

Figure 9. NATURE Tool tabulated output depicting changes in Natural Capital scores following distinct interventions, allowing for post-hoc comparison within the tool. Source: Hölzinger, O. (2025). Case Study A. Provided via email communication.

9.9. Land Utilisation Capability Indicator (LUCI)

9.9.1. Developer(s)

Victoria University of Wellington, UK Centre for Ecology & Hydrology (UKCEH).

9.9.2. Interventions and/or services that the tool is designed to assess

Any change in land cover type, particularly in an agricultural landscape.

9.9.3. Benefits targeted

ES include agricultural productivity, flood risk, erosion, nitrogen, phosphorus loss to rivers, carbon storage and emission rates, habitat diversity and connectivity for broadleaved woodland species.

9.9.4. Purpose of tool

Land Utilisation and Capability Indicator (LUCI) is a tool that allows users to explore the capability of a landscape to provide a variety of ES, such as agricultural production, flood and diffuse pollutant mitigation, carbon sequestration, and habitat provision. It allows for the development of alternate scenarios so that different management decisions can be assessed and compared alongside current services. It identifies potential trade-offs and opportunities for spatially optimising interventions. The model allows mapping of ES from fine spatial scales (sub-field) to national scale.

LUCI can be used to explore the cumulative impact of many small features in the landscape on a variety of ES. For example, with regard to tree planting, users can explore how riparian planting might change river water flow and quality, or where you might be able to plant trees to improve drainage on your land and provide shelter for stock. If you are managing a catchment, you could investigate where and how you could retain water in the upper catchment to improve flood risk management downstream.

The tool can be used to further conservation and productivity within agricultural landscapes by:

- Helping to prioritise the protection and/or restoration of natural remnants in agricultural landscapes that have the highest cost-benefit with respect to conservation, production, and societal values

- Identifying land that is uneconomical to farm (e.g. if it is prone to flooding or erosion), and which can be taken out of production to be managed for biodiversity values and other ES

- Helping farmers and land managers to mitigate or reduce their impacts on other ES and the environment (e.g. can be used to identify areas where targeted plantings of native vegetation are likely to maximise water quality benefits by reducing sediment and nutrient inputs into waterways)

9.9.5. Audience

The tool has been designed for policy makers, farmers and land managers, local communities, local councils and academics. The agricultural and planning sectors are the key target user groups alongside regional and national governments. There is evidence that the target audiences are using LUCI, with the Welsh Government using the tool within a £9M project to identify trade-offs and co-benefits and to project the potential outcomes of farmer interventions so that agricultural subsidies can be better targeted.

As the tool can be modified or run in addition to other programmes, the audience and application of the tool has widened. The United Nations used LUCI to help develop tools to support their SEEA framework. The tool has applications at a global level for ecosystem service modelling.

9.9.6. Tool details

The key categorisations of the tool for this report are:

- Modelling of ES – allows user inputted data
- Generates mapped outputs
- The user defines the interventions
- Prioritises/optimises interventions by analytical methods within the tool: trade-offs and synergies
  - Prioritises where to do one specific intervention
- Spatial scale: sub-field to national scale, limited information on resolution from developers

LUCI utilises a GIS Python toolbox with compiled code accessed through a geoprocessing server. Some aspects of the model are freely available on GitHub, however for the full tool the developers need to be contacted (in communications with UKCEH it is not clear whether the tool is still being supported). It is primarily a visualisation tool for determining trade-offs in ecosystem service provision. LUCI maps ES from the sub-field to national scale and models the impact of interventions on these services using multiple criteria analyses.

LUCI is a spatially explicit GIS model that consists of various tools, with the potential to add further tools into the model depending on programming skills. Most consider current and potential impacts of land management change on single service criteria; all are calculated using different model methods:

- Habitat networks (this is split into two approaches)
  - Approach A: BEETLE (Biological and Environmental Evaluation Tools for Landscape Ecology) – Forest Research (UK Government) cost-distance approach to dispersal, examining connectivity of habitats.
  - Approach B: identification of priority habitats by biophysical requirements (e.g. wet grassland).
- Flooding – Detailed topographical routing of water accounting for storage and infiltration capacity as functions of soil and land use
- Erosion – accounting for slope, curvature, contributing area, land use and soil type
- Sediment delivery – erosion combined with detailed topographical routing
- Water quality – erosion combined with detailed topographical routing

- Carbon sequestration – IPCC Tier 1 (Intergovernmental Panel on Climate Change data), based on soil and vegetation

- Agricultural productivity – accounting for slope, fertility, drainage, aspect, temperature

An additional tool explores synergies and trade-offs amongst any number of the singular ES. This trade-off tool utilises various layering options with categorised service maps (e.g. Boolean, conservative and weighted arithmetic). It is designed to be simple and transparent (but does require GIS skills to run), with the potential for customisation for project/site specific assessments.

LUCI requires three datasets to run and can be enhanced with site/project specific local data if available:

- Digital elevation model (DEM): the finer the input resolution the more detailed the output.

- Land cover information: To represent impacts of different types of vegetation and management on ES.

- Soil information: To represent the effect of soil types on ES.

Other optional information includes a stream network (waterways in the catchment), rainfall, and evapotranspiration. All LUCI calculations and valuations are produced at the resolution of the input digital elevation model (DEM) which is five metre by five metre within the UK. This is an appropriate resolution for water and diffuse pollution services and allows for sub-field management changes (e.g. riparian strips and field boundaries) as well as sub-catchment and catchment changes to be assessed. This resolution is maintained for all services to ensure each service valuation is produced at a resolution that remains consistent with the valuations of other services. This common scale is also necessary to allow trade-offs and synergies to be meaningfully calculated.

LUCI generates a baseline scenario that feeds into determining the spatial distribution, supply, and potential for delivery of the individual ES. Land cover information can be amended to explore scenarios where the land use or management have changed. The tool generates a series of ES maps that show areas of good provision and areas that would benefit from changes in management intervention. These can be visualised as “traffic light” coded impact maps that show the different impacts of different decisions on ES. Multiple ES can be compared to identify where trade-offs or synergies exist. Interactive capabilities to facilitate stakeholder engagement and to allow local requirements and knowledge to be easily incorporated in decision making are included.

One of the tools (GIS models) is a trade-off tool which allows the user to compare multiple ES at once. Its output identifies locations in the landscape where trade-offs or co-benefits/synergies in ES exist. Trade-offs are areas where one service would benefit from management interventions but lead to the degradation of a different service being provided by the same area. Co-benefits and synergies are areas where multiple services might benefit from interventions. This tool would allow users to identify priority areas in terms of locations that contribute to multiple ES.

In terms of modelling values of ES related to water and nutrient flows, the tool links combined spatial input data for each pixel (spatial area within the mapping) with a lookup table and applies process representation for flow of water and nutrients over the landscape. For habitat connectivity, this is simulated based on cost-distance approach considering characteristics of adjacent habitats. The model also considers temporal changes to give long term annual average values for the ES. Temporal changes estimate provision over time, for example as a habitat matures.

Each model produces mapped outputs using different methods, providing raster and shapefiles. For example, LUCI's flood mitigation and water supply services model calculates direction of flow over the landscape using GIS functions in topography. The model then combines this for each pixel of the spatial area with spatial data on hydrologically effective rainfall (this is calculated by subtracting estimated evapotranspiration from precipitation). The model then simulates accumulation of this water across the landscape using flow accumulation routines (Sharps *et al.* 2017). Where relevant, for each model, biophysical and topographical spatial information is combined with data from lookup tables and user inputted data. The data provided by the models comes from a range of sources, from peer reviewed reports to global datasets.

9.9.7. Tool appraisal

At a glance: Key strengths and limitations

Strengths

- Considers trade-offs and synergies
- Tool is adaptable and customisable
- The model allows mapping of ES at fine (sub-field) to landscape spatial scales

Limitations

- Requires basic GIS skills and access to software
- Requires high resolution data
- Some limitations noted for models

9.9.8. Relevance to sectors

The tool is relevant to anyone looking to make decisions regarding land use change, where these decisions are related to the ES assessed by the tool. The seven main individual ES are highly relevant to the intended audience (farmers and landowners) with a particular focus on agricultural landscapes and opportunities related to productivity. It appears useful for informing landowners of where 'win-win' opportunities for ES are. This is evidenced by the Welsh Government's use of the tool for a project identifying trade-offs and co-benefits to estimate the potential outcomes of farmer interventions.

The tool has a strong focus on agricultural landscapes and could be used in conjunction with ELM targets, nutrient neutrality, carbon markets and other natural capital elements. The mapped outputs and trade-offs may be able to suggest what interventions could go where for a farmer, and these could be interpreted alongside ELM policy.

This ability to consider trade-offs and synergies is a key benefit of this tool. In allowing for multiple trade-offs to be evaluated, the resultant mapped outputs are a valuable means for recognising the value of existing landscape features alongside the targeting and prioritisation of opportunities for landscape change.

The tool can also be used to assess general ecosystem service opportunities within spatial areas and has been utilised by the United Nations when looking at national scale opportunities and vulnerabilities (for example investigating watersheds vulnerable to soil loss across India).

9.9.9. Cost-effectiveness

Currently unknown, the tool appears to be free to not-for-profit organisations on request, but this could not be confirmed with the developers (or if the tool is still being supported). Elements of the tool have been published for free on GitHub, including the UN SEEA toolbox edition of the tool.

9.9.10. Ease of use/usability

The model requires access to GIS software and basic GIS skills. The tool is not suitable for non-technical users lacking in these skills. Interpreting the ‘traffic light’ output maps is quite simple, and visual assessments of the spatial area can easily be made. The visual representations are particularly useful for conveying the data to non-technical users, stakeholders, decision makers, etc. The timescales are unknown for inputting the data and will be project specific. If utilising the simple data sources provided within the tool, then initial input resources will be low. For running the tools this can take anywhere between minutes to several hours depending on the complexity of the input data and the spatial scale of the model.

9.9.11. Data requirements

At its simplest LUCI can run on just 3 data sources which are nationally available: a soils map, landcover map and a digital elevation map. The user can input additional information for more robust modelling. The tool requires generally higher resolution spatial data than other tools which restricts access for many users. Data collation for input is likely to be the most time-consuming element of preparing the models.

9.9.12. Tool adaptability

Users can input their own data into the models. These can be edited/run with additional models if the user has sufficient programming experience. Many of the examples of the use of LUCI have not differentiated from the standard models within the tool, but the United Nations has released its own toolbox containing elements of LUCI and other models.

9.9.13. Performance and reliability

The tool performs singular ecosystem modelling and trade-off assessments well and is one of the few modelling tools that provides trade-off opportunities. It can be run using nationally available data which means outputs are relevant to that nation’s spatial planning. The tool is modular, meaning that other models and aspects can be embedded with the tool: This has already been undertaken by the United Nations. It is fast running and enables ‘real time’ scenario exploration. The tool can be used for very small spatial scales at the sub-field level, and at a national level.

The tool assigns values for features and potential interventions by the area that is indirectly affected by an intervention, and not just the area that is being directly modified. The trade-off function and exploration of ‘win-win’ solutions is a particularly useful element that provides a useful visual output of the impacts of land use change on multiple services (which is not present in similar tools such as ARIES and InVEST). LUCI's traffic light maps allow quick and easy interpretation of the model output. The tool also respects fine-scale spatial configuration of landscape elements (Sharps *et al.* 2017).

There are limitations within the models that are similar across other ES modelling tools. The water models do not allow for surface water – groundwater interactions, where streams can either gain or lose water through the streambed (Sharps *et al.* 2017). Average inventory values for carbon fails to account for habit or land use heterogeneity within a land use type, so these could differ quite dramatically within the same land use area depending on temperature, elevation, etc. Another example is phosphorus outputs which only take into consideration the size of the human population served by sewage works within the spatial zone, and not from other human sources such as septic tanks (Sharps *et al.* 2017). However, these limitations are found across other models, and no model can be completely accurate and take all factors into account.

The tool appears to be under ongoing development and current links to the webpage through UKCEH are not functioning. It is unclear if the model is still being supported, but there are iterations of the model available to download free online. The dataset sources for the models originate from multiple sources. Precipitation and evapotranspiration data for example come from ESRI datasets and are likely to be accurate if the data has been kept refreshed (this is currently unclear). Users can add their own data which may increase the accuracy and reliability of the models.

Elements of the models are available on open source so there is transparency within these tools. According to the developers (UKCEH) cataloguing for LUCI the status of the tool's version control, internal/external model audits, quality assurance, transparency and periodic reviews are 'unknown'. Therefore, additional information would need to be sought directly from the developers. The algorithms for singular ecosystem service models have been peer reviewed and come from existing and researched calculations (Jackson *et al.* 2013). The tool is well reviewed within academic literature.

9.9.14. Examples of use

- Glastir Monitoring and Evaluation Programme. A national evaluation of agri-environmental payments in Wales was undertaken, deploying LUCI across the entirety of the country. The programme took an ecosystem service approach recognising the potential for trade-offs and co-benefits of different management practices (Emmett *et al.* 2014).

- UN SEEA framework. Utilisation of LUCI and additional SEEA tools to investigate changes in soil loss and areas vulnerable to soil loss across India and Brazil (United Nations System of Environmental-Economic Accounting (SEEA), date unknown)

- New Zealand. Assessing the capability of 'high-country' stations in delivering ES. LUCI was deployed to better assess the value of a primarily grassland spatial area under pastoral livestock production systems. This allowed the identification of neglected areas and assisted planning of best place-based management practice strategies (Pereira *et al.* 2023).

9.9.15. Land Utilisation Capability Indicator (LUCI) output example

Example tool output from Pereira *et al.* (2023) A geospatial modelling approach to assess the capability of high-country stations in delivering ecosystem services. *Land*, 12(6), 1243.

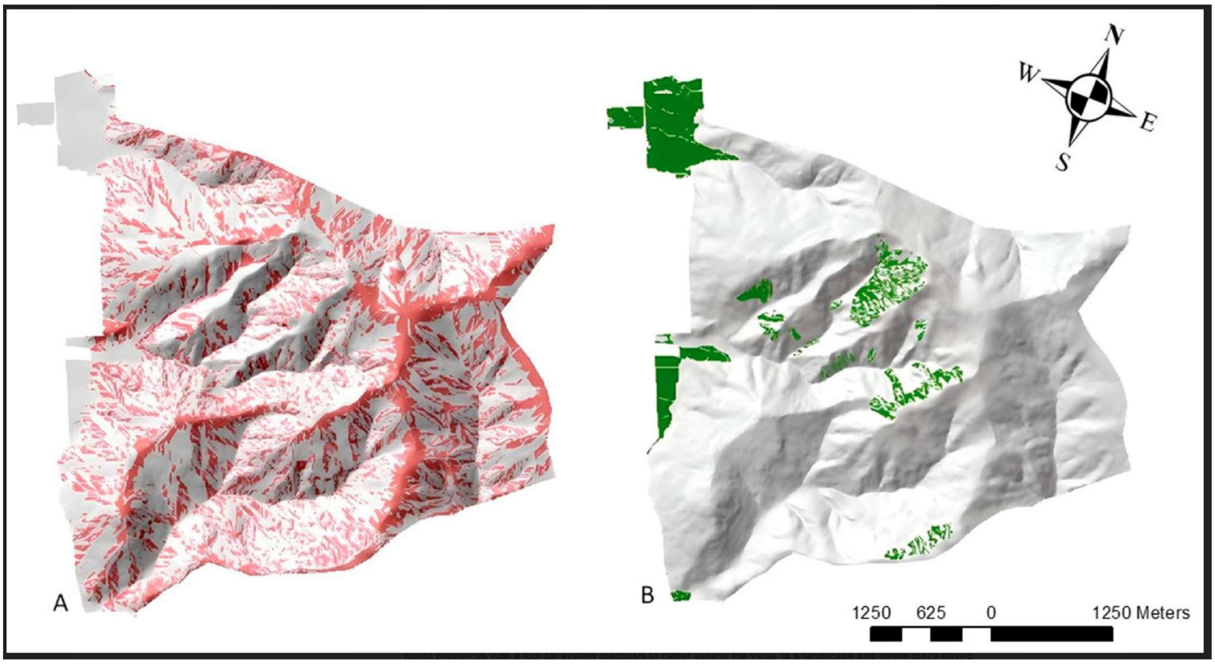


Figure 10. LUCI spatial output depicting A) areas where a management intervention to enhance one ES would negatively impact at least one other ES, and B) areas where multi ecosystem services are positively interacting and the priority of one does not negatively affect others. Source: Pereira *et al.* (2023) A geospatial modelling approach to assess the capability of high-country stations in delivering ecosystem services. *Land*, 12(6), 1243.

9.10. The Restoration Opportunities Optimization Tool (ROOT)

9.10.1. Developer/s

A partnership between IUCN and The Natural Capital Project.

9.10.2. Interventions and/or services that the tool is designed to assess

Changes to land use and biophysical values of ES.

9.10.3. Benefits targeted

Can use any ecosystem service information that users input but the tool includes groundwater recharge, income generation, watershed risk management, hydropower generation, flood mitigation, agricultural production, and carbon sequestration.

9.10.4. Purpose of tool

A tool for restoration practitioners working on the assessment of multiple ES which need to be quickly understood by decision makers. It is a decision-support tool that demonstrates trade-offs among several ES and optimises delivery for their biophysical benefits and benefits to people.

9.10.5. Audience

A tool aimed at decision-makers who require a tool which can assess multiple ES. Restoration practitioners, governments, environmental organisations and conservationists would be the target users.

9.10.6. Tool details

The key categorisations of the tool for this report are:

- Scoring of land use benefits and costs – allows user inputted data
- Generates mapped outputs
- The user defines the interventions
- Prioritises/optimises interventions by analytical methods within the tool: linear programme (LP) algorithms
    - Prioritises where to do one specific intervention
- Spatial scale: local to national scale, resolution varies from 250 m^2 and 1.2 km^2

ROOT applies an integrated linear programming algorithm to identify optimal areas for restoration. It allows the user to specify multiple objectives of interest, combining expected changes in biophysical values and maps of ecosystem service demand, and generates a range of activity allocations by performing numerous optimisations that adjust the weight assigned to each objective. ROOT synthesises the results of these separate analyses with an agreement map which identifies areas that are a high priority for intervention across the range of potential priority weights. These are the key landscape locations for the provision of multiple ES.

The program consists of two modules which work independently but which together make up the full process flow. The preprocessing module converts spatial raster and vector data to tabular scenario summaries. The optimisation model uses these, alongside a linear programme algorithm, to generate optimal landscapes (additional information on the strengths and limitations of linear programme algorithms optimisation can be found in Section 3.3.2.1). ROOT utilises a series of input tables which contain pathways to GIS rasters and shapefiles. Within the optimisation, ROOT orchestrates an integrated linear optimisation algorithm that randomly assigns weights to each objective for each model iteration using a multivariate normal distribution, which is then normalised so the weight vectors equal 1. Root requires six main inputs from the user (Beatty *et al.* 2018):

- Impact potential rasters of marginal ecosystem service values: These represent differences in biophysical processes between a baseline and restored landscape scenario. Depending on context, users could consider the theoretical maximum of each potential ecosystem process change (e.g. when all degraded land is restored to native ecosystem), or they may consider incremental ecosystem process changes based on adaptation within a land use class (e.g. the sediment retention potential of agroforestry as a restoration practice).
- Ecosystem servicesheds: Spatial data (polygons) that capture which areas of the landscape are more or less important for providing services to potential beneficiaries of the ES measured. For water-related services, these could be the catchments of identified points of interest.

- Composite factors: Factors which allow the user to specify the combinations of impact potential rasters and servicesheds that connect the biophysical supply and beneficiaries to form the ES interest.
- Activity masks: Rasters which represent areas where the restoration activities could be implemented. These are the areas that ROOT will decide among the optimisations (as aggregated in the spatial decision unit maps).
- Objectives: These allow the user to specify which composite factors to include as objectives in the analysis and whether optimal values should be minimized or maximized. For instance, users would generally maximize a value calculated as sediment retention, but minimise the related value calculated as sediment export.
- Targets: These allow the user to specify constraints that the optimised solutions must meet. For instance, Bonn Challenge commitments for a given area of restoration can be captured as a target, as well as targets for specific services or budgetary limits.

The user defines which spatial decision unit (Spatial Decision Unit) will be, either hexagons or squares. They also define the scale depending on the resolution of data they have inputted.

ROOT provides the user with four outputs:

- A summary table which provides a full-landscape summary with statistics of the solutions created during the optimisation step.
- Individual solution files which give SDU-specific decisions corresponding with the points contained in the summary table.
- An agreement map which provides a visualised summary of the optimisations.
- A weight table showing the weighting values used in each optimisation.

ROOT provides suites of optimised restoration portfolios based on the input of user data, which can define the objectives for ES within the tool.

9.10.7. Tool appraisal

At a glance: Key strengths and limitations

Strengths

- Provides mapped outputs
- Well supported methodology
- Useful for large scale projects

Limitations

- Requires technical skills including GIS and statistical analysis
- High data requirements
- Requires high performing computers

9.10.8. Relevance to sectors

IUCN and The Natural Capital Project have provided a software tool which can optimise trade-offs amongst ES to help decision makers visualise their investments in restoration and where these should be made. The extensive supporting case studies provided by IUCN which have utilised the tool for Brazil, Malawi, Myanmar, Columbia and Costa Rica highlight the tools multi-national application for a range of habitats, landscapes and land uses.

It is important to highlight the scale of the projects which have used ROOT. For example, those mentioned above cover project areas up to 1 million hectares. The scale of these case studies showcase ROOT as a useful tool for large scale restoration efforts. However, when exploring forest restoration, Li *et al.* (2020) used 1.2 km resolutions, and when restoring converted lands in Canda, Currie *et al.* (2023) used 250 m resolutions, suggesting ROOT can be applied to much smaller scale projects if necessary. However, as stated by Beatty *et al.* (2018), the size of decision units is limited to the processing ability of the computer used for the analysis, and therefore often requires much coarser resolutions to be used, limiting the tools use for local planning. Further to this it limits the tools accessibility to institutions which have the computational power such as universities and research centres.

9.10.9. Cost-effectiveness

ROOT is free to use software available on the Natural Capital Project website. Due to technical skills required the resources needed for projects will depend on the user.

9.10.10. Ease of use/usability

ROOT is supported by detailed user guidance including a narrative example, workflow, interface guide and a sample data walkthrough. Guidance on installation and setup is also supplied. There is nothing to suggest the level of skill required by the user, however the availability of scientific literature would suggest this tool is aimed at users with a general competency for GIS, statistical analysis, and general computation. This is expected with the data requirements and depth of outputs.

9.10.11. Data requirements

Running ROOT requires:

- extensive spatial data on ES (e.g. from InVEST),
- projected changes in ES,
- an area of interest or priority for restoration,
- spatial data on whom or what restoration is intended to benefit (ecologically or socially),
- a monetary or geographic constraint within the area of interest, and

For the case study of Espirito Santo, Brazil, data such as sediment yield, water yield, watershed risk and average income by municipality were inputted for Impact Potential Maps and Servicesheds.

9.10.12. Tool adaptability

The tool itself is fairly rigid in terms of modelling customisation; however, user inputted data is highly adaptable and includes the spatial resolution of the data.

9.10.13. Performance and reliability

The software is clearly capable of managing large data sets; however, it is limited by the computational strength of the device/system being used to process the optimisation, which limits both its performance and its reliability. Using the case studies provided by IUCN, it is sensible to suggest that, with appropriate hardware with sufficient processing capacity, ROOT is a well performing decision-support tool which is capable of informing planning decisions on national and subnational scales.

Validation for ROOT is not yet available. At present there are no in-depth reviews for this tool, but it is important to note that validating restoration efforts, particularly forest-based efforts, takes a matter of years. At present, performance and reliability of the outputs of ROOT are uncertain.

Importantly, linear programming is a well-known algorithm for optimisation and is backed extensively by literature. However, linear programming holds one major flaw, which in conservation terms is a noticeable limitation. Linear programming, as the name suggests, requires the inputs and outputs to follow a linear relationship. In real world scenarios concerning environmental variables, most relations are not linear. However, this method of optimisation is well supported for gathering objective decisions. As a precursor for conservation, it is an appropriate tool to suggest and guide efforts.

ROOT has been developed as a decision-support tool using the Restoration Opportunities Assessment Methodology (ROAM). ROAM was developed by IUCN to provide a flexible and affordable framework to countries to rapidly identify and analyse forest landscape restoration. ROAM is a tried and tested approach to forest management and restoration, as is highlighted in an IUCN report of application in Asia (Lie *et al.* 2018).

9.10.14. Examples of use

- Brazil (Beatty *et al.* 2018) – ROOT was used to calculate areas for identifying areas for restoration which would support more water retention and reductions in sediment delivery to steams.

- Malawi (Beatty *et al.* 2018) – ROOT was used to assess actual evapotranspiration, carbon sequestration and sediment retention for priority areas identified by the National Forest Landscape Restoration Assessment.

- China (Li *et al.* 2020) – ROOT was used to assess the effects of different optimal restoration schemes on water purification, soil retention, carbon sequestration, and coastal hazard condition on Hainan Island, China.

- Canada (Currie *et al.* 2023) ROOT was used to provide an optimisation analysis for the restoration potential of converted lands by integrating carbon storage and biodiversity benefits as key considerations.

9.10.15. The Restoration Opportunities Optimization Tool (ROOT) output example

Example output from Currie *et al.* (2023) ‘Prioritizing ecological restoration of converted lands in Canada by spatially integrating organic carbon storage and biodiversity benefits’, *Conservation Science and Practice*, 5(6), e12924.

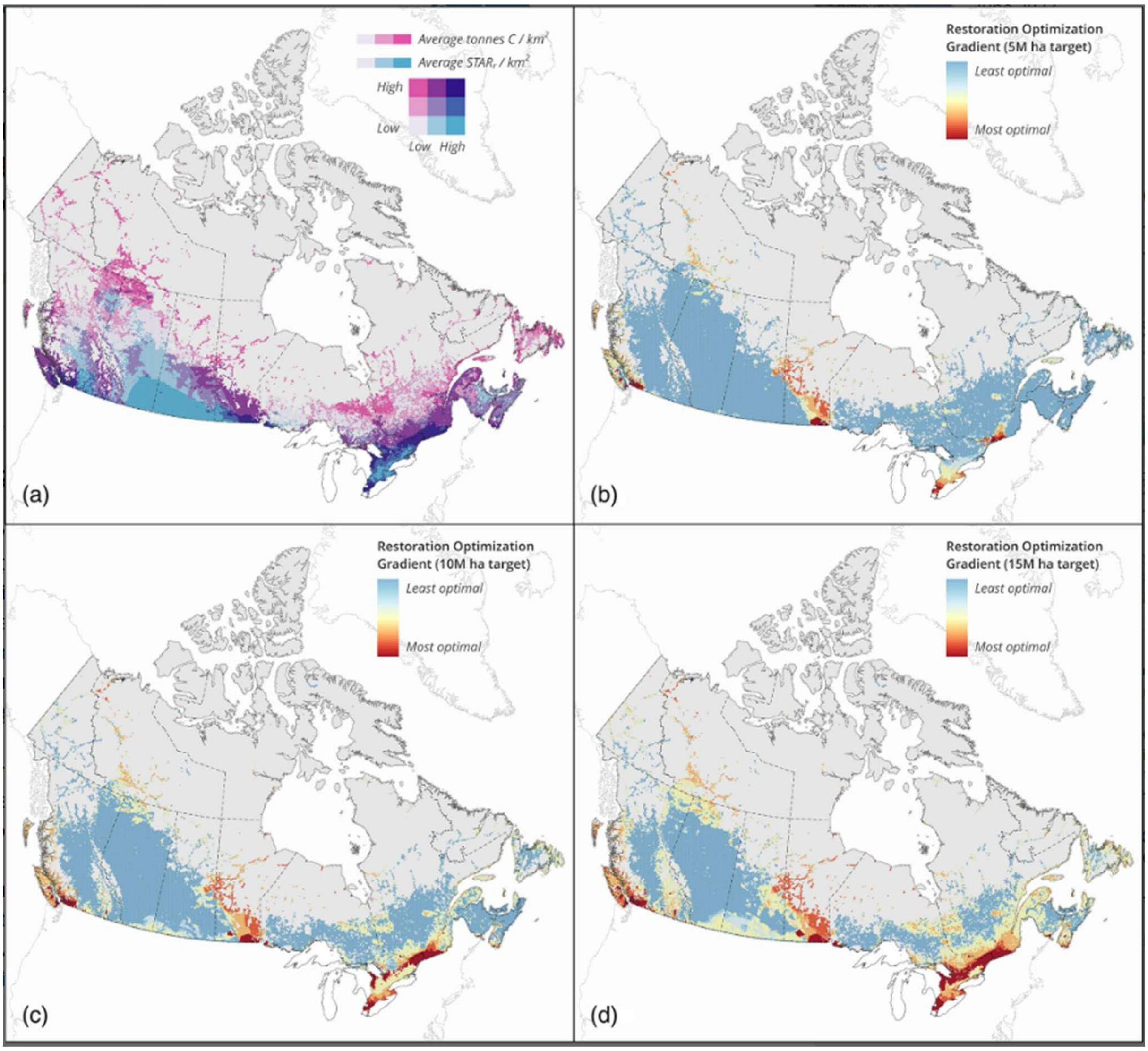


Figure 11. ROOT spatial output depicting spatial prioritisation of converted lands that would benefit from ecological restoration using (a) a simple overlay of carbon and biodiversity benefits. The three remaining maps show a linear optimisation approach using different restoration area objectives. Source: Currie *et al.* (2023) ‘Prioritizing ecological restoration of converted lands in Canada by spatially integrating organic carbon storage and biodiversity benefits’, *Conservation Science and Practice*, 5(6), e12924.

9.11. Land Use Choices Tool (LUCT)

9.11.1. Developer/s

ADAS, RSK@Stirling, led by the Environment Agency, in partnership with Natural England, the Forestry Commission, Forest Research, and Defra Land Use.

9.11.2. Interventions and/or services that the tool is designed to assess

Optimising habitat and woodland creation on agricultural land.

9.11.3. Benefits targeted

Water quality, water resources, flood risk, biodiversity, carbon storage and emissions.

9.11.4. Purpose of tool

LUCT helps decision-makers explore habitat and woodland creation scenarios for agricultural land, evaluating metrics and trade-offs between opportunities, constraints, environmental benefits, and costs. Users can compare personal preferences against optimisation scenarios to identify desirable sites and outcomes.

LUCT generates circa 50 environmental metrics allowing users to compare the different scenarios and reach conclusions about the best locations and habitat or woodland choices. The intention is that through iteration of scenarios using the LUCT, the user understands the relevance of wider data and evidence to inform their decisions about habitat and woodland creation alongside their own local data. The LUCT has been tested across several regions of England including the Solent, Cumbria, the Broads, the Tees catchment and Gloucestershire County.

The tool was developed to support decisions about the practical delivery of habitat and woodland creation, to underpin better outcomes for regulations and schemes that are currently driving land use change in the UK, including:

- Water Environment (Water Framework Directive) Regulations
- Conservation of Habitats and Species Regulations 2017 (as amended)
- Natural England Nutrient Neutrality principles
- Special Protection Areas, Special Areas of Conservation, Ramsar sites – Natura 2000 obligations
- ELMs including landscape recovery and SFI

9.11.5. Audience

The tool has been designed for spatial and environmental planners, farmers, landowners/managers, national and local government bodies and environmental organisations.

9.11.6. Tool details

The key categorisations of the tool for this report are:

- Scoring of land use benefits and costs – allows user inputted data
- Does not generate mapped outputs (but outputs can be mapped by the user)
- The user defines the interventions
- Prioritises/optimises interventions by analytical methods within the tool: cost-benefit analysis
    - Prioritises which ES or benefit to deliver in a location
- Spatial scale: the tool uses a hexagonal pixel framework of 0.41 ha per pixel

The tool is a downloadable program which runs models on inputted csv data with output results in csv format that are GIS ready (can be converted to rasters in GIS software for visualisation). It generates the 'best' uses for land under sets of objectives, preferences and constraints, as cost-benefit scenarios and by total benefit. The tool is held by the Environment Agency and the developers, for use in government projects, it is not currently available for public use.

The LUCT tool national database holds all the datasets required to operate the LUCT for England. However, within the tool the user can provide additional input data. The tool operates from a User Interface where the user must set parameters to specify the question to be asked, for example local policy options and constraints relating to habitat and woodland creation. These user preferences could include outcomes such as carbon storage, nitrate reduction or biodiversity benefit, with constraints such as avoiding BMV land or flood risk infrastructure or COMAH sites.

The tool scores all possible land uses (habitats) at all locations (at each cell) and optimises scores to meet requirements. The spatial framework for cells utilised by LUCT is the hexagonal CROME cell at 0.41 ha. The tool calculates both "scores" and "impact metrics" for each cell, about the costs and benefits of the environmental change predicted for each cell. After scoring, the tool ranks the best habitat or woodland options for each cell to meet the defined objective and the metrics and scores can be used to evaluate trade-offs between different scenario runs and to place the scenario in context. The user analyses the scenario outputs post-hoc and can feed outputs into other models to further quantify/optimise the values. The tool uses a standardised scoring approach based on existing classifications and national datasets and users can directly control key parameters according to project specific constraints.

The LUCT is intended to explore the best locations and evaluate the practical delivery implications of habitat and woodland creation. It is not a process model, and it does not run simulations. The scores for each cell (spatial area) are set under inputted preferences and constraints. It can predict the most desirable land use intervention, and it enables scenario comparisons, supported with metrics where possible such as nutrient reduction and GHG reduction. Users input policy preferences (targets toward specific outcomes such as nitrate reduction) when generating a scenario which are compared against a 'best fit' predicted by the LUCT, based on either maximum benefits or on cost-benefits, for a specified project timeframe).

The tool runs from circa 85 national datasets which can be supplemented by local data from users; this can include their own modelled input layers, site specific data and general datasets. The data used for the tool score calculations are based on the outputs of external simulation models and observation data.

The output scores suggest the best strategic/preferred land uses (habitats) that provide benefits across a wider range of environmental outcomes (or the inputted policy constraints if applicable). Outputs could be run though external tools for simulation modelling. Outputs are GIS ready and can be visualised as maps to assist users in demonstrating land use change benefits to non-technical users, supporting them in decision making.

The LUCT calculates benefits and costs of all possible land use changes at all points across a catchment. It then uses a “scenario engine” to organise and rank the scores, constraints, metrics and costs to answer the user’s scenario question and follows the following protocol:

- Benefits broken down (water quality, flood risk, biodiversity/woodland), or aggregated
- Each possible land use at each cell (~0.4 ha) calculated and stored
- Data is synthesised as best total benefit, and best cost-benefit at a cell
- Decision logic is applied to account for the inputted constraints and policy aims (e.g. best nitrate reduction for given cost)
- Outputs GIS-ready

The LUCT calculates both scores (where no quantifiable metric currently exists) and also metrics to explain the range of environmental impacts from habitat and woodland creation. The environmental metrics in the LUCT are calculated using standardised methods where available, for example the BNG metric uses the published BNG methodology as far as it can based on the datasets in the tool. The scores are calculated using different scoring systems which are specific to each module (water quality, biodiversity, etc) and define the major system parameters and constraints (so national datasets) within which habitat and woodland planting might occur. Scoring systems are formulas that calculate values depending on variables within the environmental system. For example, biodiversity is scored by the cell’s biodiversity habitat potential, productivity/naturalness woodland potential, national and local priorities, resilience to climate change, specific species connectivity and disbenefits from spread of invasive species. The basis for these scores comes from multiple sources but includes Natural England habitat mapping and Forestry England woodland data. The outputs score all the cells across the landscape, so the user can identify the best areas to implement certain habitat types (either as the maximum benefit or cost-benefit). The scoring values are fully explained within developer guidance. Data sources for the scoring values and metrics are provided in developer guidance and were agreed by a steering group of technical specialists across Defra group.

For cost-benefit analysis, costs are calculated for every cell across the landscape and for each type of land use. The user can choose a timeframe for the cost and benefit calculations. Costs are a sum of loss of earnings on existing agricultural use, establishment costs and ongoing maintenance costs. These figures have been amalgamated from multiple sources including the Nix Farm Management Handbook, estimates for environmental stewardship programme, and the Flood and Coastal Erosion Risk Management Research and Development Programme. Values can be updated manually by the user.

9.11.7. Tool appraisal

At a glance: Strengths and limitations

Strengths

- Spatial resolution is fine and suitable for sub-field assessments (0.41 ha)
- Cost-benefit analysis
- Can be run without additional data, but also allows user input data

Limitations

- Does not generate mapped outputs
- Tool only currently available through Environment Agency

9.11.8. Relevance to sectors

The tool is relevant to anyone looking to make decisions regarding land use change, specifically habitat and woodland creation, where these decisions are related to the environmental functions assessed by the tool. LUCT focuses on five key environmental functions: biodiversity, flood risk, water quality, water resources, and carbon storage and emissions. These benefits are highly relevant to the intended audience (farmers, landowners and government bodies) and are potentially very useful for current and future Defra policy.

LUCT has been used in an Environmental Land Management (ELM) case study submitted to Defra, where it demonstrated strong potential for spatial land prioritisation and informed the development of the Landscape Recovery scheme. It has also been applied in a case study exploring a nutrient market trading solution, assessing how long-term land use change could offset nitrate loads from indicative housing development while minimising land take and maximising cost-benefit. More recently, LUCT has been tested in case studies focused on achieving water quality targets in Diffuse Water Pollution Plan (DWPP) catchments in England, and in collaboration with external partners to assess land use change to support nature recovery at a catchment scale.

The tool has a strong focus on agricultural landscapes and could be used in conjunction with ELM targets, nutrient neutrality, carbon markets and other natural capital elements. The outputs and cost-benefit analysis may be able to suggest what interventions could go where for a farmer, and these could be interpreted alongside ELM policy.

9.11.9. Cost-effectiveness

Currently unknown as LUCT is not publicly available.

9.11.10. Ease of use/usability

Currently, the tool is only accessible through the Environment Agency, who run the assessments in house. All assessments are developed in collaboration with partners/clients, and the resulting outputs are mapped and shared. Work is underway to explore expanding access to a wider user base, including trials with user-testers.

9.11.11. Data requirements

National datasets are provided within the tool. Users can also input their own local or project-specific data to enhance or replace the national data. The origins of the datasets are set out by the developers; these are mostly Open Government Licence.

9.11.12. Tool adaptability

The developers have stated that there is scope for increasing the remit of the tool alongside current and upcoming Defra policy. Currently the tool focusses on water quality, water resources, flood risk, biodiversity, greenhouse gas emissions and carbon storage. The tool allows the user to input their own data, replacing national dataset information with more site-specific local information.

9.11.13. Performance and reliability

The tool has been used for and developed alongside government bodies for pilot projects and projects involving policy. It can be assumed that the tool performs well, and the outputs are reliable, but there is currently little in the literature regarding use or reviews of the tool. The default data is from national government and third-party datasets, which can be refreshed and updated.

The tool is relatively new and restricted in terms of availability. There is currently little in the literature regarding use or reviews of the tool. The tool has been developed alongside government bodies and the data sets that are used within the tool are transparent and listed within developer guidance.

Some values and scores are averages, not precise values, but account for heterogeneity within land use types where the underpinning dataset permits. However, users can input their own specific data which could improve accuracy and reliability of the tool depending on the origin of the data.

9.11.14. Examples of use

Use of the tool by Defra can be found within the ‘relevance to sectors’ section above. LUCT has been tested in several case studies and pilot projects within the Defra group and with external partners. However, technical reports and case studies have not yet been published.

9.12. HydroloGIS

9.12.1. Developer/s

Viridian Logic.

9.12.2. Interventions and/or services that the tool is designed to assess

Actions related to NFM and general water flow/quality.

9.12.3. Benefits targeted

HydroloGIS targets a variety of benefits related to water flow services, including but not exclusively, erosion, reduction of soil adsorbing pollutants (e.g. phosphates), reduction of water-soluble pollutants (e.g. nitrates), flood mitigation, groundwater recharge/baseflow control, recreation/access/connection to nature (terrestrial and marine), tranquillity/naturalness and heritage, carbon storage, urban infrastructure, terrestrial biodiversity, marine biodiversity, air quality, noise abatement, pollination, and food production.

9.12.4. Purpose of tool

HydroloGIS seeks to identify, rank and prioritise all potential solutions to water-related problems across urban and/or rural landscapes by splitting ES into two distinct categories: place-based services and water-flow services.

9.12.5. Audience

The tool has been designed for land managers, government bodies, conservation organisations and private organisations.

9.12.6. Tool details

Due to the in-house nature of HydroloGIS, evidence on its methods and performance are limited to the case studies provided by Viridian.

The key categorisations of the tool for this report are:

- Scoring of land use benefits and costs – user inputted data
- Generates mapped outputs
- Identifies potential interventions
- Prioritises/optimises interventions by analytical methods within the tool: trade-offs & synergies
- Spatial scale: 0.5 m^2 to 25 m^2 resolution

HydroloGIS identifies the most effective actions to take in the most efficient locations, as well as ranking all alternative options for how well they will reduce local problems. It calculates the current and future ability of every ‘pixel’ across a region to mitigate problems such as surface flooding, sewer flooding, water quality, erosion, and infrastructure damage. It does this at 0.5 m to 25 m resolution, depending on the area being modelled. It also looks to maximise the delivery of multiple benefits and its numerical basis aids the quantification of service delivery. Benefits can be calculated in statistical, physical, or financial terms.

The model ranks each pixel of the landscape for its current and future ability to solve erosion, reduction of soil adsorbing pollutants (e.g. phosphates), reduction of water-soluble pollutants (e.g. nitrates), flood mitigation, and groundwater recharge/baseflow control. Areas with highest potential to provide services (high opportunity) are often not the same as those areas where interventions will make the most difference (high impact). This is something Viridian understands and incorporates into the solution design.

HydroloGIS then calculates comparative provision scores for other, place-based ES. It uses a combination of datasets, rules and algorithms to identify where creating new habitats will lead to the greatest improvements to these services. They are:

- recreation/access/connection to nature (terrestrial and marine)
- tranquillity/naturalness and heritage

- carbon storage
- urban infrastructure
- terrestrial biodiversity
- marine biodiversity
- air quality
- noise abatement
- pollination
- food production (farming)

Finally, the water-flow and location-specific services are combined as layers within the GIS display, showing synergies and trade-offs. With local consultation as to priorities, maps can be produced to show best overall solutions and valuations from local to national scale.

9.12.7. Tool appraisal

At a glance: Key strengths and limitations

Strengths

- Specialisation for NFM and water flow/quality projects
- Does not require technical skills
- Broad application regarding strength and benefits

Limitations

- Lack of publicly available data/guidance
- Reliability and validation information is unavailable
- Requires a fee

9.12.8. Relevance to sectors

There is no maximum or minimum scale therefore most people requiring such software will have the opportunity to request the use of HydroloGIS.

9.12.9. Cost-effectiveness

HydroloGIS is an in-house software package used by Viridian. People requiring the use of the software pay a fee of £10/km^2 for Viridian consultants to carry out the task.

9.12.10. Ease of use/usability

An in-house software package used by Viridian, usability is unclear and assumed that customers pay for services to be completed with support from Viridian.

9.12.11. Data requirements

Full details of the data requirements for HydroloGIS are unavailable, due to the in-house nature of the tool. However, drawing from case studies, it is apparent that, at times, Viridian will use open-source data such as rainfall, land use and geology. In the case of the “Twite in the Wessenden Valley” case study, Viridian used local NGO data on twite locations and habitats.

9.12.12. Tool adaptability

Adaptability for HydroloGIS is unclear due to the in-house nature of the tool.

9.12.13. Performance and reliability

Due to the in-house nature of HydroloGIS, evidence on its performance and reliability is also limited to the case studies provided by Viridian. Also, at times it is difficult to know whether case studies are referring to HydroloGIS, or the wider Viridian modelling suite and software which came before HydroloGIS. Viridian, however, have provided some insight into the models which they have developed upon. They state that HydroloGIS is underpinned by scientific research which was collated by the Natural Capital Project and the University of Leeds.

At the core of Viridian models is the ‘Resource Investment Optimisation System’ (RIOS). RIOS was created to account for biophysical, social, and economic data when designing cost-effective investments in watershed services in Latin America. Viridian transposes and extends the functionality of RIOS to the UK setting. The key limitations highlighted by Viridian is that their models do not necessarily identify problems. For example, if a landscape is healthy, HydroloGIS will still produce recommendations based on the determining rankings. However, by adopting a ranking methodology, HydroloGIS is resistant to the impacts of systematic biases that may exist in a data source.

9.12.14. Examples of use

HydroloGIS was used to model the most efficient and effective solutions for tackling flooding, diffuse nitrate and phosphate pollution, soil erosion, water capture and storage, recreational provision, and carbon sequestration for the Stour catchment in southern England, and the Authie catchment in northern France.

No publicly accessible output examples were available to include in the report.

9.13. Ciriabest – CIRIA’s Benefits Estimation Tool (previously B£ST)

9.13.1. Developer(s)

CIRIA (Construction Industry Research and Information Association).

9.13.2. Interventions and/or services that the tool is designed to assess

Blue-green infrastructure, sustainable drainage and natural flood management.

9.13.3. Benefits targeted

Amenity, Asset Performance, Biodiversity and Ecology, Building Temperature, Carbon Reduction and Sequestration, Crime, Economic Growth, Education, Enabling Development, Flooding, Health, Noise, Recreation, Tourism, Traffic Calming, Water Quality, Water Quantity.

9.13.4. Purpose of tool

The tool has been developed to support practitioners to estimate the benefits of BGI, including SUDS and NFM. It aims to support investment decisions and can help to identify stakeholders and potential funding routes.

9.13.5. Audience

The tool is aimed at the planning and development, environment, and public sectors, including water and sewerage companies, local authorities, environmental regulators, flood risk managers, developers, communities, environmental bodies, urban designers, engineers and land use managers.

9.13.6. Tool details

Ciriabest is a new tool with relatively limited information available online. It also has costs associated with accessing the tool and instructions.

The key categorisations of the tool for this report are:

- Scoring of land use benefits and costs – allows user inputted data
- Does not generate mapped outputs
- The user defines the interventions
- Prioritises/optimises interventions by allowing post-hoc exploration of tabulated scoring value results by the user. Information on whether this can be assessed within the tool is unavailable
- Spatial scale: limited information from developers

Ciriabest is the most recent iteration of CIRIAs Benefits Estimation Tool. It was released in 2023 and information from developers was not provided for the report. The original versions of this tool were formatted in an Excel spreadsheet. Ciriabest has been updated to feature an online spatial tool which guides the user through benefits estimations with visual representations. Variations of the tool have been under development since 2012. It was first produced and released as a spreadsheet tool ('BeST') in 2015 and was updated in 2019 ('B£ST'). For the current version of Ciriabest, a beta version was released in 2021 with five benefits, and its final licenced product released in 2023.

The main elements of the tool are valuations of the benefits of BGI and NFM interventions and the ability to run comparisons of more than one assessment. It relies on user inputted data to run the benefits calculations. The user inputs the type, size, and scale of blue-green infrastructure to be built and the temporal and spatial scale of the assessment. The tool identifies the likely benefits according to the 19 categories (see ‘benefits targeted’), and an indication of their potential significance.

The tool then evaluates the benefits of the BGI interventions, and non-monetised benefits such as crime are recorded. User specific details can be added into the tool. The results are summarised and presented, with a sensitivity analysis also undertaken (details are not publicly provided by the developer but likely relates to confidence in outputs). Calculations on economic efficiency of the overall project/scenario take into consideration user inputted costs to calculate the Net Present Value and Benefit Cost Ratio.

Information on the analytical methodology for this tool is unavailable.

9.13.7. Tool appraisal

At a glance: Key strengths and limitations

Strengths

- Specialisation for NFM and BGI projects
- Cost-benefit analysis
- User inputted data

Limitations

- Lack of publicly available data/guidance
- Reliability and validation information is unavailable
- Requires a fee

Ciriabest was released in 2023, and therefore there is limited information on its functionality or case studies describing its application. A full tool appraisal was not possible.

Anecdotal evidence from the Ciriabest website suggests that it is being used in the industry, with the Welsh Government commenting on its ability to give an objective and clear cost for delivery. The tool is being used to support the 25-year blue-green plan for Hull and Haltemprice to help move water through the city and slow the flow of water and also understand the potential financial benefits to be gained.

9.13.8. Cost-effectiveness

The tool costs £600 + VAT to individual users, and £2500 + VAT to multiple user licenses which can be used by up to 10 employees simultaneously.

9.13.9. Examples of use

Examples of Ciriabest’s predecessor, B£ST, are available on Ciria’s website. Limited examples are available for the use of the current Ciriabest tool.

No publicly accessible output examples were available to include in the report.

10. Appendix 2: Other tools considered in the rapid evidence review

Full list of other tools considered for the report.

Tool names			
Dynamic Landscape Typology Tool	The Cool Farm Tool	LIS Agri-environment and Forestry (Scotland)	CRAFTY-GB (Competition for Resources between Agent Functional Types)
ASSET (part of the ASSIST programme)	Farmscoper V5	Floodmap	Managing Ecosystem Services Evidence Review
MAGIC Map	Forester GIS	Historic Land use Assessment Map (Scotland)	Green infrastructure Valuation toolkit
Zonation	Historic Environment Farm Environment Record Portal	Sitelink	NaturEtrade
ERAMMP	Land Management System	DataMapWales (formerly Lle - Map browser)	The Local Ecological Footprinting Tool (LEFT)
NFMStudio	LandPKS (Land Potential Knowledge System)	Woodland Wildlife Toolkit	Soil and Water Assessment Tool (SWAT)
Condatis	Optimised Inputs	myForest Woodland manager; myForest deer manager	SENCE (Spatial Evidence for Natural Capital Evaluation)
The Land App	SCIMAP	The Integrated Ecological Network Tool	TESSA: A toolkit for rapid assessment of ecosystem services at sites of biodiversity conservation importance
Agricultural Land Environmental Risk Tool (ALERT)	Soilscapes	Greater Manchester Ecosystem Service Opportunity Mapping	AgLand
Agrimetrics Tool	UKSO	Countryside Stewardship Targeting	ReThink Carbon
i-Tree Eco	ORVal (Outdoor Recreation Valuation Tool)	BioCap Opportunity Mapping	-