Landscape Decisions:
Towards a new framework
for using land assets

VALUING NATURE PROGRAMME

Review and Comparison of Models used for Land Allocation and Nature Valuation

Final Report on Phase 1
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Contents

Summary

This report reviews existing land allocation models (here after described as Ecosystem Service Tools) in the published scientific literature, and their capability to meet requirements of key stakeholders. This work builds upon Dr Amy Binner's work on core user's needs across the DEFRA group around spatial decision support tools (2016) and other previous reviews on natural capital tools including the review by DEFRA, Bagstad *et al*. (2013), ADAS report to Committee of Climate Change (2016), Sharps *et al*. (2017), and the NatCap Tools Workshop Report (2018). The tools included in this study are those mostly shortlisted in previous studies and those that focus on multiple ecosystem services. In the first stage, nine ecosystem service tools (ES tools) were reviewed, including InVEST, LUCI, ARIES, TIM/NEVO, Co$ting Nature, EcoServ-GIS, NCPT, Eco-metric approach and The Land Choices Guide. Feedback from stakeholder group members and steering group members showed water quantity and quality, open data, supporting guidance to analyse and interpret output, linking climate change to ES, multiple ecosystem services, opportunity mapping and outdoor recreation, as the most important user needs. All the above-mentioned ES tools were assessed for all the previously identified user's needs (Binner, 2016) and are summarised in the report.

A few of the above-listed ES tools were selected for road-testing with real-world case studies, which will follow as Phase 2 of this research. The aim in this study was to compare ES tools of differing complexity and to assess their ability to be applied across multiple scales (e.g. site to region to national level). For implementation during the second stage of this research, 6 tools/approaches for in-depth review and road-testing were selected, i.e. InVEST, LUCI, NEVO, Natural Capital Planning Tool, the Eco-metric approach and The Land Choices Guide. If time and resources are available, other widely-used tools could be included in the second phase. Strengths and weaknesses of these ES tools, data requirements, approaches, and outputs are summarised in this report. A few of the shortlisted ES tools are still under development or at piloting stage, so details for these tools are still not available for this report. However, the intention was to include as much information available in the public domain. Case studies were identified through consultation with Stakeholders and Steering Group members. The identification of ES tools, as well as, case studies reported here, provides the background for Phase 2 of the work. Phase 2 will deliver a model inter-comparison study for selected metrics using case studies identified in this study and above listed six ES tools and approaches.

Introduction

Nature and the natural environment have provided humans with basic needs for living including food, water, materials for shelter as well as a liveable climate, but nature has been exploited to an extent that the provision of these needs are not sustainable in the longer term, and there are often choices to be made. In recent decades, such benefits from nature have been identified and defined as "Ecosystem Services" (MEA, 2005) and there is a growing body of work to estimate or map such ecosystem services and value them. The Millennium Ecosystem Assessment, 2005, categorised these services into 4 categories i.e. provisioning, regulating, cultural and supporting ecosystem services. Provisioning services include products obtained from ecosystem such as food, fibre, fuel, genetic resources, biochemical, ornamental resources, and fresh water. Regulating services are the benefits obtained from the regulation of the ecosystem process including air quality, equable climate, water purification, regulation of disease and pests, pollination and natural hazard regulation. Cultural services are non-material services people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences. Supporting services are those that are necessary for the production of all other ecosystem services including soil formation, photosynthesis, primary production, and nutrient and water cycling. Subsequent ecosystem service assessments have modified these categories and have even used different terminology (e.g. "Nature's Contributions to People" [NCPs}; IPBES, 2018), but the fundamental concept, and the services considered, remains very similar to those conceptualised in the Millennium Ecosystem Assessment in 2005 (Diaz *et al*., 2018).

Anthropogenic impact on natural ecosystems not only modifies their structure but their processes and functions. In addition to anthropogenic impact, changing climate has a significant impact on these ecosystems and the natural capital underpinning them. A number of tools have been developed to assess natural capital and include innovative models that simultaneously examine several components of natural capital and the benefits they deliver. These models incorporate human behaviour and biophysical models based in environmental science, models that include the dynamics of transition, and models that give snap shots of potential future scenarios. Existing tools and models to assess natural capital and their flow i.e. defined as ecosystem service tools (ES tools from here onwards) range from simple excel based tools, to complex detailed biophysical models with GIS mapping-based toolkits using simpler biophysical models, or empirical models providing an intermediate option.

With the availability of a range of tools to assess natural capital, and the status and flow of services, selecting which tool to use for decision making is problematic. The choice of tool depends on the spatial scale at which the decision is being taken and what decision is to be made, i.e. a better understanding of the key question is often required. Since 2012, the review of these ecosystem service tools, and road testing of the tools on specific case studies has been conducted (Smart *et al*., 2012; Bagstad *et al*., 2013; Elliott *et al*., 2016; Sharps *et al*., 2017 and NatCap tool workshop, 2018). In 2016, Dr Amy Binner of the University of Exeter prepared a summary (Amy Binner 2016 – placement title: from valuing nature to policies & decision making: co-developing and implementing a 25-year planning tool for the natural environment) of core user needs across the DEFRA group around spatial decision support tools resulting from a NERC Valuing Nature funded project. This work builds upon Dr Binner's work and other previous reviews on natural capital tools including the review by DEFRA, Bagstad *et al*. (2013), ADAS Report to Committee of Climate Change (2016), Sharp *et al*. (2017) and the NatCap Tools Workshop Report (2018).

Scope of the Study

1. To bring together in one place a synthesis of what is available in terms of ecosystem service tools, and to produce a user-friendly guide of their strengths and weaknesses.

2. To select a range of ecosystem service tools and understand the assumptions behind the selected tools.

3. To assess the shortlisted tools to understand the compatibility of these tools with identified user needs from the review of Amy Binner.

4. To scope Phase 2 of the project:

    a. Suggest which ecosystem service tools could be tested in real case studies;

    b. Suggest potential datasets and case studies that could be used to test these tools;

    c. Gauge interest from modelling / data teams, and estimate costs for participating in a model data comparison exercise; and

    d. Scope an outline for the model inter-comparison, modelling protocol, suggested metrics for comparison and proposed analysis of outcomes, and propose a time-scale for Phase 2.

Review of Ecosystem Service Tools Based on User Needs

Ecosystem service tools (ES tools) can range from simple models requiring few technical skills, data input and analysis time to more complex and detailed biophysical and economic models that require advanced technical skills, intense data input requirements and longer analysis times. The underlying approaches to calculate multiple ecosystem services vary greatly from tool to tool i.e. some tools are based on simple empirical regression equations or use look up tables, and some tools are more process-based. Econometric or spatio-econometric models (e.g. Bateman *et al*, 2014; Britz *et al*., 2014; Holman *et al*., 2016) focus predominantly on economic drivers, often predicting changes in demand for a mix of products (for example as a result of increasing population or GDP), which then drive changes in land-use as required to meet that demand, and these models are often based on the principle of profit-maximisation (Elliott *et al*., 2016). Land use change and land cover change decisions are often influenced by individual land user decisions, and to simulate such effects Agent Based Models (ABMs) are used. ABMs use bottom-up approaches that provide a way of both conceptualizing and implementing complex, dynamic, and disaggregated models of human decision-making (Le *et al*., 2010; Valbuena *et al*., 2010). While national-level decision making is vital for directing overall and longer-term strategy, most practical environmental management decisions are made at a more local scale. The ES tools that are spatially explicit i.e. that can be used at both local and regional or national levels are often preferred by users (Binner *et al*., 2016).

Many ES tools already exist and have been in use for a number of years. However, feedback from stakeholders suggest the uptake of these tools has been limited because of lack of transparency for users, often described as being a "black box". Further, stakeholder feedback from Natural England during this project highlights the lack of clear information on the strengths and weaknesses of these models or their underpinning modules as a key issue.

Tools included in this review are mostly those tools short listed in previous reviews i.e. the Defra report on "Natural Capital & Ecosystem Service modelling" (Smart *et al*., 2016), the ADAS report to Committee of Climate Change (Elliot *et al*., 2016), Comparing strengths and weaknesses of three ecosystem services modelling tools in a diverse UK river catchment by Sharps *et al*. (2017) and the NatCap Tools workshop report (Porter *et al*., 2018). Additionally, we included the "Land Choices Guide" and "Eco-metric Approach" (see below) as these were identified as important current and future approaches used by our stakeholders. Feedback from stakeholders and steering group members also suggested using other tools or models i.e. iTREE, ORVAL, Bespoke GIS maps and hydrological models offered by Valuing Nature Network (VNN) partners (e.g. Viridian, RSPB/WCMC TESSA, Natural Capital Solutions methodology). Because of time limitations, and these suggestions coming at the end of the project, the detailed review of the above approaches and tools are not included in this study but are noted for future investigation.

The aim of the review was to understand the compatibility of these models with user needs as identified in the previous study by Dr Binner, and additional user needs identified by stakeholders and VNN partners during this study. The models considered in this study are: InVEST, LUCI, ARIES, NEVO, Co$ting Nature, EcoServ-GIS, the Natural Capital Planning Tool (NCPT), the Eco-metric Approach and the National Trust's Land Choices Guide. Table 1 provides details of the models considered, with some basic information about each. Table 2 shows the ecosystem services included in the shortlisted models.

Table 1. Details of the Ecosystem Services Tools shortlisted for Phase 1 of the study

	Authors/Host organisation	Year of publication	Update	Version	Description	Model approach (Empirical/Process based)	Open source	Easy data sourcing
InVEST	Stanford University		Update every 3 months	Initially Integrated with GIS , now Standalone version	InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) is a suite of models used to map and value the goods and services from nature that sustain and fulfil human life.	Both (some modules process based/ some empirical)	Yes	Yes, User guide provides information on data sources, also provides potential parameter value for each module. It has functionality to input primary data for some parts.
LUCI	Bethanna Jackson, Victoria University of Wellington, New Zealand	Not yet released for general use, however there have been limited case studies with support from developers	Ongoing development	ARIES explorer yet to be released	LUCI is a framework and associated computer model that uses information about topography, land cover, and soil to produce maps of ecosystem services and trade-offs. LUCI is a spatially explicit decision support tool.	Empirical (mostly Tier 1 approach, i.e. assuming simple relationships between variables)	Not yet released for general use, however it has been used in UK	Yes, needs only three things to run: a digital elevation model (DEM) to represent landscape topography, a land cover shapefile to represent different types of vegetation and management, and a soil shapefile to represent different types of soil.
ARIES	University of Vermont, Earth Economics, Conservation International	2007, published for general use 2012	Ongoing development		ARIES incorporates advances in ecoinformatics that allow model structures to vary ‘‘intelligently’’ based on the contexts in which they are run. This is accomplished through a technique called semantic meta-modelling (https://en.wikipedia.org/wiki/Metamodeling).	Integrated modelling includes spatial data, empirical, process based, agent-based models	Yes, for non-profit purposes	Yes, ARIES runs on one of the most sophisticated modelling platforms in existence, which allows modellers to benefit from a full suite of existing, reusable model and data components accessible through open-source modelling tools and paradigms.

Table 1 (continued)

	Authors/Host organisation	Year of publication	Update	Version	Description	Model type (Empirical/Process based)	Open source	Easy data sourcing
Natural Environment Valuation Online tool (NEVO)	University of Exeter with support from DEFRA		Development ongoing		The new NEVO tool is a map-based decision support tool to inform decisions that affect the natural environment of England and Wales. It makes use of state-of-the-art environmental and economic models developed by the University of Exeter in a user-friendly interface.	Integrated		Yes, for England and Wales
Co$ting Nature	King's college London, AmbioTEK, UNEP-WCMC		Regular update	Version 3	Costing Nature is a sophisticated, data-based phenomenological model for ecosystem services, not a fully parameterised, physically-based model. Costing Nature starts by mapping 13 ecosystem services and then combines them with analysis of current pressure, future threats, biodiversity and delphic conservation priority to produce an assessment of priority areas for conservation and careful (sustainable) management on the basis of all of these factors.	Web-enabled model with Globally available data using simple empirical models	Not free for commercial use, free for non-commercial use	Yes, can use global as well as local data
EcoServ-GIS	Durham Wildlife Trust and Scottish Wildlife trust	Winn, J.P., Bellamy, C. C., and Fisher, T, 2015	Regularly updated	Version 3.3	EcoServ-GIS is based on a service-based approach, but in comparison to InVEST it uses more simplified and generalised models of the relationships between landscape variables and services.	EcoServ-GIS overlays spatial datasets describing aspects of the landscape, such as habitat type, grey infrastructure and socio-economic factors, in order to estimate the likelihood of ecosystem service provision. The toolkit is based on the Ordnance Survey (OS) MasterMap layer. A service-based approach was used to develop EcoServ-GIS models.	Works for Mainland Britain	No

Table 1 (Continued)

	Authors/Host organisation	Year of publication	Update	Version	Description	Model type (Empirical/Process based)	Open source	Easy data sourcing
Natural Capital Planning Tool (Simple excel tool)	Consultancy for Environmental Economics & Policy (CEEP), Birmingham City Council and the UK Business Council for Sustainable Development (UK BCSD)	2014-2015	Next update planned	V1.3.3	NCPT has been specially designed for the planning and development context, can play an important role in delivering Govt's 25-year Environmental plan.	Calculates ES impact scores (ESIS) through selecting for each ES a set of feasible indicators i.e. per ha biodiversity value for each land use type. ESIS values were decided by forming different task force which composed of experts from academic, government institutes, practitioners, local authorities and businesses.	Yes	Yes
Eco-metric approach		2019			The eco-metric works alongside the Defra biodiversity metric, mirroring the approach by applying a matrix of scores for different habitats and ecosystem services, which are modified by multipliers reflecting habitat condition, spatial location, delivery risk, and the time taken for new habitats to reach maturity.	Calculates ES service scores based on the type of habitat by accessing condition taking into account spatial factors, time lag and delivery risk. Calculates ES score for each ES and land parcel.		
The Land Choices Guide	Patrick Begg, Rural Enterprises, Director, National Trust	2015			The Land choices process helps to think through options for best use of land which is done through information gathering on current maps and plans, assessment on how the land in question performs against 6 land functions in the current situation and visions and aspirations for the land, reality check through survey of the land and produce vulnerability and land cover map and final step is to set out recommendations including land function assessment and an annotated change map. The decision is visual and expert opinion based.	The elements of the process are Information, Vision, Reality and Options. First step is to prepare a statement of significances depending on all the features on existing land, access their land functions, decide which areas are to be maintained and which areas to upgrade, prepare an action plan field by field. It is a process rather than a mathematical model. Currently no models are being and it is a high priority to include carbon component.	Yes	Done manually, also land walking

Table 2a: Review of the list of regulating ecosystem services included in the selected ES tools. The Eco-metric approach is not included here as the final version is yet to be released.

	Air Quality	Water quality: nutrient retention	Soil health	Climate regulation	Carbon storage and sequestration	Biodiversity	Habitat provision	Pollination	Flood regulation	Sediment retention	Protection from coastal erosion	Protection from coastal inundation
InVEST		√			√	√		√		√	√	√
LUCI		√			√		√		√	√		
ARIES		√			√			√	√	√		√
NEVO		√			√	√						
Co$ting Nature					√			√	√		√	√
EcoServ-GIS	√	√		√	√			√				
NCPT	√	√	√	√		√			√			
The Land Choices Guide			√			√	√		√			

Table 2b: Review of the list of provisioning and cultural ecosystem services included in the selected ES tools.

	Agriculture production	Hydropower production	Timber provision	Fuel wood provision	Water quantity/supply	Food from fisheries	Food from aquaculture	Wave energy generation	Aesthetic value	Cultural value	Educational value	Outdoor Recreation value	Open space proximity	Green travel	Wildlife service/dis-service
InVEST		√	√			√	√	√	√			√			
LUCI	√														
ARIES					√	√			√			√	√		
NEVO	√		√		√							√			
Co$ting Nature			√	√	√	√			√			√			√
EcoServ-GIS											√		√	√	
NCPT	√		√	√					√			√			
The Land Choices Guide	√		√	√	√				√	√			√		√

Provisioning services | Regulating services | Cultural services | Other services

Selected User Needs and Compatibility of the Shortlisted ES tools

Stakeholders and steering committee members were asked to select 3 priority user needs from a list of already identified user needs from (Binner *et al*., 2016). Figure 1 shows the user needs and their frequency of selection as priority user needs. The priority user needs arising from this exercise were:

- water quality and quantity,
- open data,
- support guidance to analyse and interpret the output,
- linking of climate change to ES,
- multiple ecosystem services/trade-offs,
- opportunity mapping,
- outdoor recreation and,
- economic evaluations

An MSc study (Hibbert, 2017) that CaBA (Catchment Based Approach) catchment partnership groups asked about different aspect of the tools that encourage or discourage the use of the tool. Characteristics promoting uptake of the tools were found to be:

- quick to run and return results,
- open access or free,
- compares different scenarios,
- requires basic skills and
- is excel based

Factors discouraging use were:

- the need for an external consultant, and
- requirement of input data from external sources

If a tool is designed to be used by practitioners, careful consideration is required on how easy it is to collect and source input data. Practitioners are less likely to have access to data, or to have time and resources to collate primary data, so a tool with pre-loaded (default) data is favoured. Tools such as InVEST, ARIES, and Co$ting Nature have preloaded default input data. Detailed guidance on interpretation of the outcome is also essential when the tools are aimed at practitioners (Feedback from Environment Agency).

Table 3 summarises the capability of short-listed models for different user needs. When comparing between models for a specific ES, it is important to look at the relative breadth of scope between the models i.e. ARIES has a wide suite of water-related regulatory services compared to EcoServ-GIS, however both the models are scored as "yes" for the water quality and quantity user need (Feedback from Environment Agency).

It is important to establish users and uses of a model from the start, since models will be suitable for different users and uses. The models that can be used to support strategic planning for a place or region might need low resolution spatial data for a region, but for local intervention planning, where evidence and information is required at local scale, high resolution data is necessary. It is also important to establish the questions and expected outcomes to be achieved by using each tool. What is the primary aim of use of the tool? i.e., is it to influence others to support a project, to examine a range of options or scenarios, to shape a project to enhance ES provision, or to engage with the public or business? These tools should always be used as an additional support to local expertise and knowledge and should never replace them (Feedback from Environment agency), for example The

Land Choices Guide used by the National Trust relies heavily on local expertise and is used in conjunction with field survey, mapping, preparing a statement of significance, site visits, visualising any upgrade, and realising the benefits on six land functions. A decision support tool would not replace this process, but rather supplement these sources of evidence to promote better evidence-based decision making.

Feedback from Environment Agency (EA) also suggests alignment of the ES tools with goals of the 25-year Environment Plan as one of the desirable user-needs as they will be asking developers to deliver positively against the goals of the 25-year Environment Plan (see below for further details on this discussion).

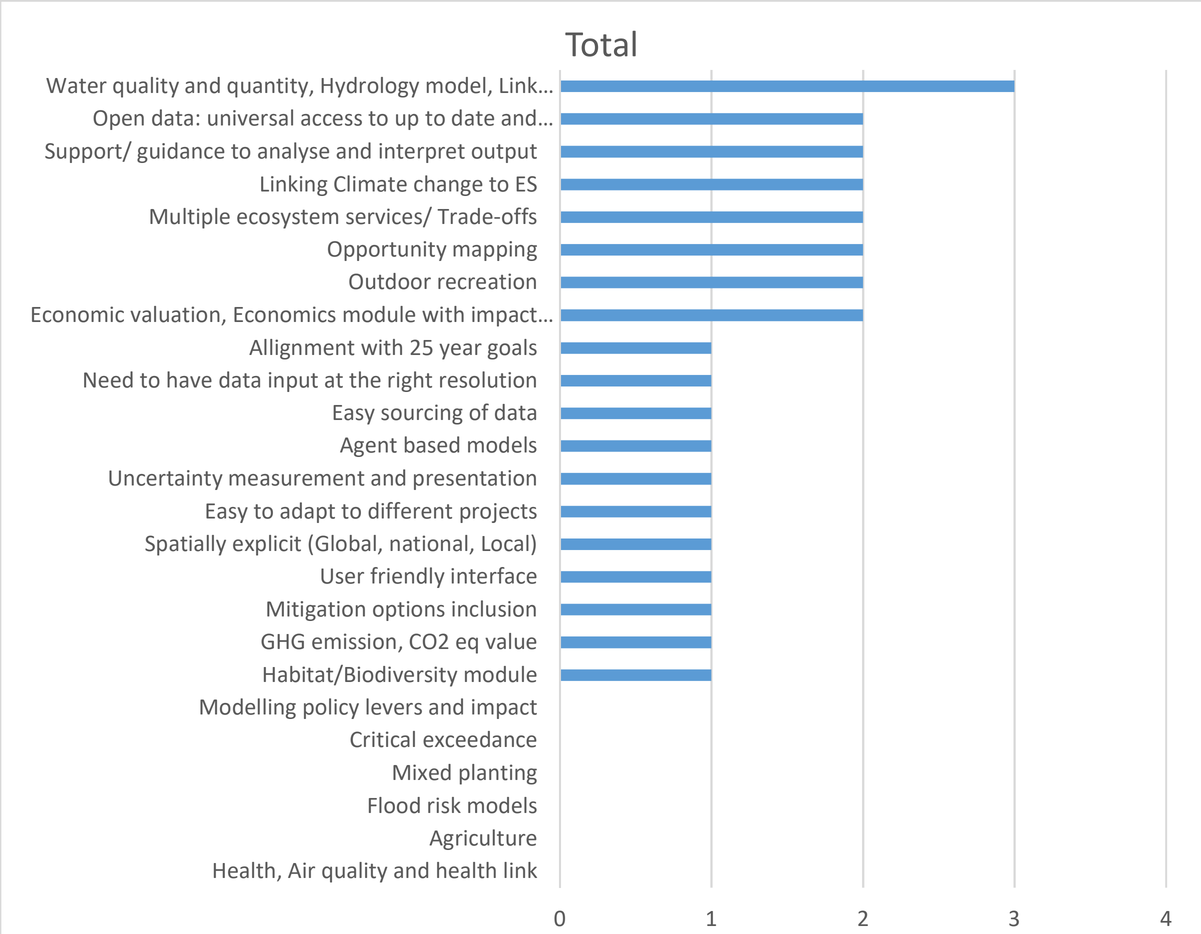

Figure 1: Frequency distribution graph of Stakeholder and Steering Group members to question "Could you please rank (in your opinion) the three most important user needs from the list? Please add any other user needs that may not have been included in the list below"

Table 3: Review of Selected Ecosystem Service Tools against Identified User Needs

ES Tools	Economic valuation, Economics module with impact on stock, discounting	Habitat/Biodiversity module	Health, Air quality and health link	Agriculture	Water quality and quantity, Hydrology model, Link of terrestrial system to hydrology	Flood risk models	Mixed planting	GHG emission, CO_2 eq value	Outdoor recreation
InVEST	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes (CO_2)	Yes
LUCI	No	Yes	No	Yes	Yes	Yes	-	Yes (CO_2)	-
ARIES	No	No	No	Yes	Yes	Yes	-	Yes (CO_2)	Yes
TIM/NEVO	Yes	Yes	No	Yes	Yes	-	Yes	Yes (CO_2, CH_4, N_2O)	Yes
Co$ting Nature	Yes	Yes	No	?	Yes	Yes		No	Yes
EcoServ-GIS	No	Yes	Yes	No	Yes	No		No	Yes
Natural Capital Planning Tool	No	Biodiversity not habitat	Yes	Yes	Yes	Yes	Yes	No	Yes
The Land Choices Guide	Yes - in some cases	Yes	Yes	Yes	Yes	Not model but in simple way by looking onto maps		No	Yes

Table 3 (Continued)

ES tools	Opportunity mapping	Critical exceedance	Mitigation options inclusion	Modelling policy levers and impact	Multiple ecosystem services/ Trade-offs	User friendly interface	Support/ guidance to analyse and interpret output	Spatially explicit (Global, national, Local)	Easy to adapt to different projects	Uncertainty measurement and presentation	Agent based models
InVEST	-	-	Yes (scenarios)	Yes (REED policy)	Yes	Yes	Yes	National, Global	-	Yes	-
LUCI	Yes	-	-	-	Yes	-	-	Local, National	-	-	-
ARIES	Yes	-		-	Yes	Yes		Local, National	Yes	Yes	Yes
TIM/NEVO	-	Yes		Yes	Yes	-	-	Catchment, National	-	-	Yes
Co$ting Nature	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
EcoServ-GIS	Yes	Yes	Yes		Yes	No		Local/regional	Yes		No
Natural Capital Planning Tool	No			No	Yes	Simple Excel tool	Yes	Local	Yes		
The land Choices Guide	Yes		Yes - with simple recommendation	No	Yes	using maps, current land function assessment, reality check and recommendation through a report	Yes	Local, field or whole property	Yes	No	No

Alignment of ES tools with the UK Government's 25-year Environment Plan

The following suggestions arise from feedback from the Environment Agency. The UK Government's 25-year Environment Plan outlines steps to achieve its ambition to leave our environment in a better state than we found it. The plan sets out actions to help the natural world regain and retain good health. The goals of the 25-year plan are:

1. Clean air
2. Clean and plentiful water
3. Thriving plants and wildlife
4. A reduced risk of harm from environmental hazards such as flooding and drought
5. Using resources from nature more sustainably and efficiently
6. Enhanced beauty, heritage and engagement with the natural environment
7. Mitigating and adapting to climate change
8. Minimising waste
9. Managing exposure to chemicals
10. Enhancing biosecurity

And to achieve the above goals, the government plans to take action on a number of fronts, looking to join up policies in a way that maximises benefits and value for money. Six key areas have been identified around which action will be focused:

I. Using and managing land sustainably
II. Recovering nature and enhancing the beauty of landscapes
III. Connecting people with the environment to improve health and wellbeing
IV. Increasing resource efficiency, and reducing pollution and waste
V. Securing clean, productive and biologically diverse seas and oceans
VI. Protecting and improving the global environment

Alignment of the ES tools with the above-mentioned goals of the 25-year Environment Plan would, therefore, be one of the desirable user needs. The Environment Land Management Scheme will soon be requiring landowners to deliver public goods for public money (Feedback from Eftec and Environment Agency). These public goods are directly aligned to the goals of the 25-year plan. The net gain approach to sustainable development will also be aligned with 25-year plan goals, and the Environment Agency will be asking developers to deliver positively against these goals.

A key question when considering the utility of ES tools is, if they are able to map opportunities to achieve these goals? Could such models use a methodology that looked at the goals first and worked backwards through the benefits that can be achieved and then back where those benefits are or could be provided? I.e. rather than start with what trees can do, start with clean air and look at which benefits could be delivered, then look at how our assets deliver each of the benefits (Feedback from Environment Agency). Natural Capital Planning Tool, Eco-metric approach and NEVO tools are being purpose built to support the 25-year plan for the environment.

Selection of ES tools for Road-testing

In this study, the review of the tools is being conducted in two Phases. In Phase 1, reported here, the tools that were short listed in previous studies, and two 2 additional approaches, were reviewed to understand their approach, accessibility, spatial scale at which they operate and were assessed for all the listed user needs. In Phase 2 of this work, some of these tools will be tested against different case studies for a multi-model comparison study using similar input datasets. The aim of Phase 2 is to compare different ES tools and apply these tools across multiple scales (e.g. site to region to national level). For Phase 2, based on the range of complexity and ease-of-use represented across the ES tools assessed, we propose 6 tools/approaches for the in-depth review and road-testing for next phase i.e. InVEST, LUCI, NEVO, Natural Capital Planning Tool, Eco-metric Approach and the Land Choices Guide. If time and resources are available, other widely-used tools could be included.

InVEST, LUCI and NEVO are simple to complex map-based biophysical models which differ from each other in their approach to calculate ES and output format. InVEST and LUCI have been compared for their strengths and weaknesses by Sharps *et al* (2017) and both were parametrized and applied to a temperate catchment with widely varying land use in North Wales. Natural capital planning tool and Eco-metric approaches are simple score-based approaches yet very useful in decision making and can be used with limited technical capacity. The Land Choices Guide is a process that is guided by a facilitator and informed by a range of information sources. It provides an assessment of the land's current potential to deliver different ES and how these services may change with the aspired transformation of the land.

Review of ES Tools

Details of each ES tool, their strength and limitations, their detailed data requirements and methodologies are described below.

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

InVEST is a suite of models used to map and value the goods and services from nature that sustain and fulfil human life. InVEST combines land use and land cover (LULC) data with information on the supply (biophysical processes) and demand of ecosystem services to provide a service output value in biophysical or economic terms (Sharps *et al*., 2017). InVEST model has been validated extensively for various case studies mostly on water yield, nutrient retention, sediment delivery (Redhead *et al*., 2016, Sharps *et al*., 2017, Hamel *et al*, 2017, Bagstad *et al*., 2018). Table 4 describes strengths and limitations of the InVEST tool, and in Table 5 the approaches, and data needs, as well as outcome for all InVEST ES models are described, with most of the information sources from Invest User's Guide, version 3.5.0 (Sharp *et al*., 2018).

Table 4: Strength and Limitations of InVEST tool

InVEST	Strengths	Limitations
Approach	- Multi-service, modular design - Production function approach specifies the output of ecosystem services provided by the environment given its condition and processes - Simple to complex biophysical models, uses regression models as well as look -up tables - Spatially explicit - Provides sample input data	- Some models e.g. InVEST carbon storage and sequestration model is over simplified uses maps of LULC and carbon storage data to estimate net amount of C stored. Needs site specific calibration, so use of a process-based rather than map-based approach would be good. - Assumes linear change in carbon sequestration over time, and potentially inaccurate discounting rates.
Temporal and spatial scale	-	- Some of the models like nutrient retention, water supply work on an annual basis and thus don't represent temporal changes. -
Data requirement/sourcing	- InVEST user's guide describes in detail regarding the data sources for each ES models - Suggest using global data only if local data is not available -	- Data intensive - Time consuming (Bagstad *et al*., 2013) which has improved with time (Sharp *et al*., 2016, Bagstad *et al*., 2018)
Transparency	- All the InVEST ES models are very well described in the user's guide, also the limitations of the models are clearly stated.	
Validation	Sharps *et al* (2017) - Water yield model performed well, Redhead *et al* (2016) - Water yield model performed well when tested for 42 catchments across UK, better result with local input than global data input Redhead *et al* (2018) - Evaluated nutrient retention model for N and P load for 36 catchments across UK - InVEST NDR model can give good results in terms of the relative magnitude of N and P export but not in absolute terms Hamel *et al*. (2017) - Sediment delivery: Calibrated InVEST SDR model performed well in 28 watersheds Bagstad *et al* (2018) - InVEST water yield model performed well for streamflow with r^2 value 0.72.	Sharps *et al* (2017) - Total carbon at catchment level overestimated by 39 to 56%. - Nutrient retention model performed less well, annual N load underestimated by 81% and P load underestimated by 42%. Highly depends on the export coefficient which is based on few case studies. Redhead *et al*. (2018) - Less accuracy in estimating actual nutrient export, over or underestimation of 44% for P and 65% for N Hamel *et al*. (2017) - Model very sensitive to digital elevation model (DEM) resolution - Local knowledge on sediment budget is required for model calibration Bagstad *et al* (2018) - Changes in spatial resolution of input data has significant impact on outcome - Invest simple models (annual water yield, carbon storage) less sensitive, InVEST complex models (seasonal water yield, sediment yield) were more sensitive
Constant updating	- Updated every 3 months	

Table 5. Description of different ES models in the InVEST tool (Data requirements, Method, and Output)

INVEST Tools to model supporting ecosystem services			
Module	Data requirements	Method	Output
Habitat Quality	Required: Current Land Cover (GIS raster data), Folder Containing Threat Rasters, Threats data (csv file), Sensitivity of Land Cover Types to Each Threat (csv file), Half-saturation constant value (half of the highest grid cee degradation value). Optional: Future Land Cover, Accessibility to Threats (GIS polygon)	The InVEST Habitat Quality model combines information on LULC and threats to biodiversity to produce habitat quality maps. Impact of threat on habitat quality depends on 4 factors i.e. the relative impact of each threat , distance between habitat and threat source, the level of legal / institutional / social / physical protection from disturbance in each cell and relative sensitivity of each habitat type to each threat on the landscape.	Relative level of habitat degradation on the current landscape and future landscape, Relative level of habitat quality on the current landscape and future landscape, Relative habitat rarity on the current landscape and future landscape (Map output with score)
Habitat Risk assessment (HRA)/Species risk assessment (SRA)	The model uses an interface to input all required and optional data.	The InVEST HRA/SRA model allows users to assess the threat of human activities to the health of these ecosystems and species. The HRA/SRA model is a quantitative approach to evaluating the cumulative influence of stressors associated with human activities on habitats and species, many of which provide important ecosystem services (Arkema *et al*. 2014, Arkema *et al*. 2015). First step in HRA/SRA is to estimate exposure of habitat to stressors and assess the direct impact of the stressors and next step is to estimate the consequences of the exposure on the habitat or species and give a score based on exposure and consequence. Cumulative risk i.e. impact of multiple stressor is additive. HRA/SRA results are connected to different ES models in InVEST.	GIS output: resilience or recovery potential for the given habitat or species for each cell, sum of habitat or species cumulative risk scores for habitats or species occurring in a given grid cell, habitat-specific cumulative risk from all the stressors in a grid cell, habitat specific and classified by amount of risk. Plots: cumulative risk for each habitat or species within the given sub region, cumulative risk to all habitats or species in the study region by sub region, set of data for all pairings of habitat and stressor within each provided sub region
Pollinator abundance: Crop pollination	Required: Land Cover Map, Land Cover Biophysical Table, Land use/land cover class code, nesting_[SUBSTRATE]_availability index, floral resources_[SEASON]_index, Guild Table, Optional: Farm vector shapefile to indicate farm areas, and the attribute table of that shapefile provides information specific to each farm.	The InVEST Pollination model focuses on the resource needs and flight behaviours of wild bees. This model is adapted from Lonsdorf *et al*. (2009), the model is an index-based model.	Pollinator supply, Pollinator yield, index of total yield attained and the contribution of wild pollinators to that yield,

Table 5 (continued)

INVEST Tools to model supporting ecosystem services			
Module	Data requirements	Method	Output
Forest carbon edge effect model	Required: Land use/land cover map with LULC code, Biophysical table on information about which classes in the land-use/land-cover map are considered forest and should have the edge effect regression applied, and carbon density (Mg per hectare) for the land cover classes that are not forest.	The InVEST carbon edge effect model simulates forest carbon degradation due to creation of forest edge. The model uses a series of regression models between forest biomass density (Mg/ha) and distance from forest edge (km). Forest edge effect only applies to aboveground biomass. (regression equations)	A map of carbon stock per pixel, with the amount in forest derived from the regression based on distance to forest edge, and the amount in non-forest classes according to the biophysical table. Aggregated carbon map.
Carbon storage and sequestration	Required: Raster of current land use/land cover, current land cover calendar year for sequestration and valuation, future land cover for sequestration, future land cover calendar year for sequestration and valuation, economic data for valuation. Optional: If want to do policy scenario then policies like REDD policy required, Value of sequestered C, discount rate	The InVEST Carbon Storage and Sequestration model aggregates the amount of carbon stored in 4 carbon pools (i.e. aboveground biomass, belowground biomass, soil, and dead organic matter) using land use/land cover maps, classifications provided by the user and amount of C stored in C pools for each LULC type also provided by user. There is an option to provide current and projected land cover maps, which allows the net change in carbon stock resulting from land-use change over time. (Mapping)	Maps with carbon storage as well as sequestration, economic valuation of sequestered carbon Units: C stock (Mg/Pixel), C sequestration (Mg/Pixel/yr)
Coastal blue carbon model	Required: LULC raster representing landscape at particular points in time, LULC code with information on if the LULC is coastal blue habitat, output from CBC pre-processor simulation Optional: Value of sequestered C, discount rate	Coastal blue carbon model calculates C storage by aggregating C stored in 3 pools i.e. biomass, sediment carbon and litter. It is done by mapping the coastal habitat map with C storage data provide by user. Carbon loss is estimated as the fraction of carbon lost from each pool's total stock with any disturbance, disturbances categorised into high, medium and low. (Mapping also considers disturbance) Calculations are done using in 2 steps by first suing CBC pre-processor and CBC main model. Output of CBC pre-processor is used by CBC main model.	Time specific C accumulation, C emission, C stock, net C sequestration, total net C sequestration and net present value
Annual water yield	Required: Raster dataset of precipitation, annual reference evapotranspiration, root restricting layer depth, plant available water content, land use/land cover, shape file of watershed and sub water shed.	The annual water yield model calculates annual delivery of water to hydropower production. Annual water yield for each pixel is calculated from actual annual evapotranspiration and precipitation. For vegetated land use/land cover type, actual annual evapotranspiration is calculated using an expression of the Budyko curve while for other LULC type such as open water, urban, wetland, actual evapotranspiration is calculated from reference evapotranspiration.	Output is total and average water yield at the sub watershed level. The model can calculate the value of the energy that would be produced if the water reached a hydropower facility.
Nutrient delivery ratio model	Required: Digital elevation model, Land use/land cover, Nutrient runoff proxy, Watersheds shapefile, Biophysical Table on land use class, Threshold flow accumulation, Borselli k parameter, Subsurface Critical Length (Nitrogen or Phosphorus), Subsurface Maximum Retention Efficiency (Nitrogen or Phosphorus)	The model uses a simple mass balance approach that represents the long-term, steady-state flow of nutrients based on land use specific nutrient sources across the landscape and retention properties for pixels belonging to same flow path. Nutrient loads are determined based on a land use/land cover (LULC) map and associated loading rates. Delivery factors are computed for each pixel based on the retention properties of pixels i.e. slope and retention efficiency of land use.	Total nutrient load in the watershed (kg/yr) Total nutrient export from the watershed (kg/ha) Nutrient export map: A pixel level map showing how much load from each pixel eventually reaches the stream (kg/pixel)

Table 5 (continued)

INVEST Tools to model final ecosystem services			
Module	Data requirements	Method	Output
Sediment delivery ratio model	Required: Digital elevation model, Rainfall erosivity index, Soil erodibility, Land use/land cover (LULC), Watersheds, Biophysical table, Threshold flow accumulation, SDRmax, Optional: Drainage layer	The SDR model calculates the amount of annual soil loss from each pixel and proportion of that soil reaching the stream. Amount of soil loss is calculated by using the revised universal soil loss equation (USLE). SDR is calculated by first calculating connectivity index i.e. hydrological connectivity between sources of sediment in the catchment and SDR ratio for a pixel which is calculated using connectivity index.	Raster output: Total potential soil loss per pixel (t $ha^{-1}yr^{-1}$) Total amount of sediment exported (t $ha^{-1}yr^{-1}$) Stream network generated from the input DEM and Threshold Flow Accumulation (1 stream, 0 non stream) Watershed result of total potential soil loss and sediment export to stream per watershed.
Scenic quality model	Required: Area of interest (AOI), Features impacting scenic quality, Digital elevation mode (DEM), Refractive coefficient, valuation functions and coefficients.	The scenic quality model provides information about the visibility of offshore objects from the surrounding landscape or seascape i.e. view-shed map. The model calculates visual impact of each feature in the landscape by calculating visibility using viewshed algorithm and by estimating value of visibility amenity or disamenity using valuation function.	Raster with a field on visual quality class within AOI, weighted sum of all visibility raster (count), economic valuation
Recreation and Tourism	Required: Area of Interest: GIS shape file, UTM coordinate system, Start year and end year: geotagged photos taken between 2005-2014, Optional: if using regression model with predictors then predictor table required, a csv table that specifies a set of GIS layers to use as predictors, scenario predictor table (optional), CSV table that specifies a set of GIS layers to use as predictors in a scenario.	The model estimates rate of visitation across landscapes (grid cells) or in discrete areas (polygons) by either building a regression model to estimate the contribution of attributes of the landscape to the visitation rate. In the absence of empirical data to build regression equation on visitation, the model is parametrised using a crowdsourced measure of visitation: geotagged photographs posted to the website flickr (Photo user day).	Map of visitation rates, visitation map with regression with predictors, estimation of visitation rate for scenarios Units: Photo user days/year, photo user days/month
Wave energy	Required: Analysis Area (from drop down menu), Machine Performance Table, Machine Parameters Table, Global Digital Elevation Model Optional: Area of Interest, user can create a polygon feature layer that defines area of interest, For economic evaluation: Grid Connection Points File, machine Economic Table , number of Machine Units,	The InVEST wave energy model (WEM) assesses potential wave power and harvested wave energy based on wave conditions (e.g., significant wave height and peak wave period) and technology-specific information of wave energy conservation (WEC) devices (e.g., performance table and maximum capacity). The model then evaluates the net present value (NPV) of building and operating a WEC facility over its life span using economic parameters (e.g., price of electricity, discount rate, as well as installation and maintenance costs).	Raster output: The potential wave power map (kW/m), The captured wave energy map (MWh/yr / WEC device), The NPV map, The landing and grid connection points
Offshore Wind energy	Required: Wind data point, Bathymetric DEM, Land polygon for distance calculation, Global wind energy data, valuation parameter Optional: Area of interest	InVEST offshore wind energy model is to provide spatial maps of energy resource availability, energy generation potential, and (optionally) energy generation value to allow users to evaluate siting decisions, use trade-offs, and an array of other marine spatial planning questions.	Model outputs include wind power potential (MWh/yr) energy generation, offset Carbon emissions (tons), net present value, and levelized cost of energy, all given at the farm level.

INVEST Tools to model final ecosystem services			
Module	Data requirements	Method	Output
Marine finfish production	Required: Finfish Farm Location (required). A GIS polygon or point dataset, farm identifier name, fish growth parameters, uncertainty analysis data, daily Water Temperature at Farm Table, farm operations table Optional: uncertainty analysis data	Currently set for Atlantic salmon. The model runs on a vector GIS dataset that maps individual aquaculture facilities for Atlantic salmon that are actively farmed over a user-defined time period, simulates impact of on farm operations and change in temperature. Can do a series of production cycle, estimates planting out date and restocking. Does uncertainty analysis.	Summary of Farm operations performed, harvested weight summed over time period (kg) modelled, uncertainty analysis, economic value (NPV).
Fisheries	Required: Population Parameters File (CSV) (required). The provided CSV file should contain all necessary parameters for population classes based on age/stage, sex, and subregion - excluding possible migration parameters, Population Classes are Sex-Specific (csv file), Habitat Dependency Parameters File (CSV), Habitat Area Change File (CSV), Gamma. Describes the relationship between the change in habitat area and a change in survival of age/stage	The InVEST Fisheries Production model produces estimates of harvest volume and economic value of single-species fisheries. The model is an age- or stage-structured population model and is presented as a generic model that can be adapted to most species and geographies.	Harvest across the entire area if interest, also if valuation is selected result provides valuation of harvest Habitat scenario tool if used give output of a csv file with modified population parameter
Crop production	Required for percentile model: Land-Use/Land-Cover Map: Raster of land use/land cover (LULC) for each pixel, where each unique integer represents a different land use/land cover class, Landcover to Crop Table : A .csv (Comma Separated Value) table that maps a Land-Use/Land-Cover integer code to a crop name, Additional requirement for regression model: Fertilization rate table path (csv file)	The InVEST crop production model is divided into a percentile-based yield model, covering 175 crops worldwide, and a regression-based model (Muller *et al.*, 2012) that accounts for fertilization rates on 12 crops. The InVEST crop Production Percentile model produces estimates of 175 crops' yield from existing data, percentile summaries, and observed yields. These observations are based on FAO and sub-national datasets for 175 crops, as tons/ha (Monfreda *et al*. 2008) and nutrition information. InVEST crop production regression model is based on Muller *et al*., 2012 and is parametrised for 12 crops: barley, maize, oil palm, potato, rapeseed, rice, rye, soybean, sugar beet, sugar cane, sunflower, and wheat	Modelled production and nutrient information

Table 5 (continued)

INVEST Tools to model final ecosystem services			
Module	Data requirements	Method	Output
Seasonal water yield	Required :Precipitation Directory with 12 rasters of monthly precipitation for each pixel, ET0 directory with 12 rasters of monthly reference evapotranspiration for each pixel, Digital Elevation Model with raster of elevation for each pixel, Land use/land cover with raster of land use/land cover (LULC) for each pixel, Soil group with raster of SCS soil hydrologic groups, AOI/Watershed : Shapefile delineating the boundary of the watershed to be modelled, Biophysical table : A .csv (Comma Separated Value) table containing model information corresponding to each of the land use classes in the LULC raster, Rain events table (CSV file),Threshold flow accumulation : The number of upstream cells that must flow into a cell before it is considered part of a stream, alpha_m, beta_i, gamma :Model parameters used for research and calibration purposes Advanced model options: Climate zone table (csv file), Climate zone :Raster of climate zones, each uniquely identified by an integer, Local recharge raster (if not using the values calculated by INVEST)	The InVEST Seasonal Water Yield model computes spatial indices that quantify the relative contribution of a parcel of land to the generation of both baseflow and quick flow. Quickflow (QF) is calculated with a Curve Number (CN)-based approach, the curve number is a simple way of capturing these soil + land cover properties - higher values of CN have higher runoff potential (for example, clay soils and low vegetation cover), lower values are more likely to infiltrate (for example, sandy soils and dense vegetation cover). For baseflow, the model uses a physics-based approach, the equations are extremely simplified at both spatial and temporal scales.	Map of baseflow (mm), quick flow (mm), local recharge (mm), available water (mm)
INVEST Tools to facilitate ecosystem service analysis			
Coastal vulnerability model	Required : Area of Interest: a polygon feature layer that defines the Area of Interest, Land Polygon: this input provides the model with a geographic shape of the coastal area of interest, and instructs it as to the boundaries of the land and seascape, Bathymetry layer: this is depth information of bodies of water within the AOI as marked by the land polygon shapefile, Digital Elevation Model: It should consist of elevation information covering the entire land polygon within the AOI, Elevation averaging radius round within which to compute the average elevation for relief, Mean sea level datum, Model resolution (segment size in meters), Rays per sector used to ample the ocean depth and land proximity within each of the 16 equiangular fetch sectors , Depth Threshold (meters), Exposure proportion (meters)	The InVEST Coastal Vulnerability model creates the exposure index and coastal population maps using a spatial representation (raster) of population and spatial representations (shapefiles and rasters) of seven bio-geophysical variables i.e. geomorphology, relief, natural habitats (biotic, abiotic), net sea level change, wind exposure, wave exposure, surge potential depth contour.	Coastal exposure index

GLOBIO-Biodiversity	Either Land use/land cover data: Vegetation specific (e.g. MODIS map)) or Land use/land cover data: Management specific (predefined GLOBIO map): Standard GIS raster file (e.g., ESRI GRID or IMG), with a column labelled 'value' that designates the LULC class code for each cell (integers only; e.g., 1 for forest, 10 for grassland, etc.), Land-cover to GLOBIO land-cover table (csv file): required if using vegetation specific land cover data,	The GLOBIO model provides an index of biodiversity according to mean species abundance (MSA), the average population-level response across a range of species, to different stressors, including land-use change, fragmentation, and infrastructure. Works for high resolution data i.e. 500m pixels from MODIS. Impact of the stressors on MSA is mainly based on meta-analysis studies.	A shapefile summarizing the average MSA, A raster of the overall MSA, A raster of MSA calculated for impacts of land-use only, fragmentation only and infrastructure only.

LUCI (Land Utilisation and Capability Indicator)

LUCI is a framework and associated computer model that uses information about topography, land cover, and soil to produce maps of ecosystem services and trade-offs. LUCI is a decision support tool that can model ecosystem service condition and identify locations where interventions or changes in land use might deliver improvements in ecosystem services. Output maps are colour-coded for ease of interpretation: in default mode green is used to indicate good opportunity for changes, and red to mean "stop, don't make changes here". Table 6 describes strength and limitations of LUCI. Table 7 describes the approaches, data needs, as well as outcome for LUCI, mostly sourced from Jackson *et al*., 2013; Emmett B.E. and the GMEP team, 2017.

Table 6. Strength and Limitations of LUCI tool

LUCI	Strengths	Limitations
Approach	- Modular, spatially explicit, multi service, provides trade-off and synergies, useful visual output for quick and easy interpretation i.e. area in red shows excellent existing provision, green area shows excellent opportunity to improve provision - Biophysical, process based, IPCC tier 1	- Can't simulate improvement of an existing natural capital rather only simulates changes (Feedback from Natural England) -
Temporal and spatial scale	- Operates at 5m scale to national scale	-
Data requirement/sourcing	- Uses locally as well as nationally easily available data	- The model is yet to be released for public use, no user's guide available yet. Jackson *et al*., 2013 describes the tool and data requirement.
Transparency	- All the sub models are described in Jackson *et al*., 2013	- However, a user's guide with details of each ES models, the linkages between the models would be handy for users.
Validation	Sharps *et al* (2017) - Modelled water supply with LUCI showed close estimate with observed annual flow data from two gauging station i.e. 1% to 6% overestimation - Performed better than InVEST for average N load, InVEST showed underestimation by 81%. Trodahl *et al* (2017) - Predicted in-stream total N concentration was no more than 20% difference than observed value. -	Sharps *et al* (2017) - Overestimation of total carbon for the catchment by 47% to 58% - Underestimation of annual average N load by 40% and P load by 29% Trodahl *et al* (2017) - For sub-catchments where ground water is sourced from beyond catchment boundary, in-stream TN concentration was under predicted by 55-90% - For sub catchments with water sourced from within catchment boundary but with very high lag time in-stream TN concentration was over predicted by 69% - Mostly over predicted total P in-stream concentration by 28- 740%.
Constant updating	- Released	- A user's guide will be very handy.

Table 7. Description of different ES model in LUCI tool (Data requirements, Method, Output)

LUCI Tools to model final ecosystem services			
Module	Data requirements	Method	Output
Habitat augmentation/protection tool	Required: 1. Digital elevation model (DEM): To represent landscape topography and ideally has a grid size of 5x5m to 10x10m, although any resolution data can be used as input 2. Land cover information: The land cover information must first be correlated to the existing database of land cover types already supported by LUCI, 3. Soil information: Optional: Stream network, rainfall, and evapotranspiration	Landscape connectivity plays an essential role in the dispersal of organisms among habitat patches and thus the conservation of biodiversity. LUCI uses a cost-distance approach, calculates cost-distance for specific organisms crossing through hostile terrain for each habitat patch with specified permeability for specific landscape. . The more hostile terrains are the less permeable.	Multiple habitat valuation layer depending on number of spices or habitat of interest
Flood mitigation tool	Required: A hydrologically consistent digital elevation model (consistent with the stream network and with local depressions removed) and land use data. A pre-processing tool is included to generate a hydrologically consistent DEM from a "standard" DEM Optional: Soil data	The flood mitigation tool takes into account storage and permeability capacity of different elements within the landscape from soil and land use data. Then it modifies the flow accumulation using an algorithm and according to storage and permeability.	The model identifies low priority and high priority area for flood risk based on land use and soil types that provides mitigation. Main output: Maps of "Mitigating land", "Mitigated land" and "Flood concentration". Average flow delivery to all points in the river network is simulated which can be used to estimate water supply.
Erosion/sediment delivery risk tool	Required: 1. Digital elevation model (DEM): To represent landscape topography and ideally has a grid size of 5x5m to 10x10m, although any resolution data can be used as input (raster data) 2. Land cover information: The land cover information must first be correlated to the existing database of land cover types already supported by LUCI, 3. Soil information: Optional: Stream network, rainfall, and evapotranspiration	Areas of land that are vulnerable to erosion are identified in LUCI using the Compound Topographic Index. CTI (m) is defined as CTI = A × S × PLANC, where A = upslope drainage area (m2) (after "sink" areas have been accounted for – see Section 2.2); S = local slope (m/m); and PLANC = planform curvature (1/100 m). PLANC is a measure of landscape convergence (negative for spurs, positive for swales) which indicates the degree of overland flow concentration. Influence of soil and vegetation is defined through the use of user-defined critical, or threshold, CTI values. To estimate sediment delivery, areas of land which are vulnerable to severe soil erosion and at risk of being linked to proximate watercourses by uninterrupted overland flow are identified in LUCI by combining the CTI layer with the flood mitigation tool.	-map of areas of land for sediment delivery mitigation

Table 7 (continued)

LUCI Tools to model final ecosystem services			
Module	Data requirements	Method	Output
Water quality-N and P export	Required: DEM, land cover data, soil data, stream network data, rainfall and evapotranspiration surfaces, location of spring addition of water to river network (Trodahl *et al*., 2017)	Water quality models within LUCI use an enhanced, spatially representative export co-efficient (EC) approach to model total nitrogen (TN) and total phosphorus (TP) exports to water.	Map output - Total N and P load generated in the catchment (kg N or P/ha/yr) - Total accumulated N or P in the catchment (Low to very high)
Carbon sequestration tool	Required: 1. Digital elevation model (DEM): To represent landscape topography and ideally has a grid size of 5x5m to 10x10m, although any resolution data can be used as input (raster data) 2. Land cover information: The land cover information must first be correlated to the existing database of land cover types already supported by LUCI, 3. Soil information:	Carbon storage and change in LUCI are based on the IPCC tier 1 method; each habitat is assigned a carbon storage value for the 4 pools i.e. carbon into above ground biomass, below ground biomass, deadwood, litter, and soil carbon. First the model calculates carbon stock at steady state i.e. assuming the soil and vegetation carbon at equilibrium and then identifies where the current management regime is likely to be either significantly decreasing or increasing stocks of carbon left by previous regime.	Map output -area of landscape prone to C loss and area that can be modified to store additional carbon
Agricultural valuation tool	Required: 1. Digital elevation model (DEM): To represent landscape topography and ideally has a grid size of 5x5m to 10x10m, although any resolution data can be used as input (raster data) 2. Land use information 3. Soil information 4. two or more critical slope values (1st is the cut-off for very productive land which is 5^{o} by default, 2nd is the cut-off for moderately productive land which is 15^{o} by default)	The agricultural valuation tool is based on simple rules examining slope, aspect, water regime (e.g., whether the soil is free draining, prone to waterlogging, etc.) and soil fertility. Flat, fertile, well-draining soils are considered to be of highest value for agricultural production. Current land utilisation is determined from land cover data. By comparing current and optimal agricultural use, LUCI identifies locations that appear to be under or over utilised and suggests where a change in land use or management could be beneficial (Trodahl *et al*, 2017)	Traffic-light maps - Current agriculture utilization map - Future optimal agriculture utilization map
Trade-off tools		LUCI includes algorithms to trade the individual ecosystem services, represented by the GIS layers, against each other in a number of ways. 1. Additive option (treats all services equally) 2. Weighted additive option (which allows the addition of weightings for individual services) 3. Conservative option (which only identifies areas where positive synergies exist) 4. A Boolean option (which enables users to select a combination of additive and conservative options for each service).	LUCI trade-off maps show where opportunities exists to improve delivery of multiple ES (Bright green, Dark green) whilst protecting area which currently delivers high level of ecosystem services (presented in bright green and dark green)

TIM (The integrated model)/NEVO (Natural Environment Valuation Online tool)

NEVO, the successor of TIM (The Integrated Model) includes biophysical models to reflect interactions between multiple ecosystem services, at various spatial and temporal scales. It also includes an economic behaviour model, which details how decision makers (e.g. farmers) respond to changes in the market, policy and the environment (Binner *et al.*, 2018). NEVO provides quantitative analyses of the integrated effects of land use change as well as economic values for these changes. An optimisation routine allows policy makers to explore the best way to achieve their objectives. The NEVO tool is yet to be released for general use and is currently at piloting stage. The strengths and weaknesses are outlined in table 8, with data requirements, approaches, and outcome outlined in Table 9. The latter information was derived from Pyatt *et al.*, 2001, Bateman *et al.*, 2014, Francesconi *et al.*, 2016, Day and Smith, 2018, and Day and Owen, 2018. Because NEVO is still in piloting stage, in Table 8 limitations of the tool are not described, as currently there is no public information available on this.

Table 8. Strength and Limitations of TIM/NEVO tool

NEVO	Strengths
Approach	- Biophysical, process-based, Empirical - Robust economic valuation
Temporal and spatial scale	- Catchment to National scale - Operates at 2km grid square - Annual but can be sub-annual
Data requirement/sourcing	- Data preloaded for England and Wales
Transparency	- Use of more widely-used models for different ES i.e. Cool Farm Tool, CARBINE model, UK SWAT model…etc
Validation	- Under development, individual ES models validated but for NEVO as an integrated system no validation yet
Constant updating	- NEVO is not yet released for public use, but it is an update of TIM model and there is work ongoing to update the tool.

Table 9. Description of different ES model in TIM/NEVO tool (Data requirements, Method, Output)

NEVO Tools to model final ecosystem services			
Module	Data requirements	Method	Output
LEEP UK Farm model (Agriculture output)	Agriculture land use data (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 (alt), share of agricultural land with slope higher than 6 degrees. Agriculture input and output prices	Consider a farm profit maximization problem with land as the only fixed allocatable input. Constrained optimisation problem. The method assumes that farm-level decisions regarding land allocation and livestock intensity are driven by a profit motive, and models historical farming behaviour accordingly. Originally used TERRAIN (2012), the June Agricultural Census (JAC, 2013), SOIL (2012) and CLIMATE (2012) combined to form a truly unique database covering the whole of Great Britain at a 2km grid square (400 ha) level. Dataset included information from the late sixties to the present on the following variables: land use shares and livestock numbers; environmental and climatic determinants; and policy and other drivers, agriculture input and output prices.	
FC Timber yield model	Water regime, soil pH, water capacity, soil carbon content, average rain and precipitation, slope, elevation, easting and northing	1. Tree volume and profit calculated for current climate using FC Ecological site classification model which is a decision model. Drawing upon the yield tables provided by Edwards and Christie (1981), the ESC (2013) model provides site specific estimates of potential timber yield class (YC) at the 2km grid cell resolution across the entirety of Great Britain 2. Timber profits are obtained by multiplying tree volume by their corresponding market price. To obtain tree volumes the ESC rounded YC values were then fed into the CARBINE model, which produces tree volume for a variety of management regimes. To obtain market values, the CARBINE tree volume is combined with the FC Forest Investment Appraisal Package (FIAP, 2013) to calculate the economic profitability of forests. 3. Semi-parametric regression used to simulate impact of climate change on forestry growth.	1. ESC predicts the maximum mean annual increment in timber volume by yield class (YC; measured in m3/ha/yr) for new plantations.
Cool Farm Tool (GHG emission and sequestration)	Soil parameters from soil database like Harmonized world soil database, Land management practices, fertilizer use data	Calculates GHG emission from agriculture, methodology in between IPCC tier 1 and IPCC tier 3, mostly uses empirical models, also uses IPCC tier 1 method	GHG emission and carbon sequestration (t CO_2ha^{-1})

NEVO Tools to model final ecosystem services			
Module	Data requirements	Method	Output
FR CARBINE model (CO_2 emission & seq)	1. Input: Output from FC timber yield model on maximum mean annual increment in timber volume by yield class (YC; measured in m3/ha/yr) for new plantations. 2. Monthly average temperature, precipitation, soil data	1. Estimates GHG emission associated with afforestation of land accounting for the emissions and sequestration associated with standing trees, harvested wood products (HWP), deadwood (litter) and soil. Management regime considered "thinning and felling". 2. Carbon sequestered in harvested wood of merchantable quality is allocated to HWP using a dynamic assortment forecasting model that accounts for variation in product out-turn specific to tree species and size classification of stem wood at the time of harvest (Rollinson and Gay, 1983). HWP are further categorised as long-lived and short-lived sawn timber, particleboard and paper. Each of these classes of wood products is modelled in terms of their service life and the consequent time profile of carbon emissions. 3. Soil carbon model is Roth-C agricultural soil C model.	1. C (t CO_2ha^{-1}) in live wood, harvested wood product per year, per rotation and total rotations 2. soil carbon (t CO_2ha^{-1}) accumulated or lost over rotations
LEEP ORVAL model (adult day visit/welfare value)	Maps for England and Wales preloaded 1. Background (Openstreet) map 2. Recreation sites 3. Land cover map 4. Designation of recreation site 5. Regions i.e. local authority area, catchment area.	1. ORVal's estimates of visitation and welfare values are derived from a statistical model that can be used to predict the number of visits that are made by adult residents of England and Wales to different greenspaces. Prediction of number of visits depends on socioeconomic characteristics of people. 2. ORVAL's estimates of welfare Values identifies how much welfare an individual enjoys as a result of beneficial attributes of a greenspace. It also identifies how much welfare is lost from each extra pound of cost incurred in travelling to a greenspace.	1. Visitation and welfare value for currently accessible greenspace 2. Predicts visitation and welfare values with change of characteristics of the greenspace 3. can create new sites and estimate visitation and welfare value
JNCC Species distribution model		Probability of species presence	
LEEP UK SWAT model	Soil data, elevation, weather, land use, several calibration parameters vegetation input and hydraulic properties i.e. runoff curve numbers, ground water delay.	Process-based hydrological model	Water yield, soil erosion for watershed, sediment deposition

NCPT (Natural Capital Planning Tool)

NCPT is a simple Excel-based tool and an expert-based approach that determines indicators, and predefined scores for different attributes for each indicator, for 10 ES simulated in the tool. NCPT is based on the Joint Nature Conservation Committee (JNCC) Phase 1 habitat survey and classification framework. It gives only an indication (direction and magnitude) of impact of the change and is not intended to replace existing planning requirements, such as an Environment Impact Assessment. The description of NCPT's strengths and limitations (Table 10) and the data requirements, methods and outputs (Table 11) are from "NCPT Introduction & User guide v.1.3.3" (Hölzinger *et al.*, 2018).

Table 10. Strength and Limitations of the NCPT

NCPT	Strength	Weaknesses
Approach	- Determines indicators and scores for different attributes of indicators - Score based approach - Calculates impact score for each ES - Development impact score is sum of all ES impact score	- Only gives an indication (direction and magnitude) of impact of the change - Scores and multipliers are expert judgement-based - Can only assess land use change, cannot assess if pre- and post- land use changes are the same
Temporal and spatial scale	-	- No, designed mainly for plans/developments.
Data requirement/sourcing	- Easily available UK national data - Information provided in User's guide on where to get the data from	-
Transparency	-	-
Validation	-	- Gives only indicative assessment
Constant updating	- Yes	

Table 11. Description of different ES models in the NCPT (Data requirements, Method, Output)

NCPT Tool to model final ecosystem services			
Module	Data requirements	Method	Output
1. Harvested product 2. Biodiversity 3. Aesthetic value 4. Recreation 5. Water quality regulation 6. Flood risk regulation 7. Air quality regulation 8. Local climate regulation 9. Global climate regulation 10. Soil contamination	- Detailed land use map for pre and post development with at least 300m buffer around the site - Flood risk map - Drinking water safe guard zone map - An access map for pre and post development - Agriculture land classification map	-Impact Score based approach score attached to each land use type and other ES specific parameters i.e. for aesthetic value local population density	- Ecosystem service impact score for each ES (ESIS) - Total developmental impact score i.e. sum of all ESIS

Eco-metric Approach

The Eco-metric Approach is currently under development and at the piloting stage and is expected to supersede NCPT (Environment Agency, Stakeholder feedback). It is a simple score-based approach, which is biodiversity led i.e. biodiversity gain is a pre-requisite. The method optimises biodiversity gain from investment in biodiversity. The approach calculates eco-metric units for each land parcel based on area, distinctiveness, condition, spatial factors, time lag and delivery risk (Alison Smith, ECI, University of Oxford, PPT, 2018). The strengths and weaknesses thus far identified are shown in table 12.

Table 12. Strength and Limitations of the Eco-metric approach

Eco-metric approach	Strength	Weaknesses
Approach	- Determines indicators and scores for different attributes of indicators - Score based approach - Calculates impact score for each ES - Individual ES impact scores are not additive - Simple tool; uses freely available data	- Only gives an indication (direction and magnitude) of impact of the change - Cannot replace detailed ES assessment - Scores and multipliers are expert judgement based
Temporal and spatial scale	- Yes, it can cover different scales	- Unknown as in development stage
Data requirement/sourcing	- Easily available UK national data - Information provided in User's guide on where to get the data from	- Unknown as in development stage
Transparency	- Under development – hence not a strength yet.	- Unknown as in development stage
Validation	-	- Unknown as in development stage
Constant updating	-	- Unknown as in development stage

The Land Choices Guide

National Trust's "The Land choices guide" process helps to think through options for best use of land, which is guided by a Land Choice Facilitator. The decision is visual and expert opinion based and the outcome is more for public benefit. Figure 2 shows the process associated with the Land Choices Guide (Begg, 2015) and it is performed by: a) collecting information, evidence and existing plans to establish how the land in question performs against six land functions; b) collecting people's vision for the land; and c) doing a reality check to see if the evidence suggests that people's vision can be achieved. A report then outlines vulnerabilities, opportunities, and describes priority actions.

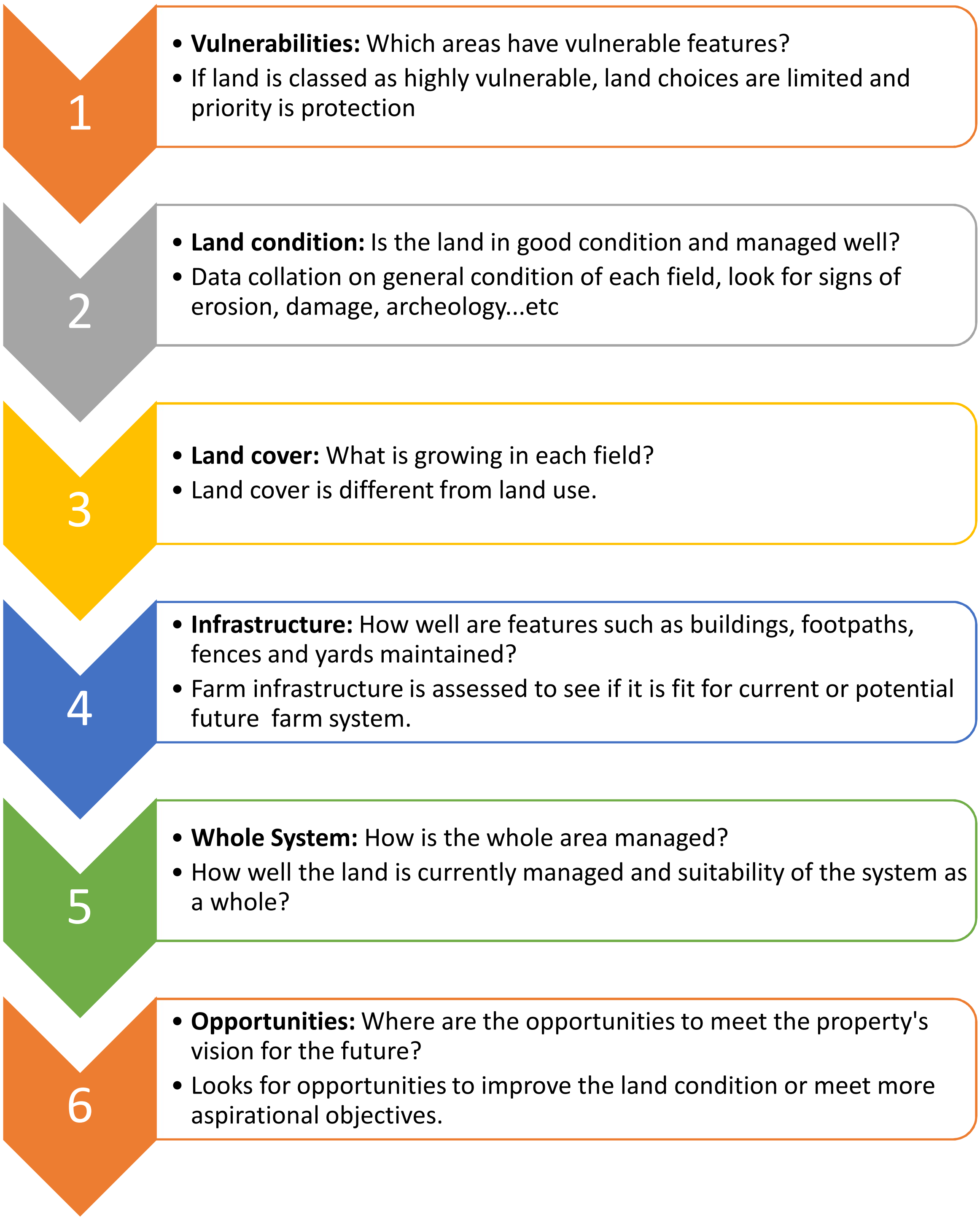

Figure 2. The processes of "The Land Choices Guide"

Identification of Potential Case Studies for Use in Phase 2

The source for the following four potential case studies was the report on “Land use: Reducing emissions and preparing for climate change”, Committee on Climate Change November 2018

Case Study 1 - Norfolk and Suffolk Broads, East Anglia

- Location: The Norfolk and Suffolk Broads case study boundary is defined according to the Broadlands River Catchment plan land area.
- Current land use: Land use mapping of the area shows that at present 86% of the land is used for farming: 71% non-irrigated arable, of which cereals and horticultural crops dominate, and 15% pastoral, comprising of a mixture of dairy and grazing. The remaining 14% is made up of urban area, woodland and coastal habitats.
- Climate change context: Flooding resulting from an increase in the frequency and severity of coastal storm events and warmer drier summer leading to drought and heat stress.
- ***Case study question: How should land use change to adapt to, or mitigate the impact of climate change i.e. flooding and drought?***

Case study 2 - The Petteril Catchment, Cumbria, Cumbria

- Location: The River Petteril is a tributary of the River Eden in Cumbria and is located in the North Pennines in the north of England. The Petteril catchment covers an area of 160 km^2 (16,075 ha).
- Current land use: 91% of the land in the case study area is used for farming. Of this, 64% is used for pastoral livestock (beef and dairy), 24% for arable (cereals, horticulture and general cropping) and 3% grassland (grazing). The remaining land uses at the location are forestry (4%) and urban (3%), with the city of Carlisle located in the far north of the area.
- Climate change context: Warmer and wetter winter seasons, warmer and drier summer season will lead to flood in winter and drought in summer.
- ***Case study question: What could be the future land use to reduce the impact of flood and drought on crop and livestock production? Can inclusion of more new crops such as sunflower, grain maize, soy, compensate for economic loss? Will conversion of arable land to agroforestry or woodland provide long term stable income?***

Case study 3 - Moor House and Upper Teesdale in the North Pennines

- Location: Moor House and Upper Teesdale comprises an 88 km^2 National Nature Reserve (NNR) in the North Pennines, in a remote Pennine dale forming the upper catchment of the River Tees. The whole area is part of the larger North Pennines Area of Outstanding Natural Beauty (AONB).
- Current land use: The majority of the land in the case study area is upland peat (70%), farmed for sheep and grouse. This falls into the lower slopes and valley bottom with areas of in-bye grassland, scattered broad-leaved woodland and the river floodplain bordered by riparian woodland. Some key special areas for biodiversity are blocks of sugar limestone

scattered across the hills, which support a rare upland calcicolous flora, and give the area its designations.
- Climate context: Severe droughts and summer heatwaves because of warmer and drier summer and lower winter rainfall. Chances of accidental and wild fire.
- ***Case study question: What future land use can reduce occurrence of fire? Can restoration of sub-optimal blanket bog to optimal condition increase their resilience to drought and fire?***

Case study 4 - Somerset, including the levels

- Location: The case study area is approximately 2,500 square kilometres in size covering the catchments of the Parrett, Axe and Brue. Large urban settlements within the case study area include Weston-Super-Mare and Bridgwater to the north, and Taunton and Yeovil in the south.
- Current land use: The vast majority of the land in the case study area is allocated to farming: 53% is used for pastoral (sheep and cattle) and 36% supports arable farming (cereals, maize, oilseed rape and field beans). Urban development represents a further 5% of land area. The remaining land at the location comprises woodland (4%, primarily broadleaved), inland wetland (1%) and non-agricultural vegetated areas (1%). Just over 5% of the case study land area is designated as Sites of Special Scientific Interest (SSSI). The peat soils of the Levels and Moors (covering 20,000ha) are also a significant store of organic carbon.
- Climate context: Sea level rise, warmer and wetter winter seasons
- ***Case study question: Can growing new crops suited to grow in a warmer climate i.e. sunflower, soy be a possible adaptation? What land use change would be best to adapt to, or mitigate, frequent flooding?***

The source for the following three potential case studies was the Environment Agency

Case study 5 - Burpham Court Farm, Guildford Borough Council

- Aim: To value/ shape a wetland & river restoration project, to try and engage with others and persuade the council (and possibly others) to put funding into the project. Guildford Borough Council plans to create a wetland nature reserve as public amenity for local population and use the site as sustainable alternative natural greenspace (SANG) to support new home development.
- ***Case study question: How the proposed planning can improve different ecosystem services and net present value of Burpham court farm?***

Case study 6 - Cranleigh waters sub catchment trial, focused on natural flood management (NFM)

- Aim: Flood mitigation, opportunity mapping for water quality and quantity.
- ***Case study question: Can land management measures improve water quality of the water-body? Particularly bringing the WFD classification status of Cranleigh waters to good.***

Case study 7 - Northamptonshire and Peterborough
- Aim: Habitat opportunity mapping to enhance biodiversity, reduce runoff, reduce erosion, improve water quality, reduce air pollution and improve access to greenspace. It is a case study done by Natural Capital Solutions Ltd.

- ***Case study question: Can new habitat creation across Northamptonshire and Peterborough provide particular benefits such as biodiversity, reduced runoff, reduced erosion, improved water quality, reduction of air pollution and improved access to greenspace?***

The source of the following potential case study was Natural England

Case study 8 - Bassenthwaite catchment (361.3km^2) in the Lake District, in the North of England

- Aim: Opportunity mapping with different land management to enhance the provision of the selected ecosystem services such as water supply; food and fibre; carbon storage and sequestration; erosion control; water quality; flood regulation; cultural landscape, historic environment; recreation, inspiration, education and health; biodiversity.
- ***Case study question: Can the five year "delivery plan" developed by the partnership of stakeholders in 2011, which focuses on seven land management actions, potentially enhance the provision of the selected ecosystem services?***

The source of the following three potential case studies was the National Trust for England, Wales and Northern Ireland

Case study 9 - Mount Stewart, County Down, Northern Ireland, run by the National Trust

- Aim: The National Trust used the Land Use Guide to determine the optimum land use for conservation at Mount Stewart. This presents the opportunity to test a range of models at the site to examine what different models would propose for managing the land.
- ***Case study question: What advise on land use and management would the different models provide for management of this site to deliver public benefit through conservation? Three priorities are biodiversity, carbon sequestration and access for the public.***

Case study 10 – Priorities for land acquisition

- Aim: The National Trust frequently considers land acquisitions, which includes agricultural land, land that could be developed and degraded habitats. The Trust routinely uses the Land Choices Guide to assist with decision making. This presents the opportunity to test a range of models at specific sites to examine what different models would propose for managing the land acquired, and what would be the public versus private benefits that could be generated.
- ***Case study question: What are the opportunities through land use change to deliver wildlife, carbon storage/sequestration and recreation, combined with commercial opportunities? What would the different models propose? What is the potential certain acquisitions to connect important wildlife habitats in its surrounding landscape, and how could this be assessed?***

Case study 11 – Choices between wildlife, carbon, recreation and food production

- Aim: Three priorities for public goods from National Trust land in the future are wildlife, carbon and public access. Even if food production is not one of the priorities, if productive land is removed from farming there could be a greater impact overseas through food imports. The current proposal is to classify land in four categories:

1. Rewilding, with minimal intervention. No food production.
2. Farming for wildlife. Minimal intervention, food production as a by-product (e.g. conservation grazing animals)
3. Nature friendly farming. Food production is a primary objective, but this is done alongside wildlife as much as possible.
4. Intensive commercial farming.

- ***Case study question: How could ES tools help to make decisions between (and within) these categories, tensioning this against the fact that the UK needs to produce a certain amount of food? Are the 'impacts/consequences overseas' included in any of the current decision support tools?***

Scoping of Phase 2

Proposed outline for the model inter-comparison, modelling protocol, suggested metrics for comparison and proposed analysis of outcomes and times-scale for Phase 2.

Collaboration with the Programme Coordination Team (PCT) for the UKRI Strategic Priorities Fund (SPF)-Landscape decision programme

The team implementing Phase 2 will work closely with the Programme Coordination Team (PCT) for the UKRI Strategic Priorities Fund (SPF) Programme 'Landscape Decisions: Towards a new framework for using land assets' (LD). Planned links between the Phase 2 work and the Landscape Decisions (LD) programme will help to provide additional value by bringing together different components of landscape models from new mathematical approaches (Landscape Decisions WP1) to the application of how models can help decision makers (Valuing Nature Programme & LAM). Through the LAM case studies, various issues of data gaps and questions raised at the model implementation end (those that address real life problems), can be identified and then fed into the mathematical models and tools of LD. The Phase 2 team will attend workshops organised by the LC PCT and will explore synergies between Phase 2 work and the new mathematics work package, together with work being done through the Isaac Newton Institute

Modelling protocol:

<u>Models</u>: During Phase 1 of the Valuing nature work we assessed different ES tools for different user's need and short listed 5 tools or approaches for road-testing in Phase 2 of the work. Based on their range of complexity, the models selected were InVEST, LUCI, NEVO, Natural Capital Planning Tool (NCPT)/ The Eco-metric Approach and the Land Choices Guide. InVEST, LUCI and NEVO are simple to complex biophysical tools, NCPT or The Eco-metric Approach are simple, score-based excel tools and the Land Choices Guide is a simple guidance process for decision making in land choices through visual processes that include assessment of the land for pre/post development, survey of the land, and walking the land.

Case studies: Eleven potential case studies have been identified. Of these, four case studies have been used to test various ES tools/approaches for decision making. For example, the Land Choices Guide will be applied to make decisions for land use planning for the land acquisition in Dorset planned by the National Trust. It is a case study for local planning using simple guidance procedures for land use decisions. Use of more simple or complex biophysical models, as well as simple score-based approaches, will provide a good basis for comparison of the outcome with the ground-based, visual decision approach used by National Trust. The LUCI tool has been applied at Bassenthwaite catchment, Lake District and this case study will be good for comparison, particularly with InVEST and NEVO.

Initially we suggest starting with these 4 case studies with the short-listed ES tools and compare the outcomes

1. Choices between wildlife, carbon, recreation and food production by National Trust
2. Bassenthwaite catchment, Lake District. The Bassenthwaite catchment Environmental Stewardship scheme has made payments to farmers to enhance and deliver carbon and protect water. Defra and Natural England are interested in what has been delivered, and what could be achieved if LUCI was employed to spatially target agri-environment measures. Findings included increased carbon storage and reduced phosphorous export and sediment loads to rivers and lakes. Trade-off maps identified opportunity to increase both broadleaf woodland habitat and flooding provision (synergy).
3. Habitat Opportunity Mapping in Northamptonshire and Peterborough: Natural capital solutions, case study on habitat opportunity mapping in Northamptonshire and Peterborough that looked for possible location where new habitat can be created to provide specific benefits, while considering certain constraints into account (Rouqueette, 2018).
4. Catchment based analysis: Cranleigh waters sub catchment trial, NEVO tool has been applied for this catchment

Of the remaining 6 case studies described in section "Identification of Potential Case Studies for use in for Phase 2", one or two cases on impact of climate change could be included if there is adequate time and resources to include them.

Plan of Research:

1) End of Phase 1: Modelling teams and case study experts will be contacted at the end of Phase 1, after the Phase 1 report has been agreed by the steering group, the stakeholder group and NERC. The modelling teams will be provided with small amount of financial support in Phase 2, if required, to contribute to staff time to do the simulations (see below).
2) Months 1-2 of Phase 2: For the first two months, the appointed PDRA will collate data for the first workshop (see below)
3) End of Month 2 of Phase 2: Two workshops are planned, one at the end of beginning of the project and the other toward the end of the project. The first workshop will bring together the case study experts and the modelling teams. The case study experts will describe their case studies and the datasets available, and the modelling teams will present their models and data requirement/format for their models. This workshop will be used to define the detailed work plan, the decision on final case studies, the data requirements and format for all the models.
4) Months 3,4,5,6 of Phase 2: During the period between workshops, the modelling teams will test their models to solve real world questions by doing the simulations using the case studies, and this exercise will be performed with strong interaction with case study experts

throughout. The PDRA will assist the modelling teams with their simulations. In addition, the PDRA will also collate data for independent evaluations for the case studies, where there are real observation data for different ecosystem services such as carbon, water flow…etc. The aim of the model inter-comparison exercise is to compare the land use decisions provided by all models for achieving a particular ES benefit or multiple benefits. Independent evaluation will compare model performance against real observed data. Transparency of the models have been identified as one of the issues why the complex biophysical models are not used in various organisations. InVEST follows a "Goal structured notations approach" to assess assumptions in the tools. If possible, such analysis will also be applied to the other biophysical models, i.e. NEVO and LUCI.

5) <u>End on month 6 of Phase 2</u>: The second workshop will be used for the modelling / case study expert teams to present their results and the PDRA to present the findings from the model inter-comparison of quantitative results. A wider audience will be included by also involving other local stakeholders and members of the steering / stakeholder groups.
6) <u>Months 7-8</u>: The PDRA, with the input of all modelling teams and case study teams writes up the final report, including recommendations for next steps, and leads the writing of a peer-reviewed paper presenting the results of the model inter-comparison.

Plan of Research activities

Activity	1	2	3	4	5	6	Action
Appointment of PDRA							University of Aberdeen (UoA)
Collation of data for modelling							UoA
1st Workshop							UoA, modelling teams and case study experts
Modelling case studies with help from PDRA; PDRA also collates data for independent evaluations							Modelling teams, case study experts and UoA
Compilation of results for model inter-comparison by PDRA with help from modelling team							UoA, Modelling teams
2nd workshop							UoA, modelling teams and case study experts
Preparation of the report and peer-reviewed publication							UoA lead – contributions from all

Gauge interest from modelling / data teams and estimate costs

The model developers/ model users for the short listed ES tools were contacted and elaborated about the current Phase 1 work and plan of research for Phase 2 model inter-comparison exercise. The opportunity was welcomed as an excellent and useful exercise by many of the modellers and they are happy to participate.

List of modellers who were contacted for participation

Ecosystem Service Tools	Contact Person	Institutions
InVEST	Katrina Sharps	Centre for Ecology and Hydrology, UK
LUCI	Bethanna Jackson	Victoria University of Wellington, New Zealand
NEVO	Ian Bateman, Brett Day	University of Exeter, UK
Natural Capital Planning Tool	Oliver Hölzinger	The Consultancy for Environmental Economics & Policy (CEEP), UK
The Eco-metric Approach	Alison Smith, Clare Warburton and Alison Chapman	Natural England, UK
The Land Choices Guide	Rosie Hails	National Trust, UK

Summary of Resources Required for Phase 2 work

Financial Resources				
Directly Incurred		Full Economic Cost	NERC Contribution	% NERC Contribution
	Staff	£23,922	£19,138	80
	Workshop, Travel and Subsistence	£19,562	£15,650	80
	Partner Institutes	£31,250	£25,000	80
	Sub total	**£74,734**	**£59,788**	
Directly Allocated	Investigators	£4,770	£3,816	80
	Estate cost	£32,996	£26,396	80
	Sub total	**£37,766**	**£30,212**	80
	Total	**£112,500**	**£90,000**	

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