Local Natural Capital Plan (LNCP) Independent Review

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Contents

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Executive Summary

The OxCam Arc contains both extensive rural/semi-rural areas as well as several large cities and towns across five counties (including Oxford, Cambridge, Luton, Milton Keynes, Aylesbury, Peterborough, Northampton, Bedford). Jacobs was engaged by the Environment Agency to carry out an independent review of existing natural approaches, tools and studies and to make a set of recommendations for the creation of a Local Natural Capital Plan (LNCP) for the Oxford Cambridge (OxCam) Arc.

The review comprised a natural capital literature review, comprising 18 approaches (initial reviews and lists in Appendix C) , 33 tools or toolkits (long list and summary of features in Table 3.1), 40+ references for natural capital accounting, 18 case studies (Appendix F), which included 10 OxCam Arc natural capital studies, and an additional 33 natural capital accounting references. All were screened against a set of evaluation criteria and detailed reviews were carried out on over 40 of these.

The review focused on the natural capital technical aspects rather than the potential information technology requirements of the LNCP. Nonetheless, throughout the review, references to developing or harnessing an existing platform and methodology to host natural capital data were collated. The LNCP will be largely based on a GIS package as a series of layers. It should include an open-source database and web-portal with a map viewer, a graph visualisation tool and an appropriate database to store evidence chains. All data sets should be geo-spatially referenced. It was also beyond the scope of this review to identify specific data sources for all indicators, thus only data and indicator types were identified.

The main body of the report is structured into review and discussion of: Approaches (Section 2), Tools and their use in the LNCP development (Section 3), Natural capital studies undertaken in the OxCam Arc and elsewhere in the UK (Section 4), LNCP platform and data (section 5) and Natural Capital Accounting (Section 6). In many cases reviews informed more than one chapters as there is overlap between the categories of documents and aspects covered in each.

A set of thirteen Recommendations have been derived from the independent review. These are located at the beginning of the report and are signposted to the relevant parts of the main body of the review where supporting information is presented.

A six-step approach was recommended based on key elements of the Natural Capital Committee 'How to do it workbook', the Treasury Green Book and the Natural Capital Coalition Natural Capital Protocol. This was further supported by detailed approaches by CEH (2017), a range of Natural England work and Anglian Water, TVERC (2016) and Highways England OxCam expressway study (2019).

The review recommended that a formalised, structured, participatory and deliberative stakeholder approach should be implemented. Key steps where this can add value include: selection of indicators, prioritising ecosystem services and benefits, identifying pressures and drivers, qualitative valuation of assets and benefits and identifying locations and opportunities for investing in biodiversity and environmental net gain.

The reviewed OxCam Arc studies are summarised in Table 4.1 as to how and whether they addressed approach, scale, asset, opportunity, ecosystem service valuation, pressure mapping etc, covered urban, infrastructure, habitat opportunity and investment planning. The studies use of tools identified challenges with availability of local data, data licensing restrictions, cost of Phase 1 data and the fundamental need for a spatial approach. The studies predominantly addressed land use and habitat and only some addressed drivers, demand and pressures mapping. In the recommendations from the studies, many recognised the importance of habitat connectivity, the role of stakeholder participation and need for data sharing and transparency.

Reviewed natural capital studies for outside the OxCam Arc summarised in Table 4.4. A number of these studies produced asset registers and flow accounts, but none can be considered as full natural capital plans and concentrated on subsets of natural capital. Risks and trends in natural capital were not commonly addressed. Most studies either demonstrated the value of stakeholder engagement or recognised this in recommendations for future implementation.

In preparing the LNCP, regard should be had to the Natural Capital Committee (2019) stated recommendation for a joined-up approach to environmental data collection and recording across the public sector, thereby preventing duplication and waste of public funds.

In the development of an evidenced database, natural capital accounting and risk management, logic evidence chains should be used for the sequence: Asset → Ecosystem Service → Benefits → Value → Drivers and Pressures → Impacts → Management Intervention and Plans. The Natural England (2018) logic chains should form the basis for this work.

The asset register would be prepared from this evidence base via the extent and condition of a recommended set of Asset Types - grasslands and heath, woodland, farmland, freshwater, wetlands, urban, geodiversity, atmosphere, boundary and linear features - and subsets (Figure 2.1). A set of Asset Indicators - baseline location and extent - land use data, ecological function, resilience, accessibility, management practice, hydrology and geomorphology, nutrient and chemical status, soil/sediment, vegetation, species, cultural, air quality, biodiversity - is also recommended with subsets (Figure 2.2) based upon but not limited to the Natural England (2018) Indicators project publications.

Ecosystem services should be classified under the Common International Classification of Ecosystem Services CICES with reference to the US-EPA Final Ecosystem Goods and Services Classification System (FEGS-CS). These are subdivided into Provisioning, Regulating and Cultural Ecosystem Services with supporting ecosystem services being considered as part of ecosystem process and functioning.

In order to derive priority ecosystem services, the initial recommended approach is to use matrix-based tools with their inherent logic evidence chains to derive the ecosystem services from the spatial asset database. This would be supported by deliberative methods, expert panel and the adopted LNCP evidence chains.

Some advice is given on developing the LNCP evidence base, and asset and ecosystem registers of the evidence baseline. When priority ecosystem services are identified, they may first be quantified by simple analysis of existing data based upon spreadsheets, statistics, spatial analyses and databases, and only then by more complex modelling tools for key priority complex ecosystems services and supporting services. Figure 3.2 is a matrix identifying which ecosystem service are addressed by which tools. Tools are often specific to small thematic ecosystem services or asset types. Care must be taken to ensure that temporal and spatial considerations are taken into account and that tools used are supported and up to date.

Tools with in-built functionality to value ecosystem benefits are identified.

It is recommended that the LNCP adopt a natural capital accounting (NCA) framework. The accounts must be underpinned by and interpreted jointly with the asset register and ecosystem services register. A natural capital accounting approach does not necessitate monetary valuation. However, monetization of some aspects will be important as it is envisaged that the LNCP will ultimately inform an asset maintenance and investment plan. Monetised accounts will only ever be partial, and the strengths and limitations of accounting should be clearly communicated. Economic valuation needs to coincide with other forms of qualitative and quantitative assessment including participatory and deliberative techniques. The significance of non-monetised ecosystem services should be presented alongside monetised results. Where possible, significance comes first, and valuation is secondary.

The review identified that, although rarely carried out in UK natural capital assessments with some notable exceptions, a Risk Register should be prepared based on a Drivers, Pressures, State, Impact, Response (DPSIR) framework. Tools for risks and trend analysis and for opportunity mapping and trade off are identified in so far as they exist.

A structured spatial opportunity database and opportunity mapping is also a key requirement to enable the "enhancement" core objective of the LNCP to be met. This will need to be considered alongside where opportunities might have the most value through for example nature recovery networks, but also constraints to realising opportunities and demand for the benefits such as for recreation and air quality. An investment database should be included in the design of the LNCP to record maintenance, investments, the type of work carried out (i.e. creation, restoration, modification), the natural capital or ecosystem service aims of the project, the method, organisations involved and costs.

Recommendations

A set of recommendations considered relevant to the development of a Local Natural Capital Plan (LNCP) has been developed from a comprehensive review of relevant approaches, tools and studies. They aim to provide direction for developing an evidence-based plan that is relevant, adaptable and accessible. They identify appropriate approaches and application of tools. The recommendations are a synthesis of the key points covered in the review report and link to sections where supporting information is presented. The OxCam Arc LNCP development is underway and as such initial steps have been undertaken or are in progress but are presented here for completeness.

RECOMMENDATON 1 LNCP Platform and Structure

The LNCP will be largely based on a GIS package as a series of layers. It should include an open-source database and web-portal with a map viewer, a graph visualisation tool and an appropriate database to store evidence chains. All data sets should be geo-spatially referenced. Licensing restrictions will mean that some data sets cannot be shared with all stakeholders. However, all sources used can be listed and derived analysis can be made available.

The overall dataset should have many more parameters than needed for any single decision or application. The 1 km^2 hexagon grid used for the Natural England natural capital maps and The Oxford to Cambridge Arc Natural Capital Indicator Maps could form the target scale. However, the LNCP spatial database should be scalable to incorporate higher resolution data for use in analysis and provide flexibility in application.

Standard practice is to use Master Map and LULC maps such as CORINE and/or CEH LCM as a starting point. For urban areas, a detailed map of green infrastructure can serve as the basis for mapping urban ecosystems service (ES) supply and demand.

The LNCP should incorporate existing statutory environmental management boundaries, for example catchments, administrative units, and National Character Areas.

The LNCP should adopt the stated Natural Capital Committee (2019) objective of a joined-up approach to environmental data collection and approach should include national published natural capital research.

RECOMMENDATION 2 Structured 6-Step Approach [report section 2.3]

It is recommended that a 6-step approach is used to develop the OxCam Arc LNCP. The steps must be iterative, and at all times strive for full transparency of methods and data. Step 6, implementation and evaluation is however not discussed further in this document.

Step 1 – Scoping and objectives [report section 2.4]

- Desk based research on natural assets, ecosystem services, benefits and plans
- Initial stakeholder and expert identification and engagement
- Define Objectives
- Develop Scope

Step 2 – Evidenced baseline [report section 2.5]

- Use existing or develop logic evidence chains for priority relationships
- Select priority indicators for assets and ecosystem services and indicators
- Detailed analysis (mapping, environmental and ecosystem modelling, economic modelling)
- Develop natural capital asset register
- Develop ecosystem services flow register

Step 3 – Drivers, pressures and risk register [report section 2.6]

- Map drivers and pressures
- Natural asset and ecosystem service trend analysis
- Develop natural capital risk register

Step 4 – Natural Capital Accounting [report section 2.7]

- Select what to measure and value, valuation type, technique and participants
- Develop natural capital accounts – qualitative, quantitative and monetised

Step 5 – Plan formulation [report section 2.9]

- Scenario modelling
- Develop enhancement opportunity mapping
- Intervention, maintenance and investment plans
- Monitoring plans
- Governance, goals, measures, milestones, accountabilities and responsibilities

Step 6 – Implementation and evaluation [report section 2.9]

- Engagement and deliberative discussions with stakeholders
- Communication
- Policy response
- Feedback

RECOMMENDATION 3 Participatory Deliberative Approach [report section 2.10]

The plan development should include a programme of formal, structured, documented, participatory and deliberative discussions. Participating stakeholders will include beneficiaries, decision makers and potential users. The following steps would benefit from this approach:

- Scoping
- Selection of indicators
- Prioritising ecosystem services and benefits
- Identifying pressures and drivers
- Qualitative valuation for assets and benefits which are complex and/or difficult to quantify but deemed likely to be important
- Recommending locations and opportunities for investing in natural capital

Provision should be considered in the longer term for additional modules to allow citizen engagement and local data input.

RECOMMENDATON 4 Logic Evidence Chains [report section 2.1]

Develop a set of logic evidence chains for the relationships between three or more of the following components: Asset (location, extent and condition), Ecosystem Service Flows (biotic and abiotic as generated from the assets), Benefits, Value, Drivers and Pressures, Impacts, Management Intervention and Plans, depending upon the Step.

It is recommended to adopt the Natural England (2018) comprehensive set of 51 logic chains for 17 ecosystem services across 8 broad habitats set out in *Natural Capital Indicators: for defining and measuring change in natural capital – NERRO76* (2018), which can serve as a basis. Examples of logic chains are given in **Appendix D.**

The core logic chains will need to be extended to select indicators for changes in the state of natural assets from drivers and pressures with consequential welfare impacts on humans.

RECOMMENDATION 5 Scoping

The scope of the LNCP should reflect the range of decision-making issues the LNCP may be used to address. These may include, but are not restricted to: planning, development, public goods, policies (such as the Environmental Land Management Scheme), strategies, master planning, green infrastructure planning, nature recovery strategies, Biodiversity Action Plans, investment in net gain, identification of areas for priority protection, implications of new infrastructure and settlements, ecosystem service supply vs demand and for water and minerals planning.

A clear Statement of Stakeholders (including beneficiaries, decision makers and potential users) from the outset will inform the selection and design of logic chains.

RECOMMENDATION 6 Asset Register [Report section 2.5.1]

The asset (also known as stock, ecosystem and/or biophysical units) register should be compiled under the headings: Grasslands & Heath, Woodland, Farmland, Freshwater, Wetlands, Urban, Geodiversity, Atmosphere, Boundary and linear features.

Linear landscape elements such as hedgerows, single trees and field margins are not typically captured but are important for regulating services such as soil retention (erosion prevention), biodiversity, habitat connectivity and pollination. Acquisition of such data should be a priority for asset baselines.

Figure 2.1 contains sub sets of these asset or ecosystem types from which the assets for inclusion in the asset register can be selected. These take into account the review findings and include recent guidance by Defra, NCC, ONS national accounts, the Natural England asset quantity and quality indicators, Natural Capital Indicator Atlas and the indicators and data types used in the many studies reviewed.

A natural capital asset baseline register is an essential step to identify the key ecosystem services that underpin ecosystem benefits. The use of bespoke tools for developing the asset baseline is not necessarily needed as this can be built up as a series of layers in GIS software based on logic evidence chains and selected indicators. Climate change projections from models or other research can also be incorporated to help inform the future natural capital baseline.

RECOMMENDATION 7 Asset Indicators [Report section 2.5.2]

It is recommended the LNCP adopt the Natural England classification of indicators for location, quantity (extent) and quality (condition) as the starting point for building evidence bases on natural capital in the OxCam Arc. These are found in the Natural England *Natural Capital Indicators: for defining and measuring change in natural capital – NERRO76* (2018) and have already been used in the *Oxford to Cambridge Arc Natural Capital Indicator Maps* (2019).

Additional asset indicators can be selected for measurement from the following comprehensive indicator types derived from the review: Location and Extent, Ecological Function, Resilience, Accessibility, Management Practice, Hydrology and Geomorphology, Nutrient and Chemical status, Soil/Sediment, Vegetation, Species, Cultural, Air quality, Biodiversity.

Figure 2.2 contains sub sets of indicators for each of these type headings.

RECOMMENDATION 8 Ecosystem Services / Flow Register [Report section 2.5.2]

The LNCP Ecosystem Services / Flow Register should be based on the high level Common International Classification of Ecosystem Services (CICES version 5.1) which groups the services into provisioning, regulating and cultural services. It is recommended in line with CICES that the category of supporting services is treated as part of the underlying structures, process and functions that characterise ecosystems. There is also a spreadsheet tool available that provides broad equivalences for the US-EPA Final Ecosystem Goods and Services Classification System (FEGS-CS). A list of ecosystem services as identified in the review is given in Figure 2.3.

Appropriate services as determined by logic chains and tools (see below) should be selected for inclusion and measurement in the ecosystem services register. Although ultimately some of these will be used for valuation, in the first instance, they should be quantitative and non-monetary.

RECOMMENDATION 9 Tools for Quantifying Ecosystem Services [Report section 3.4]

A range of decision-support aids, including but not limited to digital models, GIS-based ecosystem service models, Excel-based look-up tables of values for ecosystem benefits and web-based interactive toolkits are available to help develop the LNCP and identify priority ecosystem services.

The initial recommended approach is to use matrix-based tools such as the Natural Capital Planning Tool (NCPT) and the Eco-metric. These are simple to apply and cover a comprehensive range of services. They use logic chains that synthesise expert opinion and scientific literature on the links between natural capital assets and the ecosystem services and benefits they provide.

Although this approach is an oversimplification, it can be very useful and economical in rapid determination and prioritisation of ecosystem services for the LNCP. Most ecosystems are 'multi-functional', and natural capital assets are important to delivering more than one ecosystem service. In many cases, the allocation of ecosystem service flows and selection of priority ecosystem flows is by expert panel. The simple matrix approach to ecosystem service identification and prioritisation for the OxCam Arc LNCP should be backed up by a combination of deliberative, participatory discussions. Whatever the tool used, the incorporation of local data and knowledge will increase accuracy and confidence in the results.

Once the agreed or priority ecosystem services have been identified, the mainstay of quantifying ecosystem services will be simple analysis of existing data based upon spreadsheets, statistics, spatial analyses and databases. The applications and methods are numerous and beyond the scope of this study. Typically, these will be developed from data published by bodies such as Defra, ONS, Environment Agency, Natural England, Forestry Commission and Water companies and others for statutory and economic purposes. Examples are given in report **section 3.2**. Where no simple analysis is possible, an alternative approach to mapping and quantifying these and which tools to use can be determined.

No tools rigorously assess all ecosystem services. The grouping of tools and their overlaps is shown in Figure 3.1. The ecosystem services covered under different tools are not identical and tools often consider different aspects of the service. Tools will need to be used in combination and in sequence, rather than in isolation. Figure 3.2 is a matrix of which ecosystem services are addressed by which tools and can aid in tool selection. Only tools which are supported and updated, and which are free to access for non-commercial use should be used.

The ecosystem services most commonly and easily assessed are carbon storage/sequestration, recreation, water quality regulation and flood regulation. These can be assessed by tools but also by simple calculation based on existing data, without resorting to expensive resource consuming modelling.

Many tools assess only services or less. For example, ORVal is widely referenced in other tools as a means of assessing and valuing recreation. Specific tools can target key individual ecosystem services and assets, such as i-Tree and SustainFARM. Different approaches and tools will be required for rural and urban contexts. In the latter case examples are green infrastructure tools such as GI-Val and B£ST.

Ecosystem processes take place at different temporal and spatial scales and this should be borne in mind when selecting tools. Insect pollination, for example, is a highly localised service that takes place at a specific time of year when pollinators are active whilst carbon storage is global and is not in essence seasonal.

Detailed modelling may be required, for example, for structural habitat connectivity and pollination. These will require moderate to advanced GIS skills, and often considerable modelling skills, and other resources and should only be used for priority ecosystem services which cannot be assessed by simpler means. Tools such as InVEST, ARIES, LUCI and NEVO can assess ecosystem services and take into account the underlying ecological structures, processes and functions to characterise the capacity of ecosystems to supply a given service.

The audit trail behind the application of tools should be transparent and include a clear rationale of why and how different tools have been applied, and which ecosystem services were assessed.

RECOMMENDATION 10 Risk Register [Report sections 2.5.2 and 3.4.4]

Regular trend analysis of the impacts upon priority assets and ecosystem services should be carried out. This will allow identification of trends that might negatively affect the local environment and economy or represent opportunities for growth. It would also inform asset maintenance budgets and natural capital investment plans, thereby ensuring the core LNCP objective of protecting and enhancing the OxCam Arc environment.

To achieve this LNCP's aim to protect and enhance natural capital, the LNCP should contain a risk register. It is recommended this be done by adopting the European Environment Agency DPSIR (Drivers-Pressures-State-Impact- Response) indicator-based framework approach. Causal logic chains should also be developed for the risk register.

As well as allowing preparation of a risk register, the DPSIR can highlight the indicators needed to enable feedback to policy makers on pressures and drivers of environmental quality changes and the resulting socio-economic impact. There may also be conflicts between conservation and economic development which this can help to resolve.

Priority pressures and drivers for the OxCam Arc LNCP will include: demographic, climate change, policy, economic growth, urban expansion and development, traffic and transport, funding sources, technological change and changes in ownership. A non-comprehensive set of risks to natural capital assets and ecosystem services arising from the drivers and pressures is given in Figure 2.5

Tools do not provide a systematic way of assessing the key pressures and drivers that are likely to affect natural capital stocks although aspects of this are done in InVEST, Co$ting Nature and NEVO. Approaches to trend analysis which could be adopted include: using spatial change in land use over time as a form of trend analysis (for example CSERGE, 2018; Natural Capital Solutions; 2018) and/or a matrix-based approach that draws on the logic chains described in **Section 2.4** to link pressures/drivers to natural capital stocks.

RECOMMENDATION 11 Trade-off/Scenario Analysis [Report sections 3.4.6 and 2.5.2]

There are a number of tools that can support analysis of ecosystem service trade-off or synergy 'win-wins', although at different levels of sophistication. Simpler tools such as the Eco-metric can record the quantum of change in assets and the relative change in ES that might be expected and can advise on aspects of net gain. However, they cannot easily represent in spatial terms what the impacts may be beyond the immediate area of land use change. In contrast, tools such as LUCI and InVEST will model the change dynamically, and feed factors such as slope, terrain and vegetation roughness into the analysis of both the immediate change in stocks and flows and wider changes on the landscape.

Of the tools reviewed, LUCI and NEVO have specific trade-off modules. Other techniques can be applied to examine trade-offs among services. For example, the spatial pattern of service provision across the landscape in the before and after scenario can be analysed, or the modelled change in biophysical values as a deviation from the mean, percentage change or absolute value. Other non-spatial techniques to displaying trade-offs include the use of 'rose'/'radar' or 'spider' diagrams.

Any decision-making that assesses trade-offs should be done with caution, as it will reflect only measurable indicators for a set of ecosystem services, not the total ecosystem value, and may not contain accurate data on current condition which is not always available.

RECOMMENDATION 12 Natural Capital Accounting [Report section 6.2]

It is recommended that the LNCP adopt a natural capital accounting (NCA) framework for recording and integrating science based and economic evidence, as well as facilitating stakeholder discussions. It is acknowledged that a natural capital approach does not necessitate monetary valuation. However, monetisation of some aspects will be important as it is envisaged that the LNCP will ultimately inform an asset maintenance and investment plan.

Accounts are a way of presenting in tabular format: how much natural capital stock exists, the volume of ecosystem service benefits and in some cases the monetary value of those benefits and how these are changing over time.

In preparing a natural capital account the following should be considered:

- The accounts must be underpinned by and interpreted jointly with the asset register and ecosystem services register.
- Ideally accounts should be based on spatially disaggregated data where possible, although this is challenging particularly at larger scales.
- Accounts will only ever be partial. The strengths and limitations of accounting should be clearly communicated.
- Economic valuation needs to coincide with other forms of qualitative and quantitative assessment including participatory and deliberative techniques.
- The significance of non-monetised ecosystem services should be presented alongside monetised results. Where possible, significance comes first, and valuation is secondary.
- Accounts should consider and present a systematic approach to assigning confidence levels (e.g. RAG) to indicate the quality and appropriateness of monetary data.
- Accounts should consider and treat three types of uncertainty: data quality, methodological uncertainty and statistical uncertainty. Confidence levels should be assessed and communicated in order to interpret the implications.
- Ecosystem services selected for monetisation should be identified through stakeholder consultation, reflecting those that are most important in the OxCam Arc. It is important to avoid double counting across multiple ES benefits.
- Monetary values imply trade-offs which can undermine the preservation of stocks. It is important to resist the temptation to add things up into a single figure.
- Long-term ownership and governance. The real value in an accounting exercise is when it is repeated. It is recommended that the accounts are updated every 5 years to show trends over time and to understand whether investments are having the desired impacts. This will also demonstrate whether net gain commitments are being met.

A review of the range of natural capital accounting tools can be found in report section **3.4.7.**

RECOMMENDATION 13 Opportunity Mapping [Report section 3.4.5]

It is recommended that the LNCP prepare a structured spatial opportunity database to record investments, the type of work carried out (i.e. creation, restoration, modification), the natural capital or ecosystem service aims of the project, the method, organisations involved and costs. Development of an opportunity database and opportunity mapping is a key requirement to enable the "enhancement" core objective of the LNCP to be delivered. Opportunities to enhance natural capital should be identified in a structured manner based on an analysis of the state of natural capital, trends and risks. Some examples of opportunities which can be given are shown in Figure 2.5. Studies providing examples of approaches to opportunity mapping are identified in **sections** 4.3 and 4.43.4.5 and include taking account of constraints and demand.

1. Objectives

1.1 Introduction

Jacobs was engaged by the Environment Agency, who are coordinating the delivery of the LNCP on behalf of Defra, to carry out an independent review of existing approaches, tools and studies relevant to the creation of a Local Natural Capital Plan (LNCP) for the Oxford Cambridge (OxCam) Arc.

The National Infrastructure Commission provided Government with proposals and options to maximise the potential of the Cambridge-Milton Keynes-Oxford Arc as a connected, knowledge-intensive cluster that competes on a global stage securing the homes and jobs that the area needs whilst protecting the area's environment (Partnering for Prosperity, 2017). The OxCam Arc currently supports around 1.8 million jobs and creates £90 billion in Gross Value Added annually and has been identified as having the potential to create significant economic growth from planned road, rail, jobs and housing investment.

The OxCam Arc contains both extensive rural/semi-rural areas as well several large cities and towns across five counties (including Oxford, Cambridge, Luton, Milton Keynes, Aylesbury, Peterborough, Northampton, Bedford).

1.2 OxCam Arc Local Natural Capital Plan

The LNCP has been identified as one of the ways in which the environment could be maximised for local people. It has been commissioned as part of the Government's vision for transformational growth within the Arc. Its overarching aim is to develop an evidence baseline to support both environmental protection and enhancement across the OxCam Arc. It will have local ownership and stakeholder participation to enable strategic delivery of wider environmental gain. The LNCP will aim to:

- Collate and assess the best available evidence of the type, extent and condition of natural capital assets in the OxCam Arc in a spatial format;
- Map the OxCam Arc's natural capital and ecosystem services;
- Identify existing environmental assets that must be protected and opportunities for supporting wider environmental gains;
- Provide a valuation (not necessarily monetary) of the natural capital / ecosystem services within the OxCam Arc;
- Set common data standards and approaches to natural capital baselines, registers and accounts;
- Provide shareable and accessible data such as the natural capital evidence baseline;
- Define a set of environmental indicators for the OxCam Arc to analyse future trends; and
- Provide recommendations for the next steps for the OxCam Arc's LNCP and a 'lessons learnt report' to inform future LNCPs and natural capital approaches.

The OxCam Arc LNCP is the first Government-endorsed LNCP and was first proposed in the 25 Year Environment Plan (25 YEP) strategy which set out the Government's ambition to improve the environment within a generation. The LNCPs will be strategic place-based plans that articulate the local vision and benefits of delivering the 25 YEP goals. Delivery working groups, responsible for setting priorities at a regional level, would include core stakeholders such as Local Authorities, Local Enterprise Partnerships, Local Nature Partnerships and the Defra family.

1.3 Objectives of the independent review

It is recognised that a range of different approaches are available to undertake the work needed to develop the LNCP. The LNCP should make appropriate use of existing data, assessments and tools, where practicable, whilst also ensuring that the approach can be understood, and outputs used by stakeholders.

The objective of the review is:

- To complete a systematic, critical and independent review of the different natural capital and ecosystem services studies, approaches and tools that have the potential to inform the strategic Oxford Cambridge Local Natural Capital Plan (LNCP) (or are currently in use within the OxCam Arc).

Outcomes from the review are to include:

- Summary Table(s) - Consideration of the strengths and limitations of the different natural capital and ecosystem services studies, approaches and tools that could inform the LNCP.

- Assessment of the relevance of a formal natural capital and ecosystem services accounting approach as a means of organising spatial natural capital and ecosystem services information on a repeatable basis for the OxCam Arc.

- A set of guidelines for taking forward the creation of an LNCP that meets users' needs, and provides information for use by others within the OxCam Arc (and elsewhere) to take forward natural capital assessments

1.4 Methodology

1.4.1 Reviewed references

In total, 117 references of natural capital framework approaches, tools and studies were collated, comprising tools (28), studies (18 case studies from 23 references), data sources (5) natural capital approaches (18) and natural capital accounting references (43). A number of these references cut across more than one category but in most cases are only reviewed in one section of the report. The references were reviewed and screened at high level and where appropriate, a detailed review was undertaken. A full list of all references collated is given in **Appendix A**.

1.4.2 Evaluation criteria

A set of evaluation criteria was developed to ensure a consistent approach to initial screening and detailed review of selected references. There was unavoidable overlap in the evaluation criteria applied across the various categories of references which were grouped into the following: Ease of Use, Purpose and Use in Decision Making, Scale, Stakeholders, Comprehensiveness and Data. A full set of criteria are presented in **Appendix B**.

1.4.3 Technical Group

A LNCP Technical Group convened by the OxCam LNCP Project Team. A Technical Group workshop was held in September 2019 on asset condition and in October 2019 to discuss interim findings of the review. Several Technical Group meetings which also informed the study with respect to data and platforms took place before the project commenced. In addition, the LNCP held a series of meetings with councils, infrastructure and industry stakeholders which further informed the review.

2. Approach to developing LNCP

2.1 Review of Approach Frameworks

A literature review of approaches to natural capital studies and plans was carried out. The key findings from the review are reflected in the discussion throughout the report. Summaries of selected approach reviews are given in **Appendix C1**, and a summary of selected study reviews in **Appendix G**.

A comparative review of the three most widely used frameworks for natural capital assessments in the UK - the Natural Capital Committee *How to do it workbook*, the Treasury *Green Book* and the Natural Capital Coalition Natural Capital Protocol - is given in **Appendix C2**.

The Centre for Ecology and Hydrology study *Natural Capital Metrics Phase 1 Final Report: Central components* CEH Project (2017) gives a review of some additional component framework approaches. These included the Cascade model (Potschin and Haines-Young, 2011) and various extensions or refinements of it, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Framework for Ecosystem Service Provision (FESP).

Several studies used a conceptual evidence chain framework. Logic evidence chains capture the links and interactions between natural capital ecosystem assets, ecosystem services and human benefits and beneficiaries. They provide the underpinning scientific audit trail.

Logic chains are also useful in determining which indicators can be used to define relationships. Maps can be linked to the evidence chains representing primary or derived indicators or model outputs.

Natural England (Natural England, 2018) have developed a relatively comprehensive set of 51 logic chains for 17 ecosystem services across 8 broad habitats in *Natural Capital Indicators: for defining and measuring change in natural capital – NERRO76*. Upward of 90 specialists from Natural England and the Environment Agency input into the development of these logic chains.

Several of the studies and approaches (CEH 2017, CSERGE 2018, Vivid Economics, 2017) have recommended and adopted the European Environment Agency DPSIR (Drivers-Pressures-State-Impact- Response) framework to account for risk. Logic chains can be extended to look at changes in the state of natural assets from drivers and pressures with consequential impacts.

Most natural capital assessments, plans and accounts are built upon logic evidence chains containing three or more of the following components:

- Asset (location, extent and condition)
- Ecosystem service flows (biotic and abiotic)
- Benefits
- Value
- Drivers and pressures
- Impact
- Management intervention and plans

Examples of logic chains are provided in **Appendix D**.

All natural capital approaches are designed to improve decision making for policy makers, businesses, land managers and funders/investors in order to manage the risks and maximise opportunities around changes in natural capital. While the main approaches differ, they generally follow a process of framing the assessment, scoping, creating an evidence base, valuation, interpretation, implementation and evaluation.

The specific approach of natural capital accounting is discussed in detail in **Section 6**.

2.2 Natural Capital Classification

Beyond the fundamental distinction between natural capital assets and the resulting ecosystem service flows producing benefits there is no definitive natural capital asset classification system.

2.2.1 Asset Classification

There is an increasing focus on natural capital assets, having evolved from ecosystem services, in recognition that protection and enhancement of stocks is critical to safeguarding ecosystem service flows. Assets are also known as stock, ecosystem and biophysical units.

Most assessments and plans classify assets by broad habitat with many sub categories and variations in use. Recent developments have further subdivided the broad habitat classifications and a selection of these are shown in **Appendix C3**. Increasingly atmosphere, geodiversity and other abiotic assets types are being adding to the broad habitat classification.

The broad habitat classification is used in the UK Office for National Statistics (ONS) Natural Capital Accounts. ONS have produced asset accounts for the eight broad habitat (UKNEA 2011) categories of woodland, farmland, freshwater, mountain, moor and heath and urban areas (the last two in part only) with scoping accounts for semi-natural grassland, coastal margins, marine and additional aspects of urban and mountains, moorland and heath. These habitat-based accounts measure the extent and condition of the habitat, as well as estimates of the ecosystem services provided by these. Cross-cutting or enabling accounts are also being scoped and developed for natural assets including peatland, carbon, coastal margins and land cover. These feed into the habitat accounts.

The Natural England (2018) asset classification system is based on the eight UKNEA broad habitats. The Natural England work evaluated freshwaters on a whole catchment basis. Natural England introduced a geodiversity asset type. They recognised that further asset classifications to those based on broad habitat and geodiversity exist, and explicitly used indicators to include these other asset types to avoid overlap and double counting. These are further discussed below in **section 2.5**. The report *A natural capital account of the National Nature Reserves managed by Natural England* (2018) uses the same broad habitat typology with some modifications.

The *Oxford to Cambridge Arc Natural Capital Indicator Maps* (LNCP, 2019) tool for early engagement produced maps of natural capital which are also based on the Natural England indicator and asset types. The indicator maps address freshwater, grassland & heath, woodland and urban environment as asset types using indicators of hydrology and geomorphology, nutrient and quality status, soil and sediment processes and species composition and vegetation.

The Defra *Measuring environmental change: Outcome Indicator framework for the 25 YEP* (2018), although not strictly addressing natural capital only, identified 10 broad themes – atmosphere, water, seas and estuaries, wildlife, natural resources, resilience, natural beauty and engagement, biosecurity, chemicals and noise and use of natural resources. The Natural Capital Committee's *Advice on an environmental baseline census of natural capital stocks: an essential foundation for the government's 25 Year Environment Plan* (2019) building upon the Defra (2018) work proposed an asset set of atmosphere, freshwater, soils, ecological communities, land and coasts, species, urban natural capital and oceans.

A set of natural capital asset indicators were taken from the above references and supplemented by the indicators used across the main studies reviewed and are presented in **Appendix C3**.

2.2.2 Ecosystem Services

Ecosystem Services are the variety of goods, services and benefits upon which people depend, and that arise from the natural environment and from ecosystems. Ecosystem services can arise from actions and interventions by people: i.e. be co-produced by ecosystems and society.

They are commonly categorised (MEA 2006) into Provisioning (e.g. water, food production), Regulating (e.g. the control of climate and diseases), Cultural (e.g. aesthetic values, recreational opportunities), and the underpinning

Supporting services (e.g. crop pollination). The Economics of Ecosystems and Biodiversity (TEEB) replaced "Supporting Services" with "Habitat Services" and "ecosystem functions", defined as "a subset of the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services" (Teeb 2010).

Action 5 of the EU Biodiversity Strategy requires member states to "map and assess the state of ecosystems and their services, assess the economic value of such services, and promote the integration of these values".

Further ecosystem service classifications reviewed include the Framework for Final Ecosystem Goods and Services (FEGS) developed by the US-EPA (Landers and Nahlik, 2013) and the widely used Common International Classification of Ecosystem Services (CICES version 5.1) which follows the EU Mapping and Assessment of Ecosystems and their Services (MAES) (2013) and UK Millennium Ecosystem Assessment (MEA) classification.

2.3 Recommended Approach Framework

A proposed best practice framework for the creation of an OxCam LNCP, derived from the literature review, is set out below. The following report is broadly structured around these steps. All frameworks emphasise that steps must be iterative, that assessments are done consistently and with full transparency of methods and data.

Step 1 – Scoping and objectives

- Desk based research on natural assets, ecosystem services, benefits and plans
- Initial stakeholder and expert identification and engagement
- Define Objectives
- Develop Scope

Step 2 – Evidenced baseline

- Review and select key logic chains
- Select priority assets and ecosystem services indicators
- Detailed analysis (mapping, environmental and ecosystem modelling, economic modelling)
- Develop natural capital asset register
- Develop ecosystem services flow register

Step 3 – Risk register

- Map drivers and pressures
- Develop natural capital risk register
- Natural capital asset and ecosystem service trend analysis

Step 4 – Natural Capital Accounting

- Select what to measure and value, valuation type, technique and participants
- Develop natural capital accounts – qualitative, quantitative and monetised

Step 5 – Plan formulation

- Enhancement opportunity mapping
- Intervention, maintenance and investment plans
- Monitoring plans
- Governance, goals, measures, milestones, accountabilities and responsibilities

Step 6 – Implementation and evaluation,

- Engagement and deliberative discussions with stakeholders
- Communication
- Policy response
- Feedback

2.4 Step 1 Scoping and Objectives

A clear Statement of Stakeholders (including beneficiaries, decision makers and potential users) and their objectives from the outset will inform the selection and design of logic chains and the components that follow.

Ensuring that the plan includes indicators which allow measurement and valuation of issues high on stakeholders' agendas will increase the likelihood of the LNCP being taken up and incorporated into decision-making.

The objectives of the LNCP must reflect the range of decision-making issues the plan may be used to address. These may include, but are not restricted to:

- Planning and development policies, strategies and master planning
- Green infrastructure planning
- Nature recovery strategies
- Biodiversity Action Plans (BAPs)
- Identification of areas for priority protection - the focus should not just be on protecting the highest quality assets as the poorer quality elements still provide value and may allow for enhancement.
- Implications of new infrastructure and settlement
- Opportunity mapping
- Investment in net gain
- Facilitating agricultural and land use management decisions
- Use of baseline to measure the success of public goods policies (such as the future Environmental Land Management Scheme)
- Ecosystem service supply vs demand – for example to inform water or minerals planning
- Consistency with ONS Natural Capital, Environmental and Social Capital Accounts, Environment Agency, Natural England and other databases, reporting and developing targets for the 25 YEP.

2.5 Step 2 Evidenced Baseline

The evidenced baseline will comprise of logic chains, an asset register and an ecosystem services physical flow register. The spatially-explicit natural capital baseline allows the extent, distribution and condition of natural capital assets in relation to human populations and economic and social activities across the landscape to be visualised and analysed. It will quantify the current stock of assets in the given area, from which future changes can be measured. It can also act as a baseline for any natural capital accounting which may be decided upon. The

asset baseline is also a necessary step to derive a spatially-explicit ecosystem services baseline, and to run tools that can perform more sophisticated analysis of the interaction between stocks and flows that underpin ecosystem benefits.

2.5.1 Asset Types

The natural capital asset register for the OxCam Arc will be based on asset type. The work done by Natural England on *Natural Capital Indicators for defining and measuring change in natural capital* (2018) and the associated *Oxford to Cambridge Arc Natural Capital Indicator Maps* (2019) form a valuable starting point for building the evidence base on natural capital in the OxCam Arc. A long-list from which to select specific asset types to be measured and valued in the Asset Register is given below and in **Appendix E1**. These include an additional two asset types from the Natural England classification.

Asset type groups	Asset examples
Grasslands & Heath	Hay meadows, heather, heather grassland, dwarf shrub heath, improved grassland, semi natural grassland - neutral grassland, calcareous grassland, acid grassland
Woodland	Broadleaved, mixed and yew woodland; coniferous woodland, individual trees/ancient/veteran trees, woodland priority habitats, ancient woodland
Farmland	Arable and rotational leys, horticulture, cropped and improved grassland, orchards and top fruit, permanent pasture grassland, plus hedges, ditches and small woodlands interspersed
Freshwater	Active flood plain, blanket bog, coastal and floodplain grazing marsh Main rivers, stream network, headwaters, standing waters (lakes, ponds, gravel pits), springs, groundwater management units, aquifers, catchments
Wetlands	Floodplains, reedbeds, swamp, marshes, raised and blanket bogs, floodplain grazing marsh, wet woodlands, reedbeds
Urban	Blue-green infrastructure, open mosaic habitats, urban/street trees, woodland scrub and hedge, semi-natural habitat, allotments, accessible greenspace.
Geodiversity	Soils and sediment, minerals, topography, slope, digital terrain model, geophysical, geological strata/bedrock type, unconsolidated deposits, fossils, aggregates and fossil fuels. (Geodiversity is critical in its underpinning of ecosystem and abiotic services)
Atmosphere	Precipitation (incl. distribution, seasonality, intensity), air and water temperature, evapotranspiration, emissions, sunlight/cloud cover, snow cover and length of snow lie, wind (including localised effects due to buildings, length of growing season (for vegetation), microclimate – particularly reduced temperature from green space and street trees
Boundary and linear features	Hedgerows, lines of trees, dry stone walls

Figure 2-1 – List of asset types

2.5.2 Asset Indicators

Asset indicators will be used to describe the asset types. A set of indicators derived from the review of approaches and studies is presented below in Figure 2.3. These take into account recent guidance by Defra and the Natural Capital Committee, ONS national accounts, the Natural England Asset Quantity and Quality indicators, the

Natural Capital Indicator Atlas, CEH 2015 and EC database (Corine 2012), as well as the indicators used in the many studies reviewed.

To build upon the stated Natural Capital Committee (2019) objective of a joined-up approach to environmental data collection and recording across the public sector, thereby preventing duplication and waste of public funds, it is recommended to include the Natural England classification of indicators. However, as with the asset types, these extend beyond the Natural England categories to take into account good practice in other studies. As such the indicator types are described under headings which cross cut the Natural England scheme for location, quantity (extent) and quality (condition).

These indicators are not exhaustive and apply to more than one asset type. As only some will be required in the LNCP, a key process in developing the evidenced baseline and asset register step will be the selection of indicators from the list (indicator lists are grouped 1-3 in Figure 2.2 below).

Natural Capital asset indicators - list 1	
Baseline location and extent - land use data	Typically, the database will be underpinned by ordinance Survey Master Map (underlying polygon layer) and a range of other data associated with each polygon, to measure extent of area (and provide location and basis for other indicators) including: Land use data: CEH 2015 Land Cover Map (LCM) and/or EEA Corine Landcover Map 2015 Habitat data: Natural England Open Mosaic Habitat (Draft) & Priority Habitat Inventory, NE SSSI Units & Ancient Woodlands, Forestry Commission National Forest Inventory. OS Open Green Space, Vector Map District & Strategy Environment Agency Main River & Artificial Canals
Ecological Function indicators	Connectivity of aquatic and terrestrial habitats, landscape fragmentation index naturalness of configuration of habitats, Mosaics/spatial distribution of different habitats, patch size, fragmentation Naturalness of habitat distributions allowing for dynamic movement of habitats (including transitions from marine to terrestrial); patch size, shape and edge Proximity to other semi-natural habitats, naturalness of spatial configuration of habitats, proximity to other habitat patches, patch size/shape Proximity of boundary features and semi-natural habitats to insect pollinator crops
Resilience indicators	Mass stabilisation and erosion control such as the location of habitats and boundary features in relation to soil erosion and landslip risk Distribution of flood mitigating land and features in relation to infrastructure & settlements
Accessibility indicators	Distribution of asset (e.g. woodland) in relation to settlements and infrastructure Proximity and accessibility of green space and blue space in relation to people – length, density (km/ha), presence of paths accessible to all – e.g. wheelchairs, pushchairs Cultural: % population who can access a minimum of 2 ha accessible green space / blue space within 2 miles of home, mean number of perimeter access points per km

Natural Capital asset indicators - list 2	
Hydrology and Geomorphology indicators	Amount of surface water run-off/overland flow, extent of artificial drainage, natural aquifer function-recharge and discharge Naturalness of flooding, lake, hydrological and groundwater flows regimes Channel morphology and sediment processes, physical modifications of water bodies, river continuity – lack of obstructions Condition of invertebrates, plants, fish in water bodies, for example through WFD ecological status, river water bodies assessed to be at risk of failing WFD objectives or at risk of deteriorating for a number of different environmental pressures, Nitrate Vulnerable Zones (NVZs) Loss of natural flood plain or its connection to rivers, permeability of ground surface, aquifer permeability and porosity properties, substrate, structures (tectonic, sedimentary, faulting & jointing), catchment characteristics, active geomorphological processes, drought statistics
Nutrient and Chemical status	Atmospheric deposition-exceedance of critical loads: particulates; ozone; N; S; pH Chemical status of water bodies, agrochemical use, nutrient status of water bodies (e.g. P, N, C, BOD, NH3), pH, soil and water contamination, nutrient status of soil N, P, K, C, pH, geochemical composition (including pH, carbon, nutrients)
Soil/Sediment Process indicators	Soil type, sediment supply/availability (including type, grain size), soil depth, soil/sediment carbon/organic matter content Soil/sediment biota and invertebrates bulk soil density, soil compaction Sedimentological regime: erosion & deposition, soil water retention esp. peat/organic soils, soil erosion, infiltration, soil moisture Soil integrity including: peatland erosion; tracking; braiding, surface roughness/microtopography, vulnerability mapping
Vegetation related indicators	Extent and condition of linear vegetation, features and pockets of semi natural vegetation, plant growth rate Presence and frequency of pollinator and food plants Proportion of peat mass actively forming peat, surface/vegetation roughness, vegetation cover/bare soil, vegetation next to water bodies, vegetation structural diversity, habitat distinctiveness, age structure (including veteran trees) Canopy – density and species composition, understorey - density and species composition, vegetation litter including debris dams, shadiness Composition e.g. root depth, evapo-transpiration, interception, above and below ground biomass, building integrated vegetation: including green roofs & walls, naturalness of vegetation, vegetation

Natural Capital Asset Indicators – list 3	
Management practice/protection policy indicators	Areas identified for protection through designation or policy or specific management objectives such as: Biodiversity Designations (National Nature Reserves (NNRs), Local Nature Reserves (LNRs), Natura 2000 sites, RAMSAR sites, SSSIs, SAC, SPA, UK BAP Priority Habitats, Local Sites in Positive Conservation management, County or local Wildlife sites) RSPB Reserves, Wildlife Trust and Woodland Trust sites, ancient woodland National Parks, National Trust Land, Registered parks and gardens Drinking Water Safeguard Zones (Water and Groundwater), Water Quality Priority Areas Countryside Stewardship /Environmental Land Management schemes Air Quality Management Areas Agricultural Land Classification grade1, 2 and 3a (best and most versatile) Areas of Outstanding Natural Beauty (AONB), National Character Areas, Conservation areas and Tree Preservation Orders Geological designated sites: e.g. Geosites. GeoParks; SSSIs, Local Geological Sites; Limestone Pavement Orders, Geoarchaeological sites Designated Historic Environment Assets – World Heritage Sites, Scheduled Monuments, Historic Parks & Gardens, Listed Buildings, Conservation Area; Registered Battlefields, Undesignated historical & archaeological remains

Figure 2-2: Asset Indicators: lists 1, 2 and 3

2.5.3 Ecosystem Service

An initial set of ecosystem services collated from the independent literature review is given below in Figure 2.3. Specific services from these lists should be selected for inclusion and measurement in the ecosystem services register. Although ultimately these will be used for valuation, in the first instance, they should be quantitative and non-monetary.

Ecosystem Services examples	
Provisioning	Statistics and indicators related to livestock, crops, pasture, horticultural products, agricultural biomass, Water supply for drinking and non-drinking purposes - surface water, groundwater, rainfall and health & productivity of water for abstraction. Energy provision for oil, gas and renewable energy (abiotic), minerals quarried, rock/mineral extraction (abiotic), plant-based fuel harvested / plant-based energy Timber, paper & other wood products, wild plants, algae & their outputs, aquaculture, abstraction reliability, water resource availability, other food and drink provision
Regulating Services	Statistics and indicators related to richness of pollinators and seed dispersers, proximity of boundary features and semi-natural habitat patches to insect pollinator crops Pest controlling species and general pest control, intact fungal networks to reduce infections in plants

	Thriving wildlife, maintaining nursery populations and habitats, air filtration and air pollutants removed Climate regulation – local and global, urban cooling Water quality regulation (chemical and biological, including pH viral & bacterial), erosion control Noise abatement, flood regulation, protection, drought resilience, mediation of waste, toxins and other nuisances by ecosystems and biota Maintenance of sustainable ecosystems & life cycle stages, stabilisation of soil/sediment, carbon sequestration by soil and biota
Cultural	Statistics and indicators related to scientific and educational value, aesthetic nature, sense of place appreciation, interaction with nature, recreation, spiritual and/or emblematic, culture and history Visibility of wildlife (birds, mammals, butterflies), presence of flagship species, presence of rare (red list) species, number of research projects; PhD / Masters projects, number of visits - duration of visits, range of activities undertaken, number of people carrying out each activity, frequency and time spent, number of school visits, distance travelled from car park / transport, number/continuation of traditional festivals and practices Public access, public footpaths, accessible paths, public rights of way; footpaths, bridleways, byways Above and below ground heritage and archaeology, ancient routes – condition, geo-heritage: building stones, industrial heritage, history of geoscience, scientific importance e.g. for past climate/environmental history, geoarchaeology including human evolution Cultural associations with artists, writers, legends, folklore, presence of land/environmental art, landscape - uninterrupted views – absence of pylons, turbines, attributes of landscape character, quietness - dark skies, tranquillity, remoteness, noise levels

Figure 2-3: Classification of Ecosystem Services

2.6 Step 3 Risk Register

2.6.1 Drivers, Pressures, State, Impact, Response (DPSIR) framework

To satisfy the LNCP objective to protect and enhance key environmental assets, it recommended that the LNCP develop a register of drivers and pressures from which a risk register can be prepared.

This would inform the maintenance budget for assets and natural capital investment planning to ensure the core LNCP objective of protecting and enhancing the OxCam Arc environment is achieved.

Several approaches and studies (CEH 2017, CSERGE 2018, Vivid Economics 2017) have adopted the European Environment Agency DPSIR (Drivers-Pressures-State-Impact- Response) framework. This is recommended for the OxCam Arc LNCP. As with the evidenced baseline, DPSIR is an indicator-based approach. It will use causal logic chains to look at changes to the evidenced natural capital baseline from drivers and pressures with consequential state changes and welfare impacts on humans (Elliott et al., 2017).

As well as allowing preparation of a risk register, the DPSIR can highlight the indicators needed to enable feedback to policy makers on pressures and drivers of environmental quality changes and resulting socio-economic impact. There may also be conflicts between conservation and economic development which this can help to resolve.

Drivers and pressures of change can be immediate or more long term and can be influenced by location or external pressures and management. A range of pressures and drivers (or impact drivers in the language of the Natural Capital Protocol) have been identified from the studies and the guidance for consideration within the LNCP:

Examples of drivers and pressures	
Demographic	Population growth, seasonal peaks in human population e.g. with tourism, deprivation, pressures on recreation
Climate change	Altered temperature, precipitation, land cover, water supply, sea level rise, increased storms, acidification, extreme events
Urban expansion and development	Infrastructure development, land take, new housing & transport needs, increased density of development
Policy	Legislative change, regulation/de-regulation, local initiatives & targets, attitudes to greenspace & public health
Economic growth	Market forces, commercial growth/decline, domestic and global - decline in heavy industry, dereliction, new industry, new or increased natural resource exploitation including renewables and solar, mining activity and quarries, use of agrochemicals, plastics etc., waste disposal
Traffic and transport	Change in domestic traffic and/or public transport
Funding Sources	Availability of funding & management for urban greenspace: public, private, lottery, charitable, agri-environment, bio-energy schemes, awards/accreditation e.g. Green Flag
Technological change and advances	For example, water-efficient crops, GM, machinery & methods, biofuels, biochar
Changes in land ownership	Private/public ownership, tenancy types

Figure 2-4: Examples of drivers and pressures

Data and indicators supporting these will be taken from many sources including but by no means limited to: Local Plans, Spatial Plans, climate change projections, JNCC, Forestry Commission and NERC published projections for species and habitats.

2.6.2 Risks

Risks consequent to the Drivers and Pressures can include:

- Unfavourable declining condition of international, national, regional and local designated sites, habitats and species
- Habitat loss
- Habitat fragmentation leading to decline in fauna and flora diversity e.g. by forest cover loss, roads and other linear features
- Invasive species, pests and diseases
- Changed water abstraction and water availability for domestic, commercial and industrial, agricultural and hydro-ecological purposes - disruption from water shortages, drought, flooding and other extreme weather
- Atmospheric deposition (acidification, eutrophication) and pollution – especially particulates & ozone - acidification, eutrophication, increased Greenhouse Gas (GHG) emissions and depositions

- Pollution – toxic & nutrient enrichment (including oil, endocrine disruptors, nanoparticles, plastics & pharmaceuticals)
- Change to water quality affecting health and ecology - including urban & road run-off, cross connections: overflows from foul to storm sewers, effluent and other releases
- Noise and light pollution
- Agricultural change including increased use of insecticides and pesticides
- Impacts on recreation and wellbeing
- Increase in demand for certain ecosystem services
- Changes in natural hazard and resilience requirements e.g. soil erosion and landslips

2.6.3 Trend analysis

Regular trend analysis of priority assets and ecosystem services should be carried out to map the change in condition of assets over time. This will allow identification of trends and further risks that might negatively affect the local natural capital and economy or represent opportunities for growth. The LNCP project would ideally show this narrative visually and in statistics as part of its reporting structure.

It should be an aspiration of the LNCP to identify specific risks to the OxCam Arc natural capital once it is completed. This may include identifying specific habitats and high value areas at risk due to increasingly isolated areas of biodiversity.

However, many data sources will have insufficient spatial resolution nor a consistent time series to monitor change over time. This must be borne in mind when selecting indicators and when deciding what ongoing or increased monitoring is required.

2.7 Step 4 Natural Capital Accounting

NCA is an approach in and of itself and is considered in detail in **Section 6** of this report. It is acknowledged that a natural capital approach does not necessitate monetary valuation; however, accounting provides a framework for collating and synthesising the information garnered though Steps 1-3. Further, as it is envisaged that the LNCP will ultimately inform an investment plan, it is recommended that an account is produced.

As discussed further in **Section 6**, the benefits and limitations of NCA should form part of any communication of the accounting approach. The benefits and limitations of NCA are discussed in detail in **Section 6** of the report.

2.8 Step 5 Plan Formulation

2.8.1 Opportunity Mapping

Development of an opportunity database and opportunity mapping is a key requirement to enable the "enhancement" core objective of the LNCP to be met. The objective would be to protect local economies against environmental risks by improving the natural environment rather than just mitigating or compensating for loss and making local communities more attractive places to live and work.

Opportunities to enhance natural capital should be identified in a structured manner based on an analysis of the state of natural capital, trends and risks. To prioritise opportunities, the relative demand should be compared to their current supply and cost-effectiveness analysis undertaken for measures that deliver new or enhanced benefits.

Opportunities may include the following:

Opportunities for enhancement	
Flood incident reduction	Natural flood management schemes, reduce surface water runoff, increase natural flood plain or its connections to a river, bank reinforcements, review of in-channel structures
Water resource and quality improvement	Improvements in water supply and quality (including bacterial, viral and suspended sediment) for both people and the environment, stored water to increase drought resilience, control pattern/timing of abstraction, discharges, pollution control strategies, catchment water demand management (e.g. abstraction license planning/spray irrigation restriction), land wetting, flow modification/ water level regulation, impoundment & diversion, water efficiency (e.g. metering, leakages, farm advice), alternative sources of abstraction (e.g. desalination) or relocate abstraction/discharge, river augmentation from groundwater, river restoration, water transfer
Urban environment	Creation, design and retrofit of wider green infrastructure networks to manage risks from urban stormwater and to enhance well-being and connectivity for biodiversity, SuDS, pollination corridors, grassland management measures, enhancing grassland/woodland e.g. planting, seed sowing, urban tree management, improve air quality and reduce the urban heat island effect, land reclamation
Habitat improvement	Habitat creation and restoration, scrub, bracken, gorse control, management of aquatic & terrestrial vegetation, removal of wood, biodiversity enhancement by increasing connectivity, expanding the size of existing ecological and habitat networks – both terrestrial and aquatic and reducing fragmentation, restoring and creating woodland & wetlands, improve condition of designated sites, river restoration, improve undesignated land with a high cumulative landscape and ecological value, focus on areas for priority protection, bio-energy crops, hedge management and enhancement, field boundary management and restoration
Recreation/cultural	New or enhanced nature-based recreation, educational opportunities, increased awareness and engagement with environment
Climate Change	Reduced GHG emissions, increased carbon sequestration.

Figure 2-5 Examples of opportunities

It is recommended that the LNCP prepare a structured spatial database to record investments, the type of work carried out (i.e. creation, restoration, modification), the natural capital or ecosystem service aims of the project, the method, organisations involved and costs.

2.8.2 Wider Plan Formulation

Plan formulation is largely beyond the scope of the independent review, but some general comments are made, deriving from the review:

i. The LNCP should be fronted by a regularly updated and compelling narrative.

ii. Develop the plans based on the risk register in the first instance

iii. Focus on maintaining, protecting and enhancing natural assets as these underpin the benefits and ecosystem services to society, for example incentivising prevention of asset degradation.

iv. Urban and rural natural capital, whilst following the same overall framework and structure, will necessarily be treated differently within the overall framework.

v. Include updated narratives, maps of natural capital assets and ecosystem services

2.9 Step 6 Implementation and Evaluation

Guidance on approaches to natural capital emphasise that engagement and deliberative discussions with stakeholders must occur throughout as an integral part of the process. Stakeholders will include beneficiaries, decision makers and potential users.

Deliberative techniques are an approach to decision-making that allows participants to consider relevant information from multiple points of view. Deliberation enables participants to discuss the issues and options and to develop their thinking together before coming to a view, taking into account the values that inform people's opinions. To be deliberative, a process must:

- Have a clear task or purpose, related to influencing a specific decision, policy, service, project or programme;
- Be interactive (including through online technologies);
- Provide time and space for participants to learn from a variety of sources;
- Have a logical path through learning and discussion;
- Work with a range of people and information sources – including information, evidence and views from people with different perspectives, backgrounds and interests; and
- Manage discussions to ensure that a diversity of views from people with different perspectives are included, that minority or disadvantaged groups are not excluded, and that discussions are not dominated by any faction.

2.10 Stakeholder Engagement

Participatory stakeholder workshops and deliberative processes were undertaken to inform many of the studies reviewed, such as the North Devon Landscape Pioneer (Eftec, 2018; Thomson, 2019) and will form an increasingly important role in natural capital approaches.

It is recommended that a formalised, structured stakeholder participation and deliberative approach should be used in the following tasks or purposes for developing the OxCam Arc LNCP:

- Scoping (Step 1)
- Selection of indicators (Step 2)
- Prioritising ecosystem services and benefits (Step 2)
- Identifying pressures and drivers (Step 3)
- Qualitative valuation of assets and benefits which are complex and/or difficult to quantify but deemed likely to be important (Step 4)
- Recommending locations and opportunities for investing in natural capital (Step 5)

All stakeholder engagement should be documented. Provision should be considered in the longer term for additional modules to allow citizen engagement and local data input.

3. Tools

3.1 Definition of tools

The term 'tools' is used to describe a range of decision-support aids, including but not limited to digital models, GIS-based ecosystem service models, Excel-based look-up tables of values for ecosystem benefits and web-based interactive toolkits.

The review focuses on tools developed or adapted for use in the UK and that compare, quantify or value natural capital assets and ecosystem services. Ecological, hydrological and other discipline-specific tools or modelling packages are not reviewed. Analyses based on existing data are also not reviewed but are commented on below.

3.2 Quantification of assets and ecosystem services

The mainstay of quantifying assets and ecosystem services is simple analysis of existing data using, or based upon, spreadsheets, statistics, spatial analyses and databases. The applications and methods are numerous and beyond the scope of this study. Typically, these are developed from data published by bodies such as Defra, ONS, Environment Agency, Natural England, Forestry Commission, Water companies and others for statutory purposes, such as:

- Environment Agency flood risk modelling
- Water resource management
- Nutrient supply and occurrence
- Nature Recovery strategies and BAPs
- Agricultural and horticultural data sets
- Carbon data
- Climate change projections from models or other research
- Provisioning data, e.g. minerals, food, drink and fibre

It is clear from looking at the long list of Provisioning, Regulating and Cultural ecosystem services in Figure 2.3 that many of these can be quantified by a combination of existing published statistical, spatial and analytical data. For examples arable production and carbon storage in soil and biomass in the OxCam expressway study which was derived from analysis of arable land area within the CEH Land Cover 2017 plus Crops map, and carbon data derived from NATMAP and SOILSERIES datasets.

3.3 Tool screening

A longlist of 28 tools, some of which are families of tools or toolkits, was produced from a desktop review of literature and online platforms. These included the Ecosystem Knowledge Network (EKN) Tool Assessor and the Values Methods Database,. Existing tool reviews were also consulted including Natural England Access to Evidence - Natural Capital, JNCC, and the Tools for Assessing Natural Capital workshop report (Defra, 2018) to understand what tools have been applied to different contexts and spatial scales. Links to the tools and further information about these tools and their strengths and limitations is provided below and in **Appendix E**.

The long list of tools, their name, tool acronym and key features (scale of application, tool interface, level of skill required to apply the tool, form of output) are presented in Table 3.1 below.

Table 3-1: Long list and features of natural capital and ecosystem service tools

Tool name	Acronym	Scale	Interface	Skill requirements	Review priority
Artificial Intelligence for Ecosystem Services	ARIES	Landscape / regional	Specialised software (k.LAB/Eclipse) Web Explorer version just launched	High. Low for ARIES Explorer	ARIES is a modelling platform with artificial intelligence features (semantics and machine learning) that allows for best available data and models to model ecosystem services. On further enquiry, the developers indicated that several models – e.g. fluvial regulation, nutrient regulation, water supply are being redeveloped. The newly released Web Explorer currently has limited UK data. Not reviewed further.
Benefits Estimation Tool (Valuing the Benefits of Blue-Green Infrastructure) (5.1.1)	B£ST	Site-level / precincts	Excel-based	Medium	B£ST is an Excel-based tool that values 17 environmental, social and economic benefits of blue-green infrastructure and natural flood management schemes, all but 3 of which can be monetized within the tool. The evidence base for the tool was updated in 2018/19. The tool includes a screening stage to help users determine the benefits to be evaluated. The tool supports both independent assessments (and the values derived) or provides one or more approaches to allow for valuation of potential benefits. A results dashboard and sensitivity analysis allows the user to test how the confidence scores and time horizon influences the results. The tool has been applied in the UK. It is largely suited for site-level applications and cannot immediately inform the key LNCP objectives. High-level review completed.
Capital Asset Valuation of Amenity Trees	CAVAT	Site-level	Excel-based	Low	CAVAT takes account of location, relative amenity, social value and appropriateness, functionality and life expectancy to calculate the value of trees. It uses a replacement cost approach rather than an ecosystem services approach, which is better captured in more widely used tools e.g.-Tree Eco. Not reviewed further.
Co$ting Nature (3.0)	C$N	Global to local	Web application	Medium	C$N is a web-based spatial analysis tool. It uses pre-loaded global datasets at 1km^2 or 1ha resolution and aggregates values into 'bundled service index' on a scale of 0-1. It takes account of service supply, location of beneficiaries and therefore both potential and realized services and provides a globally or locally relative index of service provision. It also supports analysis of co-benefits, pressures and threats. The main drawbacks are that it does not support mapping of individual services or their valuation, and uses global data, so is less well suited to the LNCP aims. High-level review completed.
Defra Biodiversity Metric (2.0)	-	Site-level / precincts	Excel-based	Medium	The Defra Biodiversity Metric purpose is to determine what the before and after land use change implications are for biodiversity net gain. It is linked to but has a narrower focus than the current LNCP objectives. Not reviewed further.
Eco-metric (2.0)	-	Site-level / precincts	Excel-based	Medium	The Eco-metric tool was developed to be used after the Defra Biodiversity Metric to assess the impact of land use change on the delivery of ecosystem services. Although intended for site-based applications, the tool may be able to be adapted for baseline development. The logic chain approach has a strong evidence base taking account of expert opinion on the influence of habitat condition and spatial location to service delivery. Detailed review completed.

Tool name	Acronym	Scale	Interface	Skill requirements	Review priority
EcoServ-GIS (3.3)	-	Regional (1500-5000km^2)	GIS-based (ArcGIS 10.2.2 with Spatial Analyst Extension)	Medium	EcoServ-GIS is a GIS-based suite of ecosystem service models. The tool has been used in the Arc for opportunity mapping by Natural Capital Solutions. There are currently no resources available to maintain the tool and limited user support is available. Detailed review completed.
Environmental Valuation Look-up Tool	EVL	Data base of monetary values – multi scale application	Web-based	Low	The Environmental Values Lookup Tool is an online searchable database which contains indicative monetary values for environmental impacts and secondary/incidental impacts that might otherwise overlook environmental impacts. Based on a review of over 350 UK valuation studies conducted since 2000. High-level review completed.
Environmental Valuation Reference Inventory	EVRI	Data base of monetary values – multi scale application	Excel-based database	Low	EVRI is a comprehensive benefit transfer database of valuation studies. Coordinated by Environment Canada, over 25% are European studies, and 10% UK studies. Consultants are asked to input studies they have conducted for Defra. High-level review completed.
Green Infrastructure Valuation tool	GI-Val	Local/ site level	Excel-based calculator PDF User Guide	Low	The Green Infrastructure Valuation Toolkit provides a set of calculator tools to assess the range of GI benefits from an asset or investment in monetary, or quantitative terms. It also provides a range of recommendations on the recommended timeframe for appraising value and returns for each ES. It is not suited to be applied at the scale of the Arc but could be used at smaller spatial scales by partner authorities. It has been applied to residential developments and district improvement schemes in the UK. High-level review completed.
Health Economic Assessment Tool for Walking and Cycling	HEAT	Policy /Site level	Excel-based	Low	The Health Economic Assessment Tool (HEAT) is a health impact assessment model that estimates the value of reduced mortality associated with interventions that provide walking and cycling opportunities. The tool could be used as part of ecosystem service valuation but is likely to be best suited to assessing benefits of policy interventions or at a project scale once a baseline has been developed. High-level review completed.
The Helliwell System	-	Local/ site level	Excel-based	Low	The Helliwell System is a tool that monetises the visual amenity provided by individual trees or woodlands. The tool allocates scores for several factors, which are combined to give a comparative score for a tree or woodland. A value can be attached to this point score through use of a monetary conversion factor. A previous review by Natural England (2013) determined that the source of the unit economic factor was not clear, and bundling effects were not considered by the tool. It is therefore not recommended for use by the LNCP. High-level review completed.
HydroloGIS	-	Regional to local level	GIS-based	Consultancy only	HydroloGIS was developed from the EcoServices Platform by Viridian Logic. The tool is focused on 5 flow-related ecosystem services and ranks areas of landscape for ability to best address the target problem e.g. flooding, pollution etc. It is designed to inform decisions about what type of habitat to create and where to provide nature-based solutions to local problems. It models place-based services and water-flow services. This review focuses on multiple ecosystem

Tool name	Acronym	Scale	Interface	Skill requirements	Review priority
					service tools, but this tool could be used for flow-based services. High-level review completed.
Integrated Valuation of Ecosystem Services and Tradeoffs (3.7.0)	InVEST	Regional to local/ site level	GIS-based Desktop application; Python API (optional)	Medium	InVEST is a suite of ecosystem service models to map and value ecosystem goods and services provided by terrestrial, freshwater and marine ecosystems. It can be used either with ArcGIS geographical information software or as a standalone software package. It is one of the more widely applied modelling tools and has been applied and been the subject of validation studies in the UK. Detailed review completed.
i-Tree Eco (6.0)	-	Local/site level	Excel-based	Low	i-Tree Eco is one of a suite of i-Tree tools, developed in the US and adapted to the UK context. It values regulating services associated with individual trees or urban forests. The tool has been applied by several Local Authorities in the UK to develop urban tree/woodland accounts. Not suited to developing Arc-wide baseline but could be used at smaller spatial scales and integrated at a later stage. High-level review completed.
Local Environment and Economic Development toolkit	LEED	Regional		Low	LEED is a strategic economic decision-making toolkit for LEPs to systematically consider evidence relating to the local economy/environment relationship in order to reveal opportunities and threats; and consider appropriate responses. The tool consists of a workbook and reporting templates to support a 3-tier workshop approach to identifying ecosystem service opportunities and threats in an area. The documentation can be accessed from the EKN website. High-level review completed.
Land Use Capability Indicator	LUCI	Landscape/ regional/sub-field	GIS-based	High	LUCI is GIS-based suite of ecosystem models that assesses the potential gain and loss, and tradeoffs in ecosystem services under different land management scenarios. It can be applied from a very fine (subfield) scale to a regional or national level. It is one of the more widely applied multiple ES modelling tools and has been applied in collaboration with CEH and been the subject of validation studies in the UK. Detailed review completed.
Multiscale Integrated Earth Systems Model	MIMES	Local/regional	MIDAS/SIMILE software required (not open source)	Low	MIMES has been the subject of previous tool reviews but the tool could not be accessed online for review and no contact could be made with the tool developer. Not reviewed further.
National Ecosystem Approach Toolkit	NEATree	Information on other tools and approaches	Interactive web-based guidance	Low	NEATree is a web-hosted toolkit providing information on various approaches and tools, not a tool in itself. It is not clear when it was last updated. Not reviewed further.
Natural Capital Planning Tool (1.5)	NCPT	Site-based	Excel-based	Low	Design principles of NCPT were incorporated into the Eco-metric. However, NCPT aggregates ES to generate a 'development impact score' which is not standard practice. Not reviewed further.
Natural Environment Valuation Online	NEVO	National to local levels ($2km^2$ grid) including catchment and administrative areas	Web-based GIS interface	Low	Natural Environment Valuation Online is a recently launched web-based tool that incorporates several ES models (including ORVal). It allows users to select an administrative or terrain based area and includes 3 types of functionality to view how land use and ES are predicted to change between 2020-2030 and how flows of ES change under land use or price changes,

Tool name	Acronym	Scale	Interface	Skill requirements	Review priority
					where the optimal outputs can be delivered based on area and type of land use change or to determine the best location for the delivery of selected services, by quantity or value. Outputs can be downloaded in Excel or as maps. Detailed review completed.
Outdoor Recreation Valuation Tool	ORVal	Regional to local/site level including catchments and administrative areas	Web-based GIS interface	Low	ORVal predicts visitation and welfare value for currently accessible greenspace, and changes to these values based on change in greenspace characteristics. The tool also predicts visitation and welfare value of new sites created by users. Results can be grouped by local authority area or catchment and can be split by socio-economic group. The tool is widely used to value recreation and is also integrated into the NEVO model. Not reviewed further
Participatory GIS tool	PGIS	Local/regional	Web-based GIS interface	Low	Not an 'off-the-shelf' solution. PGIS is a prototype specific to area in the North of England but approach/design could be considered - mapping social preferences can support wider valuation of cultural ES. High-level review completed.
Spatial Evidence for Natural Capital Evaluation	SENCE	National to regional	GIS-based	Low	This is a tool provided as part of a consultancy offering and it is adapted according to project need. The data collation stage is particularly robust. It has been applied in the Scottish Borders (Vorstius and Spray, 2015), Wales (NRW, 2016), Ireland (Parker *et al* 2016) and to the West of England Nature Partnership (2019). High-level review completed.
Social Values for Ecosystem Services Tool (3.0)	SolVES	Not applicable	GIS-based	N/A Consultancy only	SolVES requires primary data collection which is then computed spatially by the tool. It was developed in the US and no examples of UK applications were found. The requirement for data collection reduces its immediate use for the LNCP. Not reviewed further.
SustainFARM Public Goods Tool	-	Farm level	Excel-based	Medium	The SustainFARM Public Goods Tool incorporates elements of natural capital within wider analysis of farm sustainability (e.g. taking account of human activity). For the current LNCP it is not recommended as being particularly suited to the stages mapped out but could be used at smaller scales to evaluate contribution of individual farms to ecosystem service provision. Not reviewed further.
Toolkit for Ecosystem Service Site-based Assessment	TESSA	Site level	Interactive toolkit	Low	TESSA is structured as a series of modules for each service and is primarily aimed at conservation practitioners and addresses contexts with considerable gaps in data (e.g. developing countries) Links and guidance to other tools to are provided. TESSA is not considered suited to application at the scale of the LNCP Arc. It has been applied to Wicken Fen and could be considered to support decisions on individual sites. Not reviewed further.
Woodland Valuation Tool	-	Any level	Excel-based	Low	The Woodland Valuation Tool is an Excel-based look up tool focused specifically on ecosystem service benefits of woodland. The tool was developed in 2015 and updated in 2018. The tool allows users to search by goods/services, types of beneficiaries, units of measurement or region, amongst other categories. Not reviewed further.

Some general observations can be made.

- Ecosystem services most commonly assessed by tools are carbon storage/sequestration (15 out of 20 tools), recreation (13) and water quality regulation (12). In contrast, very few tools assess pest regulation (2 out of 20), noise regulation (2) or education (2).
- Several tools assess 3 services or less: CAVAT, the Helliwell System, PGIS, ORVal, SustainFARM. However, ORVal is widely referenced in other tools as a means of assessing and valuing recreation.
- Carbon sequestration and flood regulation tend to be the most commonly assessed services. This is likely to be because a) the stock or service is readily monetised, and b) the assessment method is relatively well developed and documented.
- Several tools also assess, and value other benefits not strictly classified as ecosystem service benefits:
    - B£ST: Crime, economic growth, pumping wastewater and wastewater treatment, rainwater harvesting, traffic calming, enabled development
    - Co$ting Nature: Threats and pressures
    - EcoServ-GIS: Green travel, multi-functional landscapes, multi green-infrastructure assets
    - GI-Val: Place and communities, land and property values, investment, tourism
    - I-Tree Eco: Urban forest resource structure
    - NCPT: Soil contamination
    - SustainFARM Public Goods Tool: Heritage
    - TESSA: Rainwater harvesting
- The time requirement to apply any tool depends on the size of the area the tool is applied to, the numbers of services to be assessed, the quality of the data available and level of pre-processing required, and the required format of outputs. Some tools include estimates for the typical amount of time it would take to apply or run the tool, but this data is not available for all tools.
- Most tools that are reviewed are free to access for non-commercial use. Two are proprietary tools available as part of a consultancy offering (HydroloGIS, SENCE) and another two are in principle free for non-profit purposes, at the request of the tool developer (LUCI, TESSA).
- Most tools provide some flexibility in the scale at which they can applied.
- Most of the modelling tools are also flexible and can accommodate different datasets (if these are provided as standard by the tool) but adaptation by expert practitioners is recommended.
- Tools intended to be applied at a site or local level are more commonly Excel-based.
- Generally, the tools are revised on a regular basis to increase their functionality and/or to review and update the evidence base (e.g. InVEST, B£ST, Eco-metric, LUCI etc). For some tools there is no support available to help apply the tool (e.g. EcoServ-GIS, MIMES). However, we were unable to review all tools in detail.
- Tools may not accurately reflect local conditions due to data gaps: e.g. carbon sequestration in soils only usually refers to topsoil (0-15 or 30cm in depth) and not at greater depths. Studies show this likely underestimates extent of carbon storage in peat in the Cambridgeshire Fens (CSERGE, 2018) and in the Otmoor Nature Reserve (pers.comms, Smith 2019).

Seven tools were shortlisted for further analysis. These are Eco-metric, EcoServGIS, InVEST, LUCI, SENCE, Co$ting Nature and NEVO. Further detail describing each of these tools is provided in **Appendix E.1** (**E2.1** to **E2.4**).

3.4 Tool evaluation

3.4.1 Tool Grouping

There is no generally accepted framework by which tools can be easily classified. To help inform the analysis, the following broad grouping shown in Figure 3. 1 was developed, based on tool classifications used in previous reviews:

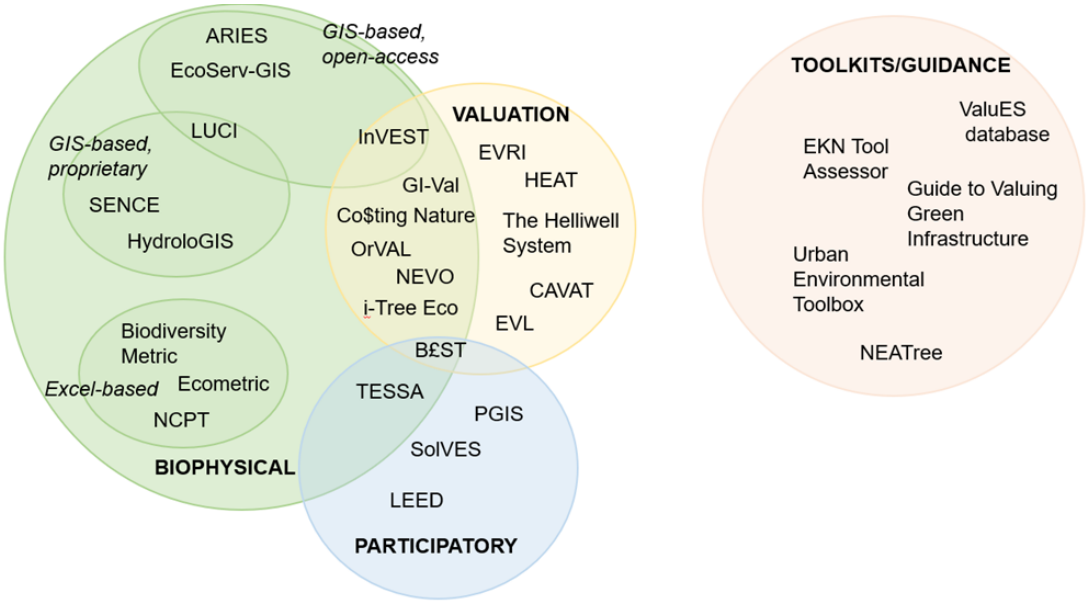


Figure 3-1: Conceptual grouping of tools based on primary function and interface

3.4.2 Natural capital asset baseline

The type of data relevant to gather for an asset baseline will depend on the scale and nature of the ecosystem, and the ecosystem services being assessed. The studies reviewed typically use 40-50 datasets. Several GIS-based tools can generate an asset baseline, but the use of bespoke tools is not necessarily needed as data can be built up as a series of layers in GIS software based on existing data.

Landscape elements such as hedgerows, single trees and field margins are not typically captured in LULC data, traditionally the base of natural capital assessments. These are important for regulating services such as soil retention (erosion prevention), as well as biodiversity, connectivity and pollination.

It is recommended that engagement with OxCam Arc partners and stakeholders is undertaken to obtain local data for certain assets. For example, data on recreational areas tends to be collected and grouped differently by local authorities. The level of effort at this early stage will need to be proportionate to the resources available, as the baseline can be improved over time.

3.4.3 Ecosystem services baseline

Linkages between stocks and services is complex. There are challenges in quantifying the flows of ecosystem services deriving from an asset baseline due to the complex relationships between natural capital assets and ecosystem service flows. Ecosystem services often derive from more than one asset or habitat type. Ecosystem service assessment tools started to emerge in the late 1990s (Gret-Regamey *et al.*, 2017) and have increased as the Ecosystem Service Approach has become more widespread.

There are three approaches with respect to tools to identify ecosystem services from assets:

- Matrix-based tools such as the Natural Capital Planning Tool (NCPT) and Eco-metric tool which use logic chains that synthesise expert opinion and scientific literature on the links between natural capital assets and the ecosystem services and benefits they provide (Lusardi *et al.*, 2018). Although this approach is an oversimplification, it can be very useful and economical in rapid determination and prioritisation of ecosystem services to study.
- Spatially-explicit tools for generating an ES baseline which take into account the underlying ecological structures, processes and functions to characterise the capacity of ecosystems to supply a given service. These tools generally require moderate to advanced GIS skills, and sometimes also modelling skills.
- In some studies, allocation of ecosystem service flows and selection of priority ecosystem flows tends to be by expert panel. Whatever the tool used, the incorporation of local data and knowledge will increase accuracy and confidence in the results. For example, many of the studies in the OxCam Arc that have applied

tools for natural capital assessment have used workshops to validate tool outputs, and adjust ecosystem service scores (Smith, 2019 pers. comm).

The strengths and drawbacks of several matrix-based and biophysical tools are summarised in **Appendix E.2.1** – Eco-metric, EcoServ-GIS, InVEST, LUCI, SENCE.

Figure 3.2 below presents a matrix of which ecosystem services are addressed by which tools:

	Provisioning					Regulating									Cultural			
	Biodiversity	Fish production	Food production	Timber production	Water supply	Sediment retention	Air quality regulation	Carbon sequestration	Flood regulation	Noise regulation	Pest control	Pollination	Temperature regulation	Water quality regulation	Amenity./Sense of place	Education	Health	Recreation/visitation
ARIES		✓		✓	✓	✓		✓	✓			✓			✓			✓
B£ST	✓				✓		✓	✓	✓				✓	✓	✓		✓	✓
CAVAT	✓														✓			
C$N	✓				✓													✓
Eco-metric	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
EcoServ-GIS							✓	✓		✓		✓		✓		✓		✓
GI-Val	✓		✓	✓	✓		✓	✓					✓				✓	✓
HydroloGIS					✓	✓			✓					✓				
InVEST	✓	✓				✓		✓				✓	✓	✓				
i-Tree Eco	✓						✓	✓	✓		✓		✓		✓			
LUCI	✓	✓				✓		✓	✓					✓				
NCPT	✓		✓				✓	✓	✓				✓	✓	✓			✓
NEVO				✓	✓			✓						✓				✓
ORVal																		✓
PGIS																	✓	✓
SENCE		✓	✓	✓		✓		✓	✓			✓						✓
SolVES	✓		✓			✓		✓										
SustainFARM	✓		✓			✓		✓						✓				✓
TESSA	✓	✓	✓	✓	✓			✓	✓					✓				✓
Water World					✓	✓								✓				

Figure 3-2: Ecosystem services assessed by tools

The Eco-metric tool provides the most comprehensive baseline of services of the tools reviewed. This shows clearly that habitats are 'multi-functional' and important to delivering multiple ecosystem services. It also reflects that more disturbed habitats still provide services. Although the Eco-metric is an Excel-based tool, it relies on analysis of GIS data and that the habitat-ecosystem service scores can be mapped. This approach has been used to generate a natural capital and ecosystem service baseline in Oxfordshire (Smith, 2019 pers.comms). The full outputs are not yet published but could be considered as part of the development of the LNCP.

Tools that are simpler to apply and which cover a comprehensive range of services can be used to derive ecosystem services from natural capital assets. The Eco-metric is quick to apply, the habitat-service scoring introduces fewer uncertainties into the early stage of assessment and results can be validated through engagement with partner agencies and stakeholders in the study area.

The approach built into the EcoServ-GIS tool is useful for strategic planning as it assesses areas where there is potential to enhance ES supply, and for some ES where the demand is greatest, taking account of the location and need of beneficiaries. None of the other tools reviewed take the same approach, which is unfortunate as the EcoServ-GIS tool is currently not supported.

In practice, the ecosystem services covered under different tools are not identical and tools often consider different aspects of the service (Vorstius and Spray, 2015). This makes comparison between tools and analysis of the integration of tool outputs challenging.

There is a lack of reviews or studies to compare how different ecosystem service and natural capital tool reviews perform in quantifying the same ecosystem services in the same area (Howard et al, 2016). An illustration is provided by comparing the indicator metrics and datasets required for each ecosystem service assessed by EcoServ-GIS, InVEST and LUCI (**Appendix E.3**).

Many studies are not explicit about the reasons for selecting subsets of services (Pagella and Sinclair, 2014). For this reason, the application of tools should be transparent and include a clear rationale of why and how the tool has been applied, and what ecosystem services were assessed.

Once the agreed or priority ecosystem services have been identified, the mapping approach or tools to use can be determined.

Few tools assess all the ecosystem services important to both rural and urban contexts.

Ecosystem processes take place at different temporal and spatial scales. Insect pollination, for example, is a highly localised service that takes place at a specific time of year when pollinators are active, whereas groundwater recharge is a large-scale process measured over decades (MAES, 2017).

Tools generate a wide range of output. They must be used in combination and in sequence, rather than in isolation having regard to the risk of overlap in which ecosystem services are assessed.

3.4.4 Identification of risks and trends

Only a couple of the tools reviewed attempt to take account of drivers and pressures in a spatial context (**Appendix E.2.2**), InVEST, Co$ting Nature and NEVO. The broad finding is that tools do not provide a systematic way of assessing all the key pressures and drivers that are likely to affect natural capital stocks, including climate change, habitat fragmentation, presence of invasive species or pests.

Instead, the studies reviewed tend to use spatial change in land use over time as a form of trend analysis (for example CSERGE, 2018; Natural Capital Solutions; 2018) and/or a matrix-based approach that draws on the logic chains described in **section 2.5** (see also logic chain examples in **Appendix D)** to link pressures/drivers to natural capital stocks (for example CSERGE, 2018 and Parker et al, 2016).

Toolkits that provide step-by-step guidance on natural capital assessments also recommend the use of risk assessment methods used in other environmental and industry sectors, such as the Driver-Pressure-State-Impact-Response framework (described in 2.6.1). Climate change projections from models or other research can also be incorporated to help inform the future natural capital baseline (Peh *et al.,* 2017).

3.4.5 Opportunity mapping

Opportunity mapping assesses where a change in land use or land management could improve the extent and condition of natural capital assets and enhance the delivery of ecosystem services.

Most of the tools follow similar steps in developing opportunity maps. As with estimating ecosystem service quantities, in-built tool design and decisions by the user over data visualisation can produce quite different outputs. In order to combine ecosystem service opportunity maps, two general approaches are adopted:

- Mapping land parcels by the highest possible ecosystem service associated with that habitat e.g. polygons in the top 10% of values for each ecosystem service (Natural Capital Solutions, 2015; Natural Capital Solutions, 2018) or maximum possible habitat-service score, based on relevant quality and location multipliers for delivery of that service (Smith, 2019).

- Mapping the coincidence of ecosystem services per habitat parcel i.e. stacking the potential benefits at the point of generation. This shows which habitat parcels are associated with the greatest number of ecosystem services, but not the level of importance of the parcel to each service (for example TEP et al., 2018).

Only a couple of tools explicitly take account of population and demand for ecosystem services in opportunity mapping. This is a key principle of the approach used by Natural Capital Solutions in applying an adapted version of EcoServ-GIS. This approach emphasises that for certain ecosystem service benefits to be realised, a beneficiary population must be close by – for example, noise regulation. For other services such as carbon sequestration, the demand is global, and proximity of people to the service is not important.

The same approach can combine consideration of demand as shown in the Habitat Opportunity Mapping for Northamptonshire and Peterborough (Natural Capital Solutions, 2018). One of the most advanced and locally-specific examples reviewed is the Greater Manchester Ecosystem Service Opportunity Mapping layers in MappingGM, which generate a summary radar chart for each habitat type and the ecosystem service scores associated with it, with suggested potential improvements (TEP/GMCA, 2018).

3.4.6 Trade-off/scenario analysis

Most ecosystems are 'multi-functional', and natural capital assets are important to delivering more than one ecosystem service. In some cases, synergies or 'win-wins' can arise where a land use or land management change enhances the output of one service and contributes to enhancing other services (Haase *et al.*, 2012). Trade-offs arise where the enhancement of one service is at the cost of reducing the provision of another service (Raudsepp-Hearne *et al.*, 2010).

There are a number of tools that can support analysis of ecosystem service trade-offs, although at different levels of sophistication. Simpler tools such as the Eco-metric can record the quantum of change in assets and the relative change in ES that might be expected but cannot represent in spatial terms what the impacts may be beyond the immediate area of land use change. In contrast, tools such as LUCI and InVEST will model the change dynamically, and factors such as slope, terrain and vegetation roughness will feed into the analysis of both the immediate change in stocks and flows and wider changes on the landscape.

Of the tools reviewed, LUCI and NEVO have specific trade-off modules. Other techniques can be applied to examine trade-offs among services if other tools are selected (Sharps *et al.*, 2017; Medcalf *et al.,* 2014). For example, the spatial pattern of service provision across the landscape in the before and after scenario can be analysed, or the modelled change in biophysical values – as a deviation from the mean, percentage change or absolute value – can communicate trade-offs. Other non-spatial techniques to displaying trade-offs include the use of 'rose'/'radar' or 'spider' diagrams.

Any decision-making that assesses trade-offs should be done with caution, as it reflects only measurable indicators for a set of ecosystem services, not the total ecosystem value, and that data on current condition is not always available.

3.4.7 Natural Capital Accounting Tools

Valuing and monetising ecosystem services is discussed under natural capital accounting (**Section 6**), but tools that have in-built functionality to value ecosystem benefits are briefly discussed here. Four types of tools that can be used in ecosystem service valuation were identified in this review:

- Tools to value ecosystem services from a specific natural capital stock e.g. i-Tree Eco and CAVAT (urban trees).
- Tools to value the ecosystem service benefits associated with green infrastructure investments on a project or local scale, such as GI-Val and B£ST. These are usually Excel-based and sometimes integrate calculators from other tools for specific stocks and services.
- Spatially-explicit tools that value services as part of a wider modelling package and allow values to be visualised on the landscape e.g. ORVal, NEVO, InVEST.
- Database/look-up tools, consisting of a library of studies with values for multiple ecosystem services e.g. Environmental Valuation Reference Inventory (EVRI).

This is not a hard and fast classification - there are cross-overs between these categories, for example the Woodland Valuation Tool is a database/look-up tool that is focused on a specific asset type.

It is not essential to use a tool with built-in valuation functionality to value ecosystem services. If the same ecosystem service unit values are used as those available in previous studies, then a value transfer approach can

be used, using the principles described in **Section 6**. Database/look up tools make this value transfer process easier by consolidating evidence in one location and allowing users to filter the search for values according to relevant criteria.

Some tools such as GI-Val and B£ST also provide guidance on how to apply values and aspects to be aware of, such as the risk of double counting ecosystem benefits. At a broader level, these Excel-based tools also help provide a level of consistency in how values are applied across studies or regions, and a way of recording where local data or priorities, such as in the form of weightings, have been incorporated. Comparative tools that use a score-based approach to measure ecosystem services, such as Eco-metric, do not support ecosystem service valuation.

4. Studies

4.1 Introduction

A comprehensive list of ecosystem service and natural capital studies undertaken in the OxCam Arc was collated and reviewed, focusing on studies published in the last 5 years. Studies outside the OxCam Arc were also reviewed. The studies have informed the approach, tools and natural capital accounting reviews and specific aspects from these studies are reported in **sections 2**, **3** and **6** as relevant.

4.2 Review approach

The studies are generally focused on specific aspects of natural capital to meet a scope or brief. The review has therefore aimed to consider what can be learned from the studies that might be relevant to developing the LNCP and avoids any direct comparison of the studies or assessment of strengths/weaknesses.

The review of studies covered the following aspects:

- Context - the purpose and scope of the study
- Approach – where a specific model is followed
- Scale of data, application and analysis
- Tools applied and how they are used
- Data sets and indicators
- Methodologies applying approach/tools
- Stakeholder participation and engagement
- What was covered by the study in terms of type of assessment, valuation and use of monetisation
- Findings and recommendations relevant to the development of the LNCP
- Gaps and limitations identified

A list of all of the studies reviewed is provided in **Appendix F.1** indicating where they are considered in this section, or in **section 6** which focuses on the valuation aspects, or both.

The review has relied on published information, with clarifications sought from the authors where proportionate. Many of the studies overlap with and form part of wider workstreams that are still under development and the review may therefore not represent fully the current stage of work.

4.3 OxCam Arc studies

Ten studies identified within the OxCam Arc have applied a range of approaches and tools for natural capital assets and ecosystem service mapping. These have been reviewed to understand how their findings might be relevant for development of the LNCP. The studies within the OxCam Arc outlined below are of interest in terms of their use of relevant indicators and reflecting natural capital assets and ecosystems services within the OxCam Arc and in most cases have also involved engagement from relevant stakeholders for the OxCam Arc region. The key studies considered are:

- **Baseline asset mapping, ecosystem service flow assessment and opportunity mapping in the Nene Valley – Natural Capital Solutions (2016).** This study focused on the Nene Valley nature improvement area NIA Project, and aimed to identify, map and value natural capital and ecosystem services across the Nene Valley. The study highlighted the key benefits provided by the natural environment, to increase understanding of the interdependencies between the natural environment, people and the economy, and to help planners and decision makers protect, enhance and restore the natural environment for the benefit of both people and wildlife.

- **Habitat Opportunities Mapping in Northamptonshire and Peterborough - Natural Capital Solutions;** This study followed on from the Nene Valley natural capital and ecosystem services mapping focusing on three broad habitat types with the aim to identify possible locations where new habitat could be created to deliver benefits whilst taking certain constraints into account.

- **Bicester and Beyond (Smith, 2018) (A Framework for Planning Green Infrastructure Green Spaces, Healthy Places (2018); Tools for Planning and Evaluating Urban Green Infrastructure (2017).** These linked studies aimed to map urban Green Infrastructure in Bicester and the ecosystem services this provides; identify opportunities to enhance existing Green infrastructure and create new areas to fill spatial and functional gaps and improve connectivity for wildlife and people. The study identified applications for site design and planning for net gain and evaluated the benefits of existing and planned Green Infrastructure in monetary terms for specific benefits and demonstrated the potential to use this to compare different options as part of making a business case for investment. Local participation was used to inform aspects of the approach. Guidance was provided on the approach and range of tools used including habitat scoring and bespoke tools covered in **section 3**.

- **Natural capital mapping in Oxfordshire (2019 draft) Oxford University's Environmental Change Institute**. This is a method used to generate preliminary Natural Capital maps for Oxfordshire developing evidence on natural capital to feed into development of the Oxfordshire Plan to 2050 and is based on habitat scoring adapted from an eco-metric scoring tool in development. The approach allows mapping of a comprehensive set of18 ecosystems services and grouping of these mapped services.

- **Jacobs and Cranfield University's natural capital assessment and ecosystem service mapping for the Expressway (2019 draft).** This study was completed on Highways England's behalf. This was in response to the Government's intention to take account, in their policy for the wider Oxford – Cambridge corridor, of the 25 Year Environment Plan's natural capital commitments. Objectives for the study included carrying out a high-level natural capital assessment (NCA) of stage 1 route options to develop an approach for including natural capital in route selection decision-making and provide a basis for taking natural capital assessment into future options assessment, net gain identification and consultation stages. The study mapped natural capital assets and used a range of tools including modelling, simple spreadsheet calculation and habitat scoring for analysis of ecosystems services with heat mapping and z scores to support comparative option analysis.

- **Natural Capital Investment Planning for the Oxford-Milton Keynes-Cambridge Growth Corridor (2018) Local Nature Partnerships and Oxfordshire Local Authorities.** This report provides a comprehensive review of data and case studies for natural capital and ecosystem services and brings together workshop findings from relevant stakeholders in the OxCam Arc area identifying challenges for natural capital planning and priority areas for investment within each county.

- **Natural Capital Valuation in the Cam and Ely Ouse Catchment (2017) Vivid Economics and Cranfield University**. A high-level assessment of the value of natural assets in the Cam and Ely-Ouse catchment, to help inform a catchment-based approach to prioritizing improvements in natural capital. The assessment included identifying drivers and pressures and the mapping of assets with focus on impact of intensive agriculture of compaction, erosion and soil carbon loss and includes modeling by Cranfield University of soil degradation risks. Valuation aspects of this study are addressed in **section 6.3**. Analysis of Ecosystems service flows highlighted the range of beneficiaries.

- **Management of Otmoor Protected Area (2008) Multifunctional Wetlands in agricultural landscapes: an evaluation of values, impacts and the application of the ecosystem-based approach.** The main objective of this study was to demonstrate a method for identifying, predicting and valuing the ecosystem services provided by the Otmoor Protected Area. Otmoor is dominated by agriculture and conservation management and is designated as a Site of Special Scientific Interest (SSSI) and an Environmentally Sensitive Area (ESA).

- **Thames Valley Environmental Record Centre (TVERC) Oxfordshire Investment Plan proposal (2019).** This sets out a proposed approach based on mapping assets, identifying ES supply and beneficiaries and – identifying demand and deficits/surplus and is based on a step wise approach covering many of the component elements which are likely to be required for the LNCP.

- **Central Bedfordshire Council (2013).** This project focused on collation of spatial databases for existing soil types, land use, and potential land use changes and is an example of a different focus compared to many of the more recent studies within the OxCam Arc area. Soil data was derived from the LandIS databases provided by the National Soil Resources Institute at Cranfield University. Land use data was obtained from CORINE 2006 to map how current and proposed future land use affects carbon storage, sequestration, soil erosion runoff and water quality. The study provides examples of simple calculations to derive ecosystems service flows from assets rather than use of modelling tools (not included in Table 4-1)

An overview of the natural capital and ecosystems services elements covered by the OxCam Arc studies review is provided in Table 4-1 below and key study summaries are included in **Appendix F.2**.

Table 4-1 OxCam Arc studies overview

Study/Project	Approach used	Scale	NC asset mapping	NC asset register	ES mapping	Opp. mapping	Demand or Threat/ pressure mapping	Trade-off/ scenario analysis	Risk/ threats matrix or register	ES valuation/ NC account	NC investment plan	Comments/ Summary
1. Habitat Opportunity Mapping in Northamptonshire and Peterborough (Natural Capital Solutions)	Mapping habitats and constraints to identify opportunities	County but spatially explicit	✓ 3 habitat types	×	✓	✓	✓ For recreation access and air quality	×	×	×	×	Combined opportunities also explored. Recommendations included cross checking and ground truthing data with stakeholder input. Potential to inform investment strategies
2. Mapping Natural Capital and Ecosystem Services in the Nene Valley (Natural Capital Solutions)	Mapping of assets-services and value use of EcoServe-GIS and bespoke models.	River valley NIA	✓	×	✓	✓	✓ Demand mapping for water, recreation and air	✓	×	✓ 4 selected services	×	Preparation of detailed baseline mapping from public and local sources, ES capacity and demand mapping used high to low heat map score and 4 monetised services also mapped using high to low scores
3. Bicester and Beyond (Smith, 2018) and 'A framework for planning Green Infrastructure' (TCPA)	Range of tools for: Mapping existing assets Opportunity mapping Design Valuation	Town/urban	✓ Habitat and land use	×	✓	×	✓	✓ For site design	×	✓ selected services	×	Application of a range of tools for different ES analysis. Included participatory input. Provides basis for mapping existing ES, master planning and assessing net gain and comparing benefits
4. Natural Capital Investment Planning for the Oxford-Milton Keynes-Cambridge Growth Corridor /Growth Corridor Report	Review of case studies and data and workshops on priorities	Regional Arc	Example baseline maps	×	×	×	×	×	×	×	Proposed priorities for investment	Review of data, tools and case studies identifying challenges and making recommendations on way forward including priorities for investment as a starting list and further collaboration
5. Jacobs and Cranfield University's natural capital assessment and ecosystem service mapping for the Expressway (draft)	NCC 2016 and NC protocol 2017 Asset indicator mapping, ecosystem services change for options comparison	Regional	✓	✓	✓	×	✓ Recreation	×	×	×	×	All asset types covered. Preparation of baseline included phase 1 habitat mapping. Focused on options comparison mapping matrices and bar chart outputs. Quantification of absolute and relative changes and use of Z score and heat mapping but overall focus was on linear option comparison
6. Oxford University's Environmental Change Institute's natural capital mapping in Oxfordshire (Draft)	Uses simple eco-metric scoring approach to map ES as an initial analysis and communication tool	County	✓ habitats/ land use	×	✓	×	✓	×	×	×	×	Preparation of detailed baseline mapping including phase 1 habitat and hedges. Range of sources for scoring including stakeholder input some scores proportionate to quantification, 18 ES mapped individually or grouped
7. TVERC Oxfordshire Investment Plan	NC protocol 2017 Proposed 4 step approach	County	✓	✓	✓	✓	✓	×	✓	✓	✓	Proposed approach based on mapping assets, identifying ES supply and beneficiaries and – identifying demand and deficits/surplus
8. Cam and Ely Ouse Catchment	DPSIR framework	Catchment	✓	✓	DPSIR logic chains	×	×	×	✓	✓	×	Physical and monetary accounts and valuation of ES by end beneficiaries, development of DPSIR chains for priority ES
9. Management of the Otmoor Protected Area	Ecosystem Approach (Convention on Biological Diversity)	Protected area		ES Register						✓		Earlier study, applying Ecosystem Approach to limited set of ES. Approach includes stakeholder engagement & evaluation of uncertainty

Case study review summaries are provided in **Appendix F.2**. The studies demonstrate a wide range of applications for natural capital assessment including:

- Urban focused studies such as the Bicester and Beyond study involved detailed urban land use and habitats information, with stakeholder and local participation. This also used a range of eco-metric scoring, modelling and valuation approaches and showed the potential for informing site or masterplan design ecosystem service priorities in response to local valuation.

- Infrastructure options assessment in the draft Oxford Cambridge Expressway study is a regional study within the OxCam Arc which was unique in representing all natural capital asset types but was focused on methods for a high level comparison of development options using a range of simple data. This combined GIS analysis and modelling tools through working with Cranfield University and undertook preliminary testing of the application of the draft Eco-metric 2.0 tool.

- Habitat opportunity mapping for Northamptonshire and Peterborough is a county level study but focuses on 3 key broad habitat types and associated eco-systems services and demonstrated use of constraints data in opportunity mapping and consideration of demand for recreation and air quality.

- TVERC Oxfordshire Investment plan is currently a proposal but sets out a useful model as an approach for a plan covering key components including building from an asset baseline and register, to identifying ES supply and beneficiaries for the purpose of identifying demand. This can then be used to determine deficits/surplus relevant for opportunity mapping and investment planning.

Two example studies are presented below: the Nene Valley study is an example of mapping assets, ecosystem services and benefits and use of both quantitative analysis and monetary valuation using scoring and heat maps (Table 4.2). The Cam Ely-Ouse Catchment Study (Table 4.3) provides an example of applying a DPSIR approach.

4.3.1 Observations

Key points identified from the studies are as follows:

- Consider urban and rural separately – different focus and specific data requirements. Most studies focus on one or the other but there is potential to apply both recognising the different approaches needed for urban and rural areas.

- Preparation of baseline data is fundamental including use of spatially explicit data to provide flexibility in types of analysis possible and flexibility in scale of analysis. Use of the best land use and habitat mapping available is recommended. Sharing data from existing studies could be considered where possible.

- There are challenges especially with capturing linear habitat information at a large scale and inconsistency and availability of local data for example local open space data. Some studies have invested considerable effort in developing Phase 1 habitat data.

- Most studies focus on land use and habitat but there is potential to start with a comprehensive natural capital asset baseline.

- Eco-metric scoring approach including simple mapping and habitat scoring approaches have benefit of allowing input and engagement by stakeholders either in influencing scoring or prioritising which ecosystems services are considered further.

- Approaches may apply mapping to spatially represent ecosystems services and valuation.

- Demand and pressure analysis are needed as part of opportunity mapping and use of constraints mapping to exclude areas not available/suitable is also part of analysis

- Habitat connectivity and opportunity mapping are recognised as important aspects to take into account.

Table 4.2 Nene Valley Study

<table>
<tr><th colspan="2">Natural Capital Solutions - Mapping natural capital and ecosystem services in the Nene Valley (2016)</th></tr>
<tr><td colspan="2">Context/purpose: Undertaken for the Nene Valley NIA Project, this study aimed to identify, map and value natural capital and ecosystem services across the Nene Valley. The aims were to highlight the key benefits provided by the natural environment, to increase understanding of the interdependencies between the natural environment, people and the economy, and to help planners and decision makers protect, enhance and restore the natural environment for the benefit of both people and wildlife.</td></tr>
<tr><td>Area/scale:
River valley NIA
Approach: 3 step approach taken
• Mapping natural assets – extent and distribution of assets
• Mapping ecosystems services – level and distribution of key ecosystem services identifying hot and cold spots
• Mapping value of benefits - distribution in the values of benefits derived from ecosystem services
Maps were developed for 11 different ecosystem services: carbon storage, noise regulation, local climate regulation, air purification, water flow, water quality, pollination, agricultural production, tranquility, accessible nature, and green travel.
Capacity of the natural environment to deliver those services (the current supply) was mapped and, wherever possible, the local demand (beneficiaries) for each service was also mapped.
Mapping based on the EcoServ GIS toolkit developed by the Wildlife Trusts, but with a number of modifications to better suit the situation in the Nene Valley.
Bespoke models were created for several ecosystem services – all at a fine scale of mapping across the area.
Outputs are indicative – relative values (showing that certain areas have higher capacity or demand than other areas) and highlight areas of high and low provision and the pattern of capacity (supply) and demand for each ecosystem service. Maps were also generated of the overall supply and demand of all services.
Valuation of selected services where information was sufficient and methodology available.</td><td>Relevance for LNCP
Detailed baseline mapping preparation included:
• Development of phase 1 habitat mapping and hedgerow mapping using range of sources including manual identification from aerial photography
• Historical habitat mapping to identify change and loss.
The supply maps highlighted the importance of woodlands and the River Nene corridor at delivering multiple ecosystem services.
Demonstrated that river corridor is also effective at bringing habitats delivering high levels of ecosystem services right into the heart of urban areas, and this is particularly prominent in Peterborough, Northampton and Kettering.
The demand maps clearly highlighted the importance of the urban areas in driving demand, with the very highest demand from parts of Northampton and Peterborough
Monetisation of value undertaken for 1) Agricultural and orchard production 2.) Greenhouse gas balance, considering emissions from agriculture and carbon sequestration 3.) Pollination 4.) Expenditure on recreation
Scoring system used to identify high to low value (1-100) for non-monetized ES but also monetary values were also mapped high to low as heat map-various scales.</td></tr>
</table>

Table 4.3 Cam Ely-Ouse Catchment study

Cam and Ely-Ouse Catchment **A valuation of the natural capital of the Cam and Ely-Ouse catchment – Final report prepared for WWF UK (Vivid Economics, Cranfield University, 2017) - Appendix 2**	
Context/purpose: A high-level assessment of the value of natural assets in the Cam and Ely-Ouse (CamEO) catchment, to help inform a catchment-based approach to prioritizing improvements in natural capital. Proof of method for application of NCA to a catchment. The NCA element of the project is reviewed in **Section 6**. This summary focuses on the assessment of drivers and pressures and the mapping carried out as part of the project. This focuses on impact of intensive agriculture on compaction, erosion and soil carbon loss and includes modeling by Cranfield University of soil degradation risks. Valuation of damage costs is provided for provisioning services, carbon, water quality and flood risk. Analysis of ES flows also highlights the range of NC beneficiaries.	
Area/scale: Catchment (rural/urban) **Approach:** Physical natural capital account of extent of Broad Habitats in the catchment. Partial indicators for asset condition (freshwater only), access (freshwater and woodland only) and biodiversity (woodland and priority habitat) Natural capital mapping to illustrate distribution of land uses (agricultural production, rivers and flood risk, groundwater) Pressures identified as climate change, population growth and increasing food production. Applies DPSIR framework which is recommended as a way of organizing analysis of pressure and threats to priorities, possible responses and investment. Logic chains presented for key ES showing drivers and pressures, natural assets, ES and economic value (and relevant human capital and manufactured capital inputs) ES assessed: crop production, water abstraction, timber production, carbon sequestration in soil and biomass, water purification, flood risk regulation, recreation and biodiversity (non-use value).	**Relevance for LNCP** Stated preference values from the National Water Environment Benefit Survey (NWEBS) (Environment Agency) could potentially be used as partial valuation of non-use value of SSSIs in the OxCam Arc Logic chains present clearly the cause and effect linkages between pressures, stocks, services and value, and could be an important tool in engaging stakeholders around natural capital. The partially monetised assessment attributes ecosystem service values across beneficiaries (farmers, water company, household/society, other businesses) – which could help to identify future funding for NC investment.

4.4 Outside-of-Arc studies

Studies outside of the OxCam Arc area were selected where these demonstrated a particularly innovative or well-developed approach to assessing natural capital, were relevant to the objectives of the LNCP and had comparable assets and ES to the LNCP area (i.e. marine and coastal examples were not reviewed). The overview of eight studies considered is provided in Table 4-4.

The four studies reviewed in greater detail are Anglian Water study, for its approach to assessing drivers and pressures on natural capital and developing a risk register, and three of the Defra Pioneer projects.

The Pioneer projects established by Defra are of interest as flagship initiatives to test the application of a natural capital approach and inform the development of the 25 Year Environment Plan (ICF/eftec, 2018).

Four 'asks' were agreed between Defra and the Pioneer projects (ICF/eftec, 2018) to:

- Test new tools and methods as part of applying a natural capital approach in practice;
- Demonstrate a joined-up, integrated approach to planning and delivery;

- Pioneer and 'scale-up' the use of new funding opportunities; and
- Grow our understanding of 'what works', sharing lessons and best practice.

Each of the Pioneers developed a set of objectives relevant to the local area, although also reported constraints in the availability of resources and engaging with partners without being able to fully communicate the purpose before the 25 YEP was published (ICF/eftec, 2018).

4.4.1 Observations

Table 4-4 shows that all but two of the studies reviewed outside of the OxCam Arc have produced both a natural capital asset register and natural capital/ecosystem service account. Most of the studies were commissioned with a specific aim or to develop a specific product, with the necessary workstreams shaped accordingly and have not generally followed all steps that would be required for a plan.

- All three Pioneer Projects reviewed put considerable emphasis on stakeholder engagement and partnership working and this is a common theme either within studies or recommended as part of the next steps.
- Analysis of ecosystem service beneficiaries (including businesses) was undertaken at an early stage by the North Devon pioneer. This can contribute to paving the way to identifying investments and market opportunities.
- The Urban Pioneer demonstrates a method of scaling-up mapping protocols developed at a smaller sub-catchment level to a wider Greater Manchester study area.
- Access to data was a constraint for the Cumbria Catchment Pioneer
- The Anglian Water study is notable for focusing on mapping natural capital assets and undertaking demand and pressure analysis and considering trends in developing a risk register. Key features were the compilation of a natural capital risk register at a regional rather than national scale and spatial analysis of pressures and assets to determine where different combinations of conditions exist. Although analysis was undertaken at local authority scale, potential to use the approach at other scales such as catchment level is noted.

Table 4.4 Outside OxCam Arc studies overview

Study/Project	Approach used	Scale	NC Asset mapping	NC asset register	ES mapping	Opp. mapping	Demand or Threat/ pressure mapping	Trade-off / scenario analysis	Risk/ threats matrix or register	ES valuation/ NC account	NC investment plan	Comments/ Summary
Anglian Water (CSERGE)	NCC 2017 steps DPSIWR	Local authority area level analysis	✓	×	×	×	✓	×	✓	×	×	Recommendations for refining by added pressures and assets using accounting methods Stakeholder input for other units for analysis such as catchments.
Cumbria Catchment Pioneer: Phase 1	-	Catchment and sub-catchments	✓	✓	✓	×	×	×	×	×	×	Focused on opportunities to increase flood resilience NC summaries for sub-catchments
Greater Manchester Pioneer* & related work	-	Urban (local authorities)	✓	×	✓	✓	×	×	×	✓	✓	Multiple outputs, including investment matrix, ES interactive mapping and NC account
North Devon Landscape Pioneer	Root Cause Analysis	Protected area	✓	✓	··	×	×	×	✓	×	··	Focused on strategic analysis of pressures & threats and interventions that address multiple problems for priority ES
Natural Capital Investment Plan for Surrey – Surrey Nature Partnership (2018)	NCC approach	Local authority	×	··	×	✓	×	×	×	··	✓	Focused on process to develop investment products and project pipeline. Focus on woodlands and water to be extended to other assets
Beam Parklands Natural Capital Account*	Corporate NCA framework (NCC)	Urban (site)	×	✓	×	×	×	×	×	✓	✓	NC balance sheet of asset register flows and benefit valuation and long term maintenance costs
London Borough of Barnet corporate natural capital account	Corporate NCA framework (NCC)	Urban (local authority)	✓	✓	×	×	×	×	×	✓	··	Borough-wide NC account and estimate of costs and benefits of maintaining the green space in context of population growth and budgetary pressures
Natural Capital Accounts for Eycott Hill Nature Reserve	Principles of NCA (ONS) Corporate NCA (NCC)	Site/ Protected Area	×	✓	×	×	×	×	×	✓	×	Comparison of changes in ES and value of benefits from changes in site management (livestock farm to nature reserve)

··Denotes direction of travel/identified future stage.

5. Data and platforms

This review is focused on the natural capital technical aspects rather than the potential information technology connotations of the LNCP. It is also beyond the scope of this review to identify specific data sources for all indicators, thus only data and indicator types have been identified. These are presented in **section 2.5** and collated in **C.3**.

Nonetheless, throughout the review, references to developing or harnessing an existing platform and methodology to host natural capital data were collated. The key findings are given below for completion. This section is not a systematic review.

5.1 Core data

Datasets for indicators can be combined in a GIS package and built up as a series of layers – including land use/land cover (LULC), a digital elevation model (DEM), soils and management/protection regimes (e.g. designated sites for nature conservation, AONBs)

Standard practice is to use Master Map and a LULC map such as CORINE, CEH's LCM as a starting point. Habitat classes can then be refined using for example Priority Habitat Inventory data from Natural England, and integrating built environment features e.g. from Ordnance Survey MasterMap.

A good example of how this can be undertaken is given in Ireland (Parker et al., 2016). This was one of the most comprehensive baselines reviewed. It was developed for the National Ecosystem and Ecosystem Service Mapping Pilot in Ireland, which comprehensively audited over 150 datasets to assess licences restrictions, availability of metadata, scale and spatial coverage, ultimately using 45 datasets to generate the habitat asset register (Parker et al, 2016).

For urban areas, a detailed map of green infrastructure can serve as the basis for mapping urban ES supply and demand (Zulian et al, 2017). In semi-rural and rural areas, LULC data is key, and land management data, if available, can be used as an indicator of asset condition.

The overall dataset should have many more parameters than needed for any single decision or application. At the outset, it will be necessary to develop a high-resolution whole area baseline which should be as comprehensive as possible to inform trends for unanticipated issues that emerge in the future.

5.2 Scale

Ecosystem services interact over different scales, supply and demand are also scale-dependent, as will be many of the application requirements of the LNCP. Data sets also all have different spatial resolutions. It is therefore necessary for the LNCP spatial database to operate at the outset a high-resolution whole area baseline. The LNCP must therefore be scalable but bearing in mind that not all datasets are uniformly transferable between scales.

The LNCP should consider existing statutory environmental management assessment and monitoring functions. For example, water-related regulating services should be considered on a river basin/catchment scale. The Environment Agency Catchment Based Approach Data Package (2019) organises data on catchment characteristics, issues, causes, actions, opportunities and monitoring using available base mapping.

Planning and reporting is often based on administrative units and the scaling and structure of the database should include this functionality. For example, local demographic information supplied as Lower and Super Output Areas, health information from NHS England Clinical Commissioning Groups, Water Resource Management Plans based on Water Company Areas, River Basin Management Plans based on River Basin Districts, National Character Areas etc.

Existing grid-based scales at which data is collected include:

- 2km x 2km – e.g. Forestry Commission Statistics (grid squares are used to predict forest cover for whole of GB)

- 1 km^2 Hexagon Grid - Natural England natural capital maps and The Oxford to Cambridge Arc Natural Capital Indicator Maps July 2019. These maps of natural capital are derived from predictive modelling. They acknowledge that the choice of spatial scale in model predictions can influence the accuracy and uncertainty of prediction. The 1km^2 resolution was decided as the most appropriate scale for this project

- 1 x 1 km – Higher resolution grid squares for detailed species distribution data e.g. UK butterfly monitoring scheme, National Biodiversity Network, Countryside Survey – Field Surveys.

- 1 x 1 m – Highest resolution surveys for study of species e.g. earthworms, pollinators and plants (quadrat-based surveys)

5.3 Data characteristics

All data should be centralised in an open-source database and web-portal that could be managed by Defra or a third party. Data sets should be geo-spatially referenced, have appropriate spatial resolution and be tagged in order to facilitate updates whenever these are available.

Confidence levels (for example red/amber/green 'RAG' scores) should be applied to data sets.

The various datasets available often have inconsistencies, overlaps, gaps and limitations. Some datasets are more up to date than others. Many data sources will have neither a sufficient nor a consistent time series needed to monitor change over time. Such data sets should be treated with caution. There would be benefits in efforts to standardise and strengthen datasets nationally to make them fit for purpose for natural capital accounting.

The platform at a minimum will require (CEH 2017) a metadata catalogue describing datasets and models and a web framework to develop the portal/knowledge hub. The catalogue will allow searches to be conducted through either the dataset or model and will display linkages between them. There must be a map viewer to view relevant spatial data and an appropriate database to store evidence chains. A graph visualisation tool would enable the exploration of evidence chains and to allow users to navigate between different entry points. The website should also contain a controlled vocabulary of natural capital terms (Glossary).

6. Natural Capital Accounting (NCA)

6.1 Introduction

Natural capital accounting aims to create a systematic, standardised and repeatable framework for assessing and monitoring natural capital stocks (assets) and ecosystem service flows (benefits). Critically, it is an approach which frames natural capital as economic assets.

Accounts are a way of presenting in tabular format: how much natural capital stock exists, the volume of ecosystem service benefits and in some cases the monetary value of those benefits and how these are changing over time. From there, it is possible to calculate a capitalised asset value of a natural capital stock based on the future flow of ecosystem service benefits derived from the stock. In this way natural capital accounts bear resemblance to accounting ledgers or balance sheets (to a greater or lesser degree depending on the application).

The process is voluntary and as such there is no universal approach, however, there are several best practice examples and principles emerging. A key element of natural capital accounting, as with any natural capital approach, is that it is designed to improve decision making for policy makers, businesses, land managers and funders/investors in order to manage the risks and maximise opportunities around changes in natural capital. By organising data in the form of an account, it can also be used as a communication tool to inform a narrative and set out the building blocks for long term value.

The existing examples largely fall into three categories: national accounts, organisational accounts (typically undertaken by businesses or organisations with strong dependencies on natural capital and/or significant land holdings), and those produced at the smaller scale for individual sites or natural features.

This section is focussed on the objective to 'assess the relevance of a formal natural capital and ecosystem services accounting approach as a means of organising spatial natural capital and ecosystem services information on a repeatable basis for the Oxford Cambridge Arc'. A review of relevant guidance concerning natural capital accounting, further explanation as to what a natural capital account is and what it is for, as well as a selection of examples of natural capital accounting in practice are provided.

The remainder of this section is structured as follows:

- Review
    - Overview of approaches and methods
    - What is natural capital accounting?
    - How does it differ from other natural capital approaches?
    - Key components of an account
    - What are the benefits of NCA?
    - What are the limitations/concerns around NCA?
    - Why should a LNCP include an account?
    - What ecosystem services to value?
    - How to value ES?
    - How/whether to include costs?
- Case Studies
    - UK ONS Natural Capital Accounts
    - Examples of a corporate natural capital accounts – Kering and Yorkshire Water
    - Tresham Garden Village (Natural Capital Solutions, 2019)
    - Natural Capital Valuation in the Cam and Ely-Ouse Catchment (Vivid Economics, 2017)
    - Beam Parklands Natural Capital Account (Eftec, 2015)
    - Urban Pioneer Natural Capital Accounts: Greater Manchester (Eftec, 2019)
    - Accounting for National Nature Reserves: A Natural Capital Account of the National Nature Reserves managed by Natural England (Natural England, 2019)
    - Observations

6.2 Review

Over 40 references were identified of relevance to natural capital accounting; these include sources that are not strictly focussed on accounting as a framework, but which include a large emphasis on monetary valuation of ecosystem services.

6.2.1 Overview of approaches and methods

As NCA is an emerging field, there is no single source of guidance. Different approaches are being developed and trialled by different organisations. Most of the guidance and practical examples fall into two groups: national accounts such as those produced by the Office for National Statistics in the UK and organisational accounts which tend to follow corporate natural capital accounting (CNCA) principles. However, as noted in Sunderland et al. (2018) "Public bodies and private sector organisations have different needs from NCAs. For private sector organisations NCAs may provide extra information about public benefits, which sit alongside evidence about their core market indicators. This may usefully broaden decision-making. But for public bodies their role is to provide public benefits, and these will dominate the account."

While a number of approaches and guidance documents were reviewed in relation to the potential application of NCA for the OxCam LNCP, the following were identified as most relevant:

- Principles of Natural Capital Accounting (ONS, 2017). This includes some notes on the production of sub-national accounts.

- Developing Corporate Natural Capital Accounts (Eftec and others, 2015). This methodology was designed primarily for private land owners and managers as well as private sector organisations with nature and land conservation objectives.

- Accounting for National Nature Reserves: A natural capital account of the National Nature Reserves managed by Natural England, (Sunderland et al. 2018). As noted above, this study aimed to fill the gap by developing an approach to NCA for public bodies.

The key findings from this review are woven into the discussion below and into the recommendations.

6.2.2 What is natural capital accounting

Natural capital accounting (NCA) is an approach that attempts to combine environmental science and economic evidence into a single repeatable framework. The key advantage of NCA is that it enables the unambiguous presentation of data, providing a structured narrative. The real value arises from natural capital accounting when the process is repeated, showing trends over time.

While valuation is a key component of NCA, it is not the only step. Accounts must also record the physical state of natural capital stocks and the quantity of ecosystem service flows derived from those stocks. As such they must be underpinned by robust asset register and ecosystem service registers.

In the context of NCA there are two types of valuation: valuing ecosystem flows with the aim of identifying and isolating the contribution of the ecosystem to final benefits; and valuing ecosystem assets based on a stream of expected future benefits. The former can provide a snapshot of the value of natural capital (for example, the recreational value of a park is £x per year) or provide an ex-post view of trends over time (for example, the recreational value of a park has increased from £x to £y over a given period). The latter can be expressed as a capital asset value (for example, the lifetime recreational value of a park in present value terms is £x million) for use in cost-benefit analysis or investment appraisal.

As with traditional forms of accounting, future costs and benefits must be discounted. The choice of discount rate varies but must be consistent with the organisation's other economic and financial analyses. The appraisal period (the time frame in which the projected flows are examined) may vary but should align with the anticipated life of the natural capital asset or the length of time an organisation has stewardship of the asset. Generally, 100 years seems an appropriate time period as it reflects the longevity of renewable assets (provided they are managed sustainably).

As mentioned previously NCA is still an emerging practice, with guidance and approaches in development at different scales and by different organisations – national, corporate and local. While there is considerable overlap between the existing approaches, there are also some legitimate differences reflecting the experimental nature of NCA, as well as the objectives behind the production of an account, which can vary significantly.

At the national level, the structure and underlying principles for NCA are founded on the System of Environmental and Economic Accounts (SEEA) endorsed by the United Nations Statistical Division. SEEA establishes a standard structure, which aligns with the System of National Accounts so that countries can more easily consider and compare the economic contribution of natural capital with more traditional measures of economic activity. NCA undertaken at the national scale, such as the accounts produced by the ONS in the UK, focus on the benefits (positive impacts) derived from natural capital and are quite separate (though linked) with the environmental accounts which focus on externalities / pressures (negative impacts) derived from economic activity. For example, the natural capital account for the UK captures carbon sequestration as a benefit of natural capital, where as carbon emissions from energy production and transport etc. are reported in the environmental accounts.

Corporate Natural Capital Accounting (CNCA) is a different exercise altogether as it focuses on the impacts and dependencies on natural capital within an organisation's boundary or sphere of influence. CNCA typically groups natural capital benefits in terms of those that benefit the organisation itself (market goods) and external benefits (non-market goods). CNCA also aims to generate a net value, taking account of both positive and negative impacts on natural capital as well as maintenance and investment costs.

Another key difference between CNCA and other forms of accounting is that it is designed to measure progress toward a future target scenario (which could be based on achieving the organisation's environmental goals) and therefore takes an ex-ante view as opposed to an ex-post view. Rather than looking at past records of ecosystem service benefits and how they have changed prior to this point, CNCA projects a future time-series based on long-term estimates of the quantity, quality and value of natural capital goods and services.

There is less guidance on developing regional / public body / site level accounts; however practical examples to date reveal borrowing of principles from both national and corporate forms of accounting. One notable difference is the tendency to map ecosystem benefits according to beneficiary groups (e.g. households, businesses, public sector).

6.2.3 How does it differ from other natural capital approaches?

There are various natural capital approaches including: baseline assessment; identification of green solutions; sustainability assessment and appraisal; science-based approaches (modelling biological and physical relationships); mapping and consideration of geographical variation; monetisation of benefits; identifying beneficiaries; place making through green infrastructure; and a whole host of other tools.

In accounting the focus is how much of something has been provided (or used) over a particular time period so that annual trends can be identified.

The essential components of NCA that make it different to other such forms of assessment are that it:

- Provides a time-series for service flows
- Focuses on benefits and excludes negative flows from human activity
- Captures the contribution of the ecosystem to final benefits
- Provides a consistent conceptual approach across all services
- Is a transparent and repeatable structure for organising scientific and economic data
- Demonstrates gains/losses over time, contributing to achieving objectives

In addition to these attributes, desirable features of NCA include involving a wide range of users/experts, using spatially disaggregated data, and the ability to be integrated into other forms of assessment and reporting.

Perhaps the most closely related approach is the monetisation of environmental impacts. While NCA also contains an element of valuation, they are not one and the same.

Valuation takes two forms. The first estimates the marginal change in benefits or costs resulting from an intervention or project, relative to the 'business as usual' scenario. This is to feed into options appraisal or Cost-Benefit Analysis (CBA). In the case of unpriced goods or services, valuation in this context is often implicit. For

example, decision to invest in a scheme that improves air quality at a cost of £10 million implies that the benefits of improved air quality must be worth at least that. The second form is an assessment of the overall value of stocks and flows using average values and monitoring changes in these over time. This is natural capital accounting.

Does valuation for appraisal purposes and NCA use the same unit monetary values? In practice, it often does. Depending on the nature of the ecosystem service, the same values might be used if there is no significant difference between average and marginal values. For example, ten hectares of woodland will produce approximately ten times more carbon sequestration benefit than one hectare of woodland; hence average values are appropriate. On the other hand, ten hectares of woodland may produce more or less than ten times the recreational benefits of one hectare of woodland depending on where it is sited, the features of the site, the availability of alternatives, etc. In this case marginal or adjusted values are more appropriate.

Appraisal frameworks such as cost benefit analysis (CBA) typically use welfare values – i.e. what the product or service is actually worth, as opposed to accounting frameworks which use exchange values (akin to market price which exclude consumer surplus). For many ecosystem services there is no exchange value as the services are non-traded, in which case values must be indirectly measured or estimated. Practical examples of natural capital accounts apply a mixture of welfare and exchange values. In theory this is not a problem; however, inconsistencies between provisioning services valued at market rates and non-market services estimated using welfare values (which include consumer surplus) may appear.

Another difference between one-off valuation and NCA is that accounting should aim to isolate the contribution of the ecosystem by excluding human inputs and other factors. For example, the value of agricultural production in NCA should exclude subsidies as well as the value of labour, use of fertilisers, etc. This is a challenging exercise, but it is less important at the corporate or local level than it is at the level of national accounts.

The key aspects that make NCA different from other environmental valuation exercises are that it:

- Aims to be comprehensive (versus appraisal which may focus on the key benefits driving an investment)
- Focuses on what nature provides (excluding negative values). This provides an important narrative for engaging stakeholders and highlighting the value of conservation.
- Is an ex-post assessment and therefore useful for monitoring whereas appraisal is ex-ante.
- Tends to apply baseline, average values (versus appraisal which focuses on a marginal change arising from an intervention). In this sense, it tends to inform a more strategic context and provide a basis for prioritisation rather than decision-making at the site or project scale.
- Can be used to generate asset values based on expected flows, therefore a useful store for economic data that can feed into other forms or appraisal.

6.2.4 Key components of an account

Much of the guidance and existing examples of NCA rely on a logic-chain approach (or similar). A key principle is understanding both the state of the stock and the quantity of ecosystem services that flow from it. Understanding ecosystem service values is often insufficient to identify whether or not the underlying asset is able to continue to provide those values. As such, the components of a natural capital account can be summarised as follows:

What's the asset → Extent account

What condition is it in? → Condition account (or asset register)

How much does it produce? → Physical flow account

What is it worth? → Monetary flow account → Monetary asset (stock) account.

6.2.5 What are the benefits of NCA?

As previously discussed, monetary valuation can draw attention to "hidden" values – that is goods and services provided by nature that aren't typically captured in decision making. This can inform conversation with stakeholders and generate support for a wider spectrum of environmental improvements. For example, Clark (2018) reported that NNR managers were surprised by some of the ecosystem service values such as education when they tend to focus almost exclusively on the wildlife (biodiversity) aspects within their remit.

Valuation provides a common metric to understand relative value (and therefore trade-offs) between services.

Valuation can also test pre-formed judgements about the value of a project or intervention. For example, assuming the 'hard engineering' solution is the most cost-effective when in fact a green infrastructure solution (which reduces treatment costs elsewhere) might provide more value for money, increasing wider benefits such as public health, etc.

The Natural Capital Committee identifies three general decision contexts for which valuation is helpful:

- Determining priorities for, and demonstrating value for money of, investments in natural capital.
- Determining actions affecting natural capital to (i) achieve target improvements; (ii) avoid deterioration; or (iii) compensate for losses
- Determining overall progress with objectives to protect and improve natural capital, including at aggregate level (for example, through natural capital accounts).

As previously stated, valuation and NCA are not one and the same. So, moving beyond just valuation, what are the benefits of NCA? As stated above, the monitoring aspect is key – NCA measures progress with a view to improving natural capital. In this way it will increasingly play a role in demonstrating environmental net gain. Additional benefits include:

- Focusing on both asset condition and ecosystem flows
- Highlighting key trends
- Exposing important gaps
- Providing the basis for transparency around the funding of natural capital assets
- Informing discussions with beneficiaries, enabling development of funding mechanisms
- Conversely, if shortfalls in funding arise, NCA could provide helpful insights into the implications (e.g. what is the value of ecosystem services lost through reduced maintenance/management)
- Monetised asset accounts can provide a basis for scenario development

Clark (2017) summarised that while the process of NCA threw up some practical and theoretical issues, those responsible for managing the NNRs found that applying the framework enabled them to: take a broad perspective on the wider societal benefits delivered by the NNR in addition to nature conservation; consider where benefits might be increased, including those that might be revenue generating and identify and record new information that they wouldn't otherwise have obtained.

6.2.6 What are the limitations/concerns around NCA?

Many of the concerns around NCA derive from the theoretical issues that stem from valuation. Economic valuation is an anthropocentric construct – it is about people and their preferences. It does not (it cannot) consider non-human preferences. The second point to remember is that values are only as good as the natural science underpinning them. Valuation introduces an additional layer of complexity and therefore uncertainty. Not only must the physical quantities of ecosystem services be measurable and accurate to an appropriate level, monetary unit values must be also. How robust a valuation exercise needs to be depends on the use of the results. In the context of NCA, often relative changes in values over time will be more revealing than the absolute value at any point in time. The level of reliability required from valuation increases in order from: awareness raising / policy briefing; scoping and screening options; policy and project appraisal; to financial instruments and liabilities. It goes without saying that valuation must adhere to good practice around quality assurance in all cases. Wherever possible, the use of a central point value should also be supported with a sensitivity range.

As Sunderland et al. (2018) notes, "The ideal for NCA is to value all the benefits and link them back to services and to the asset state. At present this ideal is unachievable". While the practice is ever changing and evolving, valuation will only be partial. At present there are only a handful of ecosystem services that can be reliably and repeatedly valued and those may not align with the drivers/objectives of an organisation. It is therefore important to not treat results on a balance sheet as 'the answer'; rather it is only one tool/aspect of decision-making. Sunderland et al. (2018) advocates including non-monetised ecosystem service benefits on the balance sheet and assigning a significance rating in an attempt to try and overcome the tendency to favour those services that can be valued.

In the context of NCA there are concerns around presenting total (capitalised) asset values, as valuation works best when it focuses on marginal change. It does not make sense to put an absolute value on something which is

essential for life and therefore infinitely valuable. Sunderland et al. (2018) notes that "Natural assets are systems we didn't design and don't fully understand". Another key point is that changes in values over time do not reveal underlying causes; changes could be driven by degradation or enhancement of the asset but equally the value may change due to changes in the demand (and therefore the value) of the service. Carbon sequestration is a good illustration of this effect – the damage cost per tonne of CO2 is forecasted to rise significantly over the coming years. The value of expected future flows of carbon sequestration benefits might suggest that natural capital assets are sequestering more carbon over time when, in fact, it is the unit value (not the physical quantity) that is increasing. For this reason, it is important that the monetary account is interpreted in concurrence with the physical flow account as well as the asset register/account.

The challenges and limitations around NCA can be summarised as follows:

- Requires commitment beyond the short term for data gathering and research to support updates.
- NCA at a landscape scale will require cooperation from multiple organisations and land managers providing necessary data.
- Limitations based on how infrequently the underlying datasets are updated as well as the spatial resolution of data to measure actual delivery of ecosystem services.
- With regards to forecasting future flows, cultural services are especially difficult to value as it is impossible to predict the preferences of future generations.
- Accounts tend to present values based on single point estimates only, giving a false sense of certainty.
- Values need to be considered along with other biophysical information so as not to misunderstand the purpose of accounting.
- Considering the value in a single year is misleading due to lag times involved. As Clark (2017) notes "this year's benefits are from investment over decades. And this year's investment will improve benefits for decades too".
- NCA is more strategic in nature – it may be too broad-brush to inform spatially specific land management decisions. These may require more detailed appraisal.
- Valuation will only ever be partial. It should be treated then as the absolute minimum that a natural capital asset is worth.

6.2.7 Why should LNCP include an account?

Even with the caveats above, the evidence suggests that NCA is a worthwhile exercise. Accounts will only become more valuable over time, especially as commitments around environmental net gain come to the fore.

One of the stated objectives of the LNCP is to 'contribute to an environmental vision for the OxCam Arc that clearly links to public wellbeing and economic growth'. Adopting NCA places natural capital firmly in line with other forms of capital and therefore can highlight the value of gains, losses and investment in natural capital in the context of the economic development of the area.

As set out in the recommendations up front and the guidelines (**Section 7**), the creation of an account should build on the preceding baseline, asset register and ecosystem service register and in that sense is a logical progression. The addition of an account would provide a framework for drawing together broad ranging and in some cases complex information as well as introducing an economic dimension through monetisation.

Monetary valuation provides a common metric to aggregate and compare services across habitats at an Arc scale. While unlikely to provide answers to operational questions, NCA would be useful to inform a strategic overview of the state and value of natural assets. It would also provide a way of systematically storing data that can be used in a range of decision-making contexts; for example, unit values presented in the account can be adopted (and adjusted where necessary) for use in project-scale appraisal as well as monitoring and evaluation.

As many of the existing studies point out, accounts create a strong narrative and are useful tools for communicating value, risks and trends. They can be used to coordinate and inform discussions with stakeholders and beneficiaries around who benefits from and ultimately who pays for maintaining and enhancing the natural environment.

6.2.8 What ecosystem services to value?

As previously stated, NCA aims to be as comprehensive as possible - valuing everything that is possible to value. Practically, however, it may be necessary to focus on a selected number of ecosystem service benefits. It is

important to remember here that valuation focuses on final benefits which are distinct from services. In many cases, final benefits can be mapped onto a single ecosystem service, but this is not always the case.

In prioritising which benefits to value, there are the following points to bear in mind:

- What is possible based on the data available? It is unlikely that the LNCP will generate any primary valuation data as this is time consuming and expensive to generate.
- The main priorities for the OxCam region (as identified by stakeholders / through participatory input).
- Where long-term monitoring is required, e.g. where ES flows are known to be sensitive to land management changes and therefore show a non-static trend.
- Considering the relevant risks and pressures; hence the reason NCA is recommended as Step 4 in a 6-step approach. There will be some ecosystem service benefits that are more at risk, or likely to be more in demand in the future, and therefore may merit more effort in valuation.
- Finally, it is important to avoid overlap where possible. Final benefits should be distinct from one another so as not to introduce any double counting. It is also advantageous to cover a range of provisioning, regulating and cultural benefits (at least one of each) in order to communicate the range of benefits provided by natural assets.

6.2.9 How to value Ecosystem Services?

There are numerous sources of guidance and valuation data which are not summarised here as the focus of this section is more on 'whether' to conduct NCA not 'how'. The studies summarised in the tables below provide a good overview of what values are readily available and most commonly applied. Some of the tools reviewed in **Section 3** provide estimates of ecosystem service values.

The Environmental Valuation Reference Inventory (EVRI) is widely regarded as the most comprehensive source of valuation data. The forthcoming EnviTAG (online resource expected to be published by Defra imminently) will include a wide range of published valuation data, much of which has been sourced from EVRI. The Environment Agency have also launched a beta version of a natural capital asset register, tool and scorecard which is aimed at catchment-scale assessment and enables a selection of ecosystem service benefits to be monetised.

Ultimately which values are chosen and applied is in some ways less important than the need to report them transparently. Given the experimental nature of accounting, there are likely to be significant revisions to monetary estimates of non-market goods and services as methodologies evolve. As NCA becomes more widely adopted, it is also likely that aggregation of sub-national accounts may be required; in both cases it is important to understand the derivation and selection of unit values so that they can be adjusted if necessary, at a later stage.

6.2.10 How/whether to include costs?

The national accounts produced by the ONS at a UK level by necessity do not include capital and maintenance costs as the purpose is to provide an estimate of the value of nature as an exercise in wealth accounting. Conversely, CNCA examples and approaches do often include costs in order to generate a 'net' balance sheet. However, even at the organisational level where boundaries are relatively easy to define, this exercise is difficult. Sunderland et al. (2018) noted that in regard to NNRs it was difficult to isolate the annual maintenance costs from Natural England's other core activities.

Ideally natural capital accounts produced as part of the LNCP would include capital and maintenance costs in the same way that budgets are forecasted and monitored for other areas of built capital / asset management. The accounts would provide a place to record details of expenditure in a structured format and establish / maintain the links between investment and benefits, making reporting on outcomes or against targets easier. It would also help to identify what types of activities (creation, restoration, modifications) have been successful and where, providing a basis for prioritising investments in the future. However, as noted above with multiple stakeholders involved it may be difficult to undertake this at an Arc scale.

6.3 Case studies

Perhaps the most recognisable example of natural capital accounts in the UK are those produced at the national level by the Office for National Statistics (ONS). In 2011 the government committed to incorporating natural capital into the UK Environmental Accounts by 2020. Since then, the ONS has produced annual accounts in partnership with Defra covering the UK's natural capital assets, the flows and values of services. The accounts are

recognised to be experimental and as such are frequently updated to include natural capital assets and services that weren't valued in previous years. The most recent publication in 2019 presents 13 service accounts, organised around the MEA categories of provisioning, regulating and cultural services, as shown in Table 5.1 below. As well as providing a current snapshot of the value of several ecosystem services, the national accounts illustrate trends over time – in this case the period 2009-2016; although annual flows for many services are now available back to 1997.

Table 5.1 UK ecosystem services asset valuation (£ million, 2018 prices)

Ecosystem Service	Valuation method	Value (£) 2016	Value (£) 2017	Percentage change 2016-2017	Percentage change 2009-2016
Agricultural biomass	Valued using the "residual value" resource rent approach	118,426	128,292	8	38
Fish capture	Landings (tonnage) from UK waters valued at net profit per tonne for different species	7,584	-	-	-
Fossil fuels	Oil, gas and coal production valued using the "residual value" resource rent approach	95,285	59,358	-38	-53
Minerals	Tonnes of minerals extracted valued using the "residual value" resource rent approach	5,483	6,408	17	82
Timber	Timber removals values at Forestry Commission's stumpage price	8,517	8,962	5	72
Water abstraction	Volume of water abstracted valued using the resource rent approach but including treatment and distribution cost and not just water resource cost	76,370	74,741	-2	25
Renewables generation	Valued using the "residual value" resource rent approach and apportioned using renewables proportion of total energy generation	7,887	9,501	20	133
Carbon sequestration	Carbon sequestration estimated from the UK National Atmospheric Emission Inventory (NAEI) and valued at non-traded price per tonne	103,947	105,602	2	12
Air pollutant removal	Air pollution removal by vegetation was modelled and health benefits valued using the QALY approach	43,152	43,447	0.7	0.1
Urban cooling	Impact on city-level temperatures of blue and green space features valued based on avoided air conditioning costs and increased labour productivity	11,398	13,302	17	-
Noise mitigation	Estimated the effect based on amount of vegetation and beneficiary population; change in noise (decibels) valued per household based on QALY approach	-	832	-	-
Recreation	Number of outdoor recreation visits estimated using Monitor of Engagement with the Natural Environment (MENE) Survey and valued using the travel cost method	393,707	347,592	-12	-0.4
Aesthetic (house prices)	Property price premium by distance from nearest publicly accessible green space and total amount of public green space	9,428	-	-	-16
Recreation (house prices)	Property price premium by distance from nearest publicly accessible green space and total amount of public green space accessible	68,552	-	-	23
Total		949,736	-	-	-

In addition to the service accounts, 'broad habitat' accounts are being produced at the national level including woodland, farmland and freshwater (initial accounts produced) urban, semi-natural grassland, coastal margins, marine, and mountains, moorlands and heath (scoped, in progress). These accounts quantify the physical flow and values of ecosystem services attributed to each broad habitat type.

The national accounts aim to capture the positive value (benefits) derived from natural capital assets with adverse impacts on the environment reported separately in the satellite environmental accounts. CNCA on the other hand aims to capture positive and negative impacts (referred to as assets and liabilities) to derive the net impact of an organisation's activities on the environment.

An example of a corporate natural capital account is the environmental profit and loss (EP&L) account produced by Kering, a luxury group which specialises in fashion, leather goods, jewellery and watches. Kering has been measuring and monitoring its environmental performance using the EP&L since 2012 in order to help inform product design, sourcing decisions, manufacturing research and development. Figure 5.1 below, taken from Kering's most recent (2018) EP&L report shows the environmental impacts across their supply chain, starting with the production and processing of raw materials which contributes most significantly.

A further example is provided for Yorkshire Water which, as a large landowner is responsible for managing natural capital as well as impacting on it (both positively and negatively) through its operations. Yorkshire Water has adopted a Total Impact Value and Assessment (TIVA) approach to examine its impacts and dependencies across the six capitals: financial, human, manufactured, intellectual, social and natural. Figure 5.2 is taken from 'Our Contribution to Yorkshire' (Yorkshire Water, 2018) and depicts both positive and negative impacts on natural capital, although the assessment stops short of aggregating these into a net figure.

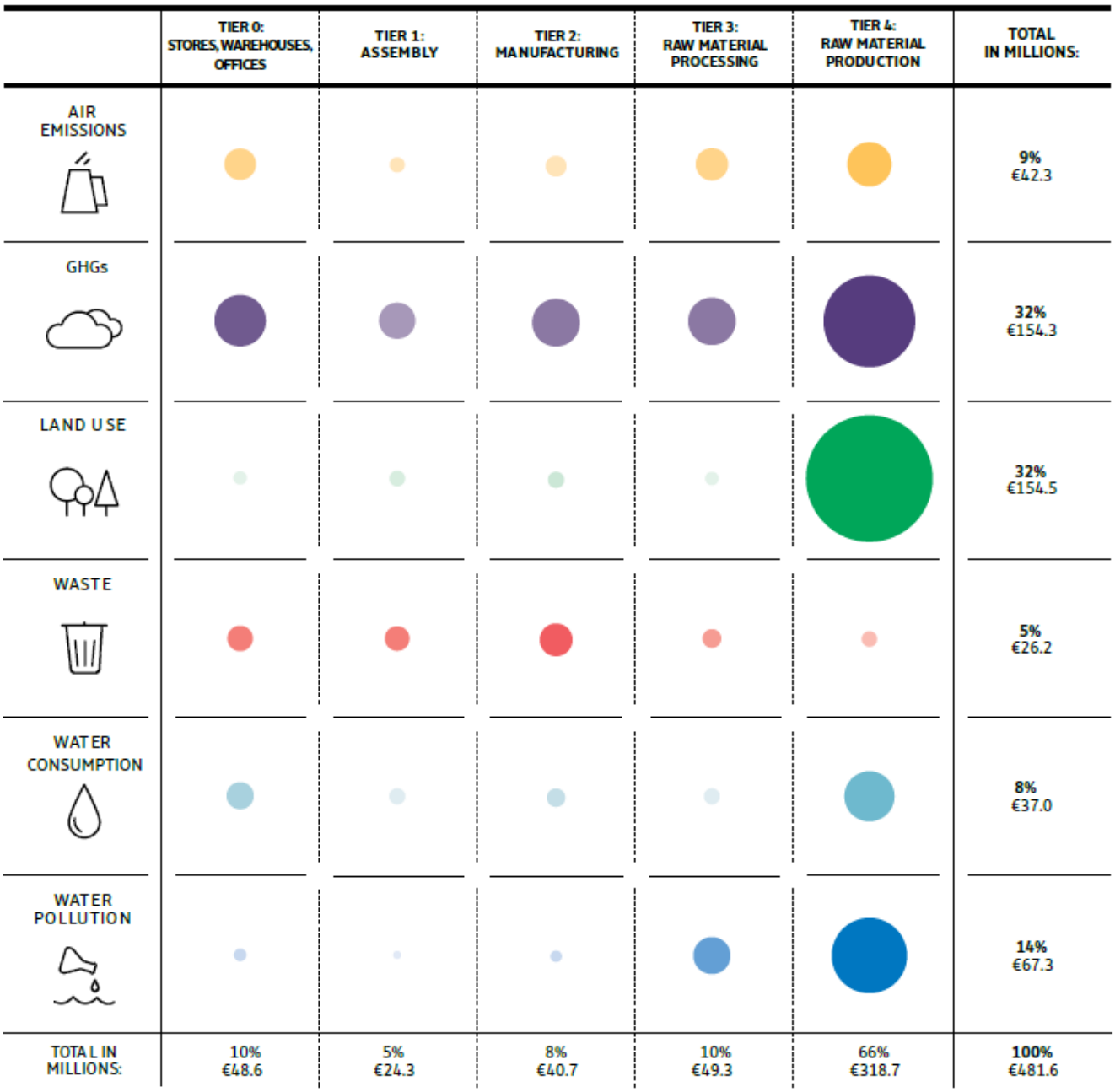


Figure 5.1 Kering's EP&L impacts across supply chain tiers

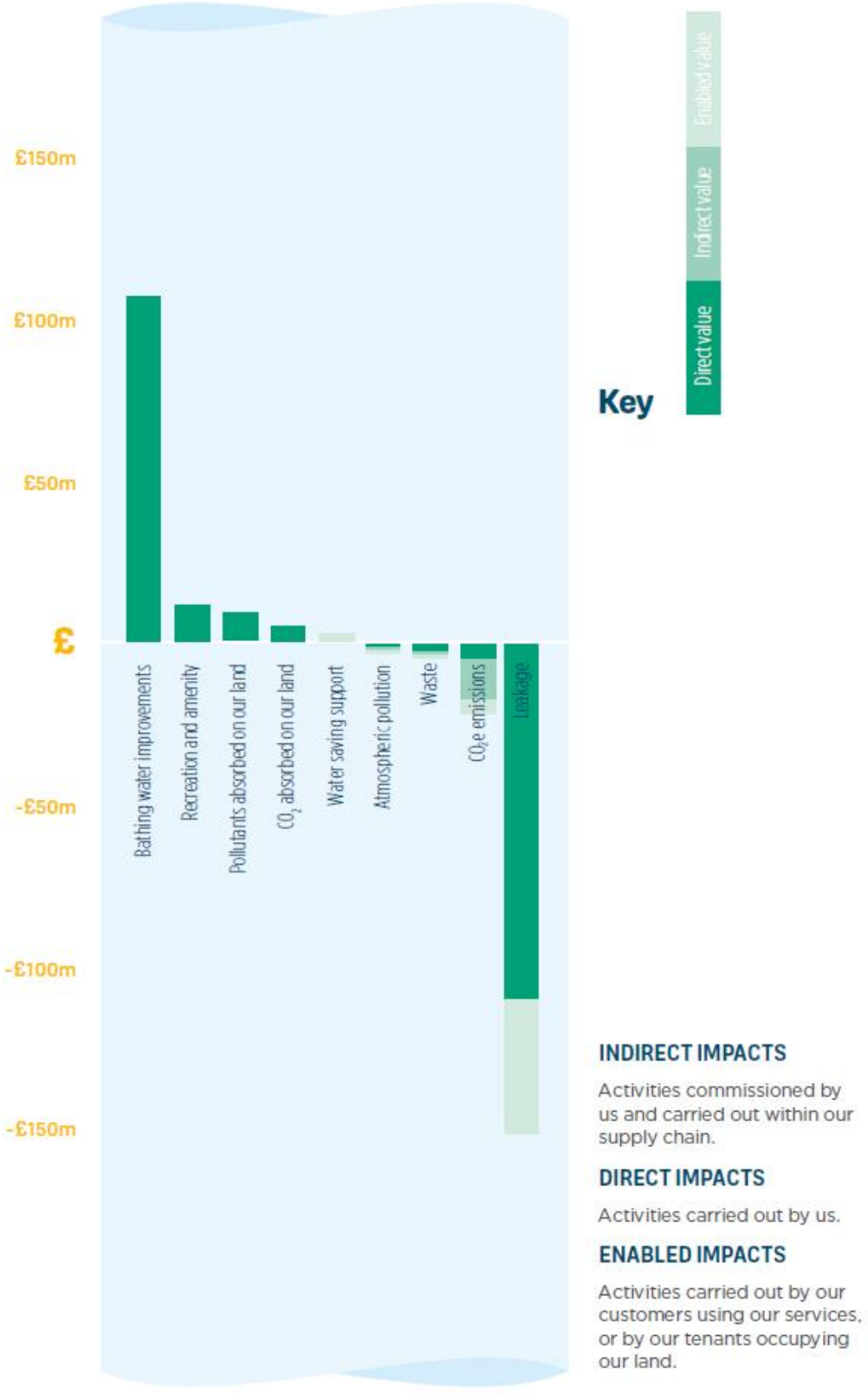


Figure 5.2 – Yorkshire Water's impact and value assessment for natural capital

The remainder of this section presents a summary of selected case studies in Tables 5.2 – Table 5.6. These references were prioritised in order to provide a spread of urban/rural examples, focussing on those which overlap spatially with, or are thought to be most similar to, the OxCam Arc. Some are not accounts in the strictest sense, but rather assessments which value ecosystem services in monetary terms and at minimum consider two time periods (a 'before' and 'after') to show trends over time. Table 5.7 depicts an overview of which ecosystem services were monetised across a range of account and valuation studies.

Table 5.2 – NCA Case Study: Tresham Garden Village

Tresham Garden Village (Natural Capital Solutions, 2019)		
Natural Capital Solutions undertook a natural capital impact assessment of the proposed Tresham Garden Village in East Northamptonshire. The proposal for development included 1,500 homes, two schools, employment zones and associated infrastructure as well as large amounts of connected green space and woodland plantings. Natural capital assets were mapped across the site which primarily consisted of arable farmland under the pre-development scenario, and under the draft masterplan scenario. A natural capital account was then implemented for the before and after development scenarios.		
Ecosystem benefits valued	**Valuation method**	**Use of Account and Key Gaps**
Climate Regulation (£/tonne of CO_2)	UK non-traded carbon prices (BEIS, 2017)	- The primary objective was to identify and assess natural capital assets with and without the development, calculating the flow of services from them (physical flow account), and then the monetary value of the resultant benefits (monetary flow account). - These annual benefit values were used to generate asset values over 100 years for use in a Cost Benefit Analysis to compare with costs of creating and maintaining the natural capital assets, providing a net natural capital value for the development. - This report values key benefits, but not all - as certain ecosystem services such as water quality, aesthetic experiences, cultural heritage, spiritual experience and sense of place are difficult to quantify.
Air Quality Regulation (£/tonne of PM10 and SO_2)	Estimates of the damage costs per tonne of emissions across the UK (Defra 2015)	
Greenhouse Gas Emissions from Agriculture (£/ha/year)	UK non-traded carbon prices (BEIS, 2017)	
Agricultural Production (£/ha/year)	Net Farm Income obtained from Defra's Farm Accounts in England (Farm Business Survey) for the three different farming systems in the Tresham area minus the income received from subsidies.	
Timber (£/m^3/year)	Forestry Commissions Coniferous Standing Sales Price Index (Forestry Commission 2018)	
Recreation (value/visit/year)	Estimated by multiplying the number of visits each year by the per person per trip recreational value for greenbelt and urban fringe farmlands from Sen et al. (2014)	
Health and Well-being (£/Quality of Adjusted Life Years/Year)	QALY scores have an associated monetary value through estimated savings in health care costs. Therefore, they are able to value this physical health benefit by calculating the total number of QALYs by active visitors to sites that meet guidelines, and multiplying this by the monetary value of QALY estimated by White et al. (2016)	

Table 5.3 – NCA Case Study: Cam and Ely-Ouse Catchment

Natural Capital Valuation in the Cam and Ely-Ouse Catchment (Vivid Economics, 2017)		
This study presents a methodology to value the natural capital assets within the Cam and Ely Ouse catchment, with the desired outcome of an evidence base that supports dialogue between stakeholders in the catchment. The natural assets considered were Woodland (Broad Leaf), Woodland (Coniferous), Enclosed Farmland (Arable and horticulture), Enclosed Farmland (Improved grassland), Semi-natural grasslands, Water (Fen marsh and swamp), Water (Freshwater), Mountains, moorland and heath, and Urban. This study also focuses on the impact of intensive agriculture in the catchment and estimates annual soil degradation costs with a range of stakeholders affected. This highlights the potential scope for investments in natural capital that reduce soil degradation to deliver a range of benefits and can be a useful starting point for future work to identify value for money natural capital investments.		
Ecosystem benefits valued	**Valuation method**	**Use of Account and Key Gaps**
Climate Regulation (£/tonne of CO_2)	UK non-traded carbon prices (BEIS)	- High level assessment of the value of natural assets in the Cam and Ely-Ouse catchment provides proof of method for the application of natural capital accounting at a catchment scale. - This study offers ways to extend this work through: a catchment ecosystems strategy addressing current and future pressures; an ecosystem services opportunities map; and stakeholder focused opportunities maps. - Phase two work would bring together various models and datasets to quantify opportunities and allow either optimised or scenario-based asset management plans to be developed. - This work is only a partial assessment with some key ecosystem services requiring a detailed modelling approach to be valued appropriately, such as flood risk reduction. - This report notes that a catchment-based approach to water and land management has important potential. More detailed work is required to identify priority areas which address the social, environmental and economic challenges the catchment faces in the future.
Timber (£/m^3/ha/year)	Vivid Economics modelling, based on data from The John Nix Farm Management Pocketbook (2016) Average timber price assumed to reflect resource rent of timber, given low marginal costs after planting.	
Water provisioning services (£/m^3/year)	Residual resource rent for public water supply. Used ONS guidance for calculations. Complemented with values for use derived from UKNEA.	
Recreation (value/visit/year)	Estimated using ORVal tool.	
Flood Damage Reduction (£/property)	Based on a weighted average damage value for residential properties recommended by Multi-Coloured Manual.	
Cultivated Crops (£/ha/year)	Residual resource rent (ONS guidance)	

Table 5.4 – NCA Case Study: Beam Parklands

Beam Parklands Natural Capital Account (Eftec, 2015)		
This report presents a natural capital account for Beam Parklands following a CNCA approach. Beam Parklands is a multi-functional greenspace in the London Borough of Barking and Dagenham. Its redevelopment during 2009 - 2011 is recognised as a highly successful green infrastructure investment. The results are presented as a natural capital balance sheet. This reports the value of natural capital assets and the costs (liabilities) of maintaining those assets.		
Ecosystem benefits valued	**Valuation method**	**Use of Account and Key Gaps**
Flood Risk Regulation	Estimated in terms of avoided damage costs to residential and non-residential properties	- The report includes a recommendation to develop a more comprehensive asset register and balance sheet to cover climate regulation, air quality, water quality and further aspects of habitats and wildlife conservation. - Highlights the order of magnitude difference between long-term natural capital maintenance (£ millions), and the value of the natural capital benefits provided (£ tens of millions) based on only two ecosystem services valued. - CNCA provides an explicit tool for demonstrating the value delivered by the Land Trust's activities. It enhances the case for financing the management of sites currently in the Land Trust's portfolio, or for sites that can be added to the portfolio. - The account reveals that the required long term provisions for the maintenance of natural capital benefits likely exceeds the endowment that is in place for the site. There is an opportunity to use the evidence base established by the account to support future funding applications.
Local Community Benefits	Calculated by applying the 3% property value uplift to the estimated number of properties in the vicinity. This approach attempts to capture a broader amenity value associated with green space, i.e. the wellbeing that is derived by local residents.	

Table 5.5 – NCA Case Study: Greater Manchester

Urban Pioneer Natural Capital Accounts: Greater Manchester (Eftec, 2019)		
This report presents a natural capital account for Greater Manchester. The account includes: a natural capital register, monetary values of services/benefits; maps showing pressures and risks to the natural capital asset and a natural capital account.		
Ecosystem benefits valued	**Valuation method**	**Use of Account and Key Gaps**
Climate Regulation (£/tonne of CO2)	UK Non traded Carbon prices (BEIS)	- Links from greenspace provision to future population health informed a Greater Manchester Combined Authority natural capital investment plan (2019). - There is a lack of information on the condition of natural capital assets as it is harder to assess across the GMCA. For some benefits, condition is to some extent reflected in benefit calculations (e.g. for agricultural production). However, for others, the condition is not known (e.g. soil).
Air Quality Regulation (£/tonne of PM10 and SO2)	Avoided respiratory health costs modelling within the Jones et al. (2017) UK study.	
Local Climate (heat) regulation (avoided costs to businesses)	Modelled the influence of urban woodland and parkland on urban heat island effects. Value of the heat regulation is estimated based on avoided costs to business: (e.g. reduce air conditioning costs).	
Noise Regulation (avoided health care costs)	Through modelling traffic noise maps, buildings were identified that receive noise mitigations due to Manchester's trees. Reduction in mental stress and health problems from disturbed sleep via avoided health costs was calculated.	
Mental health benefits (avoided health care costs)	Calculated using White et al. (2013) analysis of the extent of greenspace in neighbourhoods and mental health incidence. Then using current mental health spending in Manchester, a reduction in this spend was estimated.	
Minerals (market price of production)	Market value of minerals applied by the ONS in the UK national accounts.	
Food Production (Gross margins on production)	Estimated based on average returns (gross margins) from a typical and representative farming enterprise on each land type, taken from Nix (2018)	
Welfare benefits from Recreation (value/visit/year)	Estimated using ORVal tool	
Physical health benefits from recreation (£/Quality of Adjusted Life Years/Year)	Valued the physical health benefit by calculating the total number of QALYs by active visitors to sites that meet guidelines, and multiplying this by the monetary value of QALY estimated by White et al. (2016)	

Table 5.6 – NCA Case Study: Natural England Nature Reserves

Accounting for National Nature Reserves: A Natural Capital Account of the National Nature Reserves managed by Natural England (Natural England, 2019)		
This study presents a Natural Capital Account for Natural England's National Nature Reserves (NNRs). The study presents an aggregate view of the 141 NNRs that Natural England manages alone or in partnership, which are almost all of Natural England's land holdings. The account includes the value, state and maintenance costs of the NNRs and attempts to enable a method for natural capital accounting for public bodies.		
Ecosystem benefits valued	**Valuation method**	**Use of Account and Key Gaps**
Climate Regulation (£/tonne of CO_2)	Valued in accordance to recommendations by the Department for Business, Energy & Industrial Strategy (2018)	- The study largely took a top-down approach to aggregating information on assets, services and benefits. A recommendation for improvement is to take a bottom-up approach in future, particularly when determining the significance of ecosystem services which may vary significantly across sites. - For some benefits, there is ecological information available, but not enough to quantify the benefit, e.g. water quality. For others, the benefit can be quantified, but there is uncertainty around how this can be related to asset quality. For example, NNR visitor numbers can be estimated, however, how the quality of NNRs affects visitor numbers is not known. Simplified logic chain hides the complexity of the real system. - One of the biggest constraints has been data availability regarding the state of the assets. The study struggled to find datasets of suitable resolution, that are repeated and describe the asset attributes that were of interest. They note that whilst tools such as earth observation may help us in the future, there still needs to be maintenance and investment in datasets that provide information about the state of our natural environment at scales that make sense locally as well as nationally. This lack of information means that some aspects of quality have not been included in the accounts presented in this report.
Timber (£/m^3/year)	Estimated based on the revenue from timber sales as recorded in the financial accounts, this is in line with the approach detailed in ONS (2018).	
Recreation (value/visit/year)	Estimated using ONS (2018) exchange value per trip.	
Experiential and physical use - Volunteers	Estimated following Foster (2013), who concluded that replacement cost is the best available method to value voluntary activity in the ONS household satellite accounts.	
Crops and Livestock (£/year)	Use the concept of resource rent. Treated money paid by graziers to Natural England for grazing livestock as a proxy for resource rent.	
Income from Sporting Rights – shooting, fishing, wildfowling and angling (£/year)	Income from Sporting rights for shooting, fishing, wildfowling and angling is assumed to provide a proxy for the value of provisioning services provided by the NNRs.	
Education (value/visit/year)	Estimate using Clark (2017) exchange value of educational visits.	

Table 5.7 – Summary of ecosystem services captured in selected case studies

	Climate Regulation (Carbon)	Local Climate Regulation	Agricultural Emissions	Air Quality Regulation	Agricultural production	Timber/ wood fuel/ Biomass	Recreation /Amenity	Health and well-being	Physical Health	Visual Amenity	Water Flow	Minerals	Mental health	Noise Mitigation	Flood Risk Regulation	Water Abstraction	Local community benefits	Food	Property Value	Avoided surface runoff	Plant and Seed Supply
Tresham Garden Village Natural Capital Account (Natural Capital Solutions, 2019)	✓		✓	✓	✓	✓	✓	✓													
Forest of Marston Vale (Natural Capital Solutions, 2017)	✓		✓	✓	✓	✓	✓	✓		✓	✓										
The Value of Peterborough City Council's Trees (Natural Capital Solutions, 2018)	✓			✓			✓													✓	
Eycott Hill Nature Reserve Natural Capital Accounts (Eftec, 2018)	✓		✓	✓	✓	✓	✓	✓													
Forest Enterprise England Corporate Natural Capital Accounts (Eftec, 2016)	✓					✓	✓					✓						✓			✓
Urban Pioneer Natural Capital Accounts: Greater Manchester (Eftec, 2018)	✓	✓		✓	✓		✓		✓			✓	✓	✓							
Beam Parklands Natural Capital Account (Eftec, 2015)															✓		✓				
A Study to Scope and Develop Urban Natural Capital Accounts for the UK (Eftec, 2017)	✓	✓		✓					✓					✓				✓			
Natural capital valuation in the Cam and Ely-Ouse catchment (Vivid Economics, 2017)	✓				✓	✓	✓									✓					
Natural capital accounts for public green space in London (Vivid Economics, 2017)	✓	✓					✓		✓				✓						✓		
Benefits and costs of ecological restoration: Rapid assessment of changing ecosystem service values at a U.K. wetland (Peh et al., 2014)	✓				✓		✓														
Accounting for Nature: A Natural Capital Account of the RSPB's estate in England (RSPB, 2017)	✓		✓		✓	✓	✓	✓													

6.3.1 Observations

From the case studies provided above, it is evident that apart from the national accounts undertaken by the ONS, there are no examples of regularly updated accounts depicting a time series; rather most are snapshots in time undertaken for a discrete purpose. Apart from the Natural England study on National Nature Reserves, none of the examples present capitalised asset values; rather all present annual estimates of the benefits of selected ecosystem service flows. A range of valuation techniques and unit values are applied, covering a range of market-based and welfare approaches. Some are consistent with the national ONS accounts, but most are not.

The table above illustrates that there is a tendency to see the same benefits captured and monetised, and those tend to be a) ecosystem services which are best understood and therefore easiest to quantify or b) those that are most easily linked to economic contributions or c) have political traction.

This highlights the point that NCA is an evolving area as well as articulating the need to represent aspects that cannot be monetised. All of the studies reviewed recognise that there are key gaps and that valuation will only ever be partial. With that said, most did conclude that monetary accounts are useful.

Appendix A. References

Bagstad, K.J., (2018) A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Ecosystem Services 5: e27-e39

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

CEH (2017) Glastir Monitoring & Evaluation Programme: Final Report. Prepared by CEH on behalf of Glastir Monitoring & Evaluation Team. July 2017

Day, B. and Owen, N (2018) Natural Environmental Valuation Online (NEVO) A Web-Tool for Natural Capital Analysis. LEEP and West Cumbria Rivers Trust

Clark, R. (2017). Is Corporate Natural Capital Accounting appropriate for monitoring nature reserves? An assessment for National Nature Reserves managed by Natural England. Natural England Research Reports, Number 072. Available online at http://publications.naturalengland.org.uk/publication/5727968978010112Defra (2019) Measuring environmental change: outcome indicator framework for the 25 Year Environment Plan: May 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/802094/25-yep-indicators-2019.pdf

DEFRA (2018) Tools for assessing natural capital - NR0175. http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=20107&FromSearch=Y&Publisher=1&SearchText=tools&GridPage=12&SortString=EndMth&SortOrder=Asc&Paging=10

Eftec (2018) Natural Capital Account for Greater Manchester. Final Report for Environment Agency. 27 June 2018 https://naturegreatermanchester.co.uk/wp-content/uploads/2018/06/NCA-for-GM-Final-Report-270618.pdf

Eftec (2016) Forest Enterprise England Corporate Natural Capital Accounts. https://www.forestryengland.uk/sites/default/files/documents/NATURAL%20CAPITAL%20ACCOUNT%202015_%202016.pdf Envsys (2016) Ecosystem Services Mapping. SENCE A4 summary.

Eftec, (2015) Beam Parklands Natural Capital Account. Final Report for the Greater London Authority.

European Commission (2013) Mapping and Assessment of Ecosystems and their Services. An analytical framework for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. Final Discussion paper, April 2013. https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf

Grêt-Regamey, A., Sirén, E., Hanna Brunner, S., Weibel, B. (2017) Review of decision support tools to operationalise the ecosystem services concept. *Ecosystem Services* 26: 306-315 Haase, D., Schwarz, N., Strohbach, M., Kroll, F., & Seppelt, R., 2012. Synergies, trade-offs, and losses of ecosystem services in urban regions: an integrated multiscale framework applied to the Leipzig-Halle region, Germany. Ecology and Society 17(3): 22.

Hamel, P. (2019) Decision support tools for green infrastructure. Presentation to Financing Green Cities http://growgreenproject.eu/wp-content/uploads/2019/05/Decision-support-tools-for-green-infrastructure_Natural-Capital-Project.pdf

Harrison, P., Sier, A., Acreman, M., Bealey, B., Fry, M., Jones, L., Maskell, L., May, L., Norton, L., Read, D., Reis, S., Trembath, P., Watkins, J. (2017) Natural Capital Metrics Phase 1 Final Report: Central components. CEH Project NEC06063 https://www.ceh.ac.uk/sites/default/files/documents/Natural_Capital_Metrics_project_NEC06063_Final_Report_central_components.pdf

Healy, M and Secchi, Dr. S (2016) A Comparative Analysis of Ecosystem Service Valuation Decision Support Tools for Wetland Restoration. https://www.aswm.org/pdf_lib/ecosystem_service_valuation_032116.pdf

Howard, B, Neumann, J., O'Riordan, R. (2016) Tool Assessor: supporting practical assessment of natural capital in land-use decision making. Joint Nature Conservation Committee. May 2016

Integrated Modelling (2017) Approaches compared. http://www.integratedmodelling.org/?page_id=464

Kering (2018) Environmental Profit & Loss (EP&L) 2017 Group Results. https://www.kering.com/en/news/kering-publishes-2017-group-ep-l-results

Lusardi, J., Rice, P., Waters, R.D. and Craven J. (2018) Natural Capital Indicators: for defining and measuring change in natural capital. Natural England Research Report, Number 076 (NERR076)

Medcalf, K., Small, N., Finch, C., Williams, J., Blair, T., Haines-Young, R., Potschin, M. & Parker, J. (2014) Further development of a spatial framework for mapping ecosystem services. Briefing paper 2 - Mapping ecosystem service trade-offs, JNCC Report, No. 514 Supplemental Paper, JNCC, Peterborough. http://archive.jncc.gov.uk/pdf/JNCC_Report514_BriefingPaper_2.pdf

Natural Capital Committee (2019) Advice on an environmental baseline census of natural capital stocks: an essential foundation for the government's 25 Year Environment Plan. September 2019

Natural Capital Project (2019) In development: Urban InVEST https://naturalcapitalproject.stanford.edu/software/invest-models/development-urban-invest

Natural Capital Solutions (2019) Tresham Garden Village: A natural capital impact assessment http://www.naturalcapitalsolutions.co.uk/wp-content/uploads/2019/10/TGVnatcapassessment-1.pdf

Natural Capital Solutions (2018a) Eycott Hill Nature Reserve Natural Capital Accounts. Final Report. October 2018 https://www.cumbriawildlifetrust.org.uk/sites/default/files/2019-10/Eycott-Hill-Natural-Capital-Accounts-Report.pdf

Natural Capital Solutions (2018b) The Value of Peterborough City Council's Trees

Natural Capital Solutions (2018c) Habitat Opportunity Mapping in Northamptonshire and Peterborough. http://www.naturalcapitalsolutions.co.uk/wp-content/uploads/2018/05/HOM_project_-_final_report_FINALcompressed.pdf

Natural Capital Solutions (2016) Mapping natural capital and ecosystem services in the Nene Valley

Natural England (2013) Green Infrastructure Tools Assessment.

Natural Resources Wales (2016) The State of Natural Resources Report (SoNaRR): Assessment of the Sustainable Management of Natural Resources. Technical Report. Chapter 7 Towards sustainable management of natural resources.

Nelson,E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, R., Chan, K.M.A, Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., Shaw, R. (2009) Modeling multiple ecosystem services, biodiversity conservation, commodity production and trade-offs at landscape scales. Frontiers in Ecology and the Environment. 7 (1): 4-11 https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/080023

Neugarten, R.A., Langhammer, P.F., Osipova, E., Bagstad, K.J., Bhagabati, N., Butchart, S.H.M., Dudley, N., Elliott, V., Gerber, L.R., Gutierrez Arrellano, C., Ivanić, K.-Z., Kettunen, M., Mandle, L., Merriman, J.C., Mulligan, M., Peh, K.S.-H., Raudsepp-Hearne, C., Semmens, D.J., Stolton, S., Willcock, S. (2018). Tools for measuring, modelling, and valuing ecosystem services: Guidance for Key Biodiversity Areas, natural World Heritage Sites, and protected areas.

ONS (2015) Natural capital accounting 2020 roadmap. Interim Review and Forward Look.

https://webarchive.nationalarchives.gov.uk/20160106130009/http://www.ons.gov.uk/ons/rel/environmental/uk-natural-capital/natural-capital-accounting-2020-roadmap--interim-review-and-forward-look/index.html

ONS (2018) UK Natural Capital: interim review and revised 2020 roadmap. Last revised 12 July 2018 https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/methodologies/uknaturalcapitalinterimreviewandrevised2020roadmap

ONS (2019) UK natural capital accounts: 2019.

https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/uknaturalcapitalaccounts/2019

Pagella, T. and Sinclair, F. (2014) Development and use of a typology of mapping tools to assess their fitness for supporting management of ecosystem service provision Landscape Ecol (2014) 29: 383. https://doi.org/10.1007/s10980-013-9983-9/ and Mapping Ecosystem Services. Produced for Work Package 10 of the NEA Follow-on http://neat.ecosystemsknowledge.net/pdfs/ecosystem_mapping_ecosystem_proofed_tool.pdf

Palomo, I., Bagstad, K.J., Nedkov, S., Klug, H., Adamescu, M., Cazacu, C. (2017) Tools for mapping ecosystem services in Burkhard,B. and Maes, J. (eds) Mapping Ecosystem Services

Parker, N., Naumann, E-K., Medcalf, K., Haines-Young, R., Potschin, M., Kretsch, C., Parker, J. & Burkhard, B. (2016) National ecosystem and ecosystem service mapping pilot for a suite of prioritised services. Irish Wildlife Manuals, No. 95. National Parks and Wildlife Service, Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs, Ireland.

Peh, K. S.-H., Balmford, A. P., Bradbury, R. B., Brown, C., Butchart, S. H. M., Hughes, F. M. R., MacDonald, M. A, Stattersfield, A. J., Thomas, D. H. L., Trevelyan, R. J., Walpole, M., & Merriman, J. C. (2017) Toolkit for Ecosystem Service Site-based Assessment (TESSA). Version 2.0 Cambridge, UK Available at: http://tessa.tools

PwC, 2015. Valuing corporate environmental impacts. PwC methodology document.

https://www.pwc.co.uk/sustainability-climate-change/assets/pdf/pwc-environmental-valuation-methodologies.pdf

Raudsepp-Hearne, C., Peterson, G.D. and Bennett, E.M. (2010) Ecosystem service bundles for analysing trade-offs in diverse landscapes. *Proceedings of the National Academy of Sciences*, 107 (11): 5242–5247 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2841950/

Redhead, J.W., May, L., Oliver, T.H., Hamel, P., Sharp, R., Bullock, J.M. (2018) National scale evaluation of the InVEST nutrient retention model in the United Kingdom. *Science of the Total Environment*. 610-611: 666-677

Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron,D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik,M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M. Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., Denu, D., and Douglass, J. (2018). InVEST 3.7.0.User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

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

Smith, A. (2019) Natural Capital in Oxfordshire: short report. Unpublished copy. Draft version 0.1 November 2019

Smith, A. (2018) A Framework for Planning Green Infrastructure Green Spaces, Healthy Places

Smith, A. (2017) Tools for Planning and Evaluating Urban Green Infrastructure

Southgate, F. (2016) An analysis of EcoServ-GIS Ecosystem Service mapping outputs for the ARC Project Area, using Horsham as a case study. An Arun and Rother Connections report funded by the Heritage Lottery Fund, supported by information written by the Durham Wildlife Trust on behalf of the Royal Society of Wildlife Trusts.

Sunderland, T., Waters, R., Marsh, D., Hudson, C., Lusardi, J. (2019) Accounting for National Nature Reserves: A Natural Capital Account of the National Nature Reserves managed by Natural England. 21 February 2019

Surrey Nature Partnership (2018): Natural Capital Investment Plan for Surrey https://surreynaturepartnership.files.wordpress.com/2018/03/natural-capital-investment-plan-for-surrey.pdf

TEP/GMCA (2018) Irwell Management Catchment: Natural Capital Account and Ecosystem Service Opportunities Mapping report

TEP, vivid economics, GMCA, Natural Course (2018) Irwell Management Catchment: Natural Capital Account and Ecosystem Service Opportunities Mapping. PowerPoint presentation.

The RSPB (2017) Accounting for Nature: A Natural Capital Account of the RSPB's estate in England.

TVERC (2018) Developing a Natural Capital Investment Plan. Unpublished copy. January 2018

Vivid Economics (2017a) A Study to Scope and Develop Urban Natural Capital Accounts for the UK. Final Report. June 2017 http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19843

Vivid Economics (2017b) A valuation of the natural capital of the Cam and Ely-Ouse catchment. Final report prepared for WWF-UK. August 2017 https://www.vivideconomics.com/wp-content/uploads/2019/08/Natural-Capital-in-Cam-and-Ely-Ouse-catchment-report-1.pdf

Vivid Economics (2017c) Natural capital accounts for public green space in London. Report prepared for Greater London Authority, National Trust and Heritage Lottery Fund. https://www.london.gov.uk/sites/default/files/11015viv_natural_capital_account_for_london_v7_full_vis.pdf

Vorstius, A.C. and Spray, C.J. (2015) A comparison of ecosystem services mapping tools for their potential to support planning and decision-making on a local scale. *Ecosystem Services* 15: 75-83

Winn, J.P., Bellamy, C.C. & Fisher, T. (2018) EcoServ-GIS: a toolkit for mapping ecosystem services. Scottish Natural Heritage Research Report No. 954.

Yorkshire Water (2018) Our Contribution to Yorkshire.

https://www.yorkshirewater.com/media/1307/our-contribution-to-yorkshire.pdf

Zulian , G., Stange, E., Woods, H., Carvalho, L, Dick, J., Andrews, C., Baró, F., Vizcaino, P., Barton, D.N., Nowel, M., Rusch, G.M., Autunes, P., Fernandes, J., Ferraz, D., dos Santos, R.F., Aszalos, R., Arany, I., Czúcz, B., Priess, J.A., Hoyer, C., Bürger-Patricio, G., Lapola, D., Mederly, P., Halabuk, A., Bezak, P., Kopperoinen, L., Viinikka, A. (2018) Practical application of spatial ecosystem service models to aid decision support. *Ecosystem Services* 29: 465-480

Appendix B. Evaluation criteria

A set of evaluation criteria was developed. The purpose of the criteria was to allow initial screening and to ensure a consistent approach to the detailed review of selected references and approaches and preparing a summary table. Of necessity, there were overlapping evaluation criteria in the various categories.

The evaluation criteria were based upon the criteria identified by the Environment Agency in the Scope and was added to, consolidated and refined into key LNCP critical success factor themes:

Ease of Use

- Accessibility (including licensing and cost)?
- How affordable is it, both in terms of time and monetary resources?
- How transparent is the approach?
- How easy is it for users to drill down and understand what is going on?
- Does it allow / enable you to be transparent about confidence in data reliability, gaps and uncertainties?
- Does it require specialist knowledge and software?

Purposes and Use in Decision Making, for example:

- Does it allow an effective baseline map showing the existing natural capital assets locations, quantity and quality?
- Does it enable the identification of areas for priority protection
- Can it track losses and gains into the future?
- Does it allow trend mapping?
- Identification of key risks, source and scale of the risks and whether the risk is increasing/declining?
- Will it facilitate opportunity mapping and/or inform investment in net gain?
- Will it inform Nature Recovery strategies and BAPs?
- Does it allow for monetary valuation?
- Does it take account of green infrastructure planning?
- Does it allow for scenario or trade-off planning?
- Can it / should it help address where to put new infrastructure, a small settlement, village, town?

Scale

- Such as landscape scale, catchments, local authority areas, site-level
- Resolution

Stakeholders

- Level of stakeholder involvement in development or use
- Scope for stakeholder involvement in future development and use of the tool/approach

Comprehensiveness and data

- Accessibility to datasets, and how useable they are
- Assets and ecosystem services (benefits) covered
- Datasets used and type
- Public domain, or cost of data
- Frequency updated
- Platforms
- Does it allow effective spatial visualization of the data?

Miscellaneous

- Were these approaches used in any studies in the OxCam Arc?
- Does the approach address the range of user needs relevant to the LNCP?
- Are examples provided on how to apply the guidance or select the most appropriate tool based on the user and circumstance?
- Does it advise on baseline for assets, ES, trends, opportunities, risks and condition?
- Spatio-temporal scale flexibility
- Ecosystem Services comprehensiveness
- Re-usability and customisation
- Network of users
- Type of output and interpretation
- Treatment of values
- Means of validation
- Treatment of uncertainty
- Robustness
- Targeted audience/community
- Scoping, option assessment, baselining, financial/economic,
- Qualitative / Quantitative
- Time requirements
- Easily repeatable
- Specialist software needed
- Specialist technical knowledge required

- Scalability
- Generalizability
- Unit of valuation
- Comparative approach
- Affordability
- Analytical tools need to be seen in the context of broader methods and approaches

Appendix C. Approaches

C.1 Approaches – strengths and weaknesses

Reference	Strengths for creation of LNCP	Limitations for creation of LNCP
Green Book Approach (excluding valuation)	4 step approach focused on economic valuation – Screen, Assess bio-physical effects on natural assets; Social welfare implications; Quantification of risks and critical factors; Intervention proposals. Recommends focus on the sustainable use and degradation of natural assets and stock in addition to simple valuation of ecosystem services. Introduces natural capital framework with changes in stock and associated services, benefits and externalities. Recognises that a focus solely on the marginal valuation of a loss in services may overlook the potential for large reductions in stocks	Essential in terms of natural capital approaches but has limited detail. The approach needs to operate alongside other frameworks. It advises quantifying uncertainties which are relevant to LNCP.
How To Do it workbook (2017)	Widely used Natural Capital Committee 5 step approach for measuring and including natural capital approaches in decision-making about the natural environment. Sets out a sequence of steps for the planning and management of natural capital now and in the future: Vison; Starting point; Evidence base; Identify and assess options; Implement and evaluate. Simple to use. Evidence base includes natural capital asset register, risk register and accounts. Addresses benefits, threats and opportunities. Developed with 25YEP and LNCPs in mind. Recognises value of including stakeholders in plan formulation.	Solely a framework and recognises that a substantial body of work is required to develop the critical evidence base and to integrate with policies and plans. It contains some but limited data on sources, tools and models. Discusses formulation of a natural capital plan but not in detail.
Natural Capital Protocol (2016)	Broad 4 stage, 9 step structured framework to identify, measure, value and include natural capital in decision making: Frame, Scope, Measure and Value, Implement. Addresses risks, drivers, opportunities and dependencies. Includes useful summaries of valuation techniques for natural capital assessments. Recognises value of stakeholder participation. Consistent with many other frameworks and good reference source.	Targeted mainly at business and not infrastructure. Recognises substantial amount of work necessary for building baseline. Provides limited data on data, tools and models and plan formulation.

Reference	Strengths for creation of LNCP	Limitations for creation of LNCP
UK Natural Capital Accounts Interim Review and Revised 2020 Roadmap (2018)	Aim to record the size and condition of UK natural assets and the physical and monetary values of the services provided by nature. Comprise broad habitat-based asset accounts, and biotic and abiotic ecosystem accounts. Influential in developing LNCP and includes up-to-date land cover and condition indicators	Work in progress. Still relatively experimental. Significant gaps in economic and environmental data (including up-to-date land cover and condition indicators) and valuation. Insufficient spatial resolution or a consistent time series needed to monitor change over time, and Natural capital accounts are partial in scope.
Natural England Natural Capital Indicators for defining and measuring change in natural capital (2018)	Provides guidance for indicators to assess the state of natural capital, to inform planning. Based on the 8 MEA Broad habitat categories: Mountains Moorlands and Heaths, Semi-natural grassland, Enclosed farmland, Woodland, Freshwaters (Open waters, Wetlands and Floodplains incl. groundwaters, reservoirs, canals etc.), Urban, Coastal, Marine. Identifies 63 regularly updated datasets for asset quantity and location and ecosystem service flow (specific to individual services) short list indicators. Includes a robust suite of indicators for cultural ecosystem services and introduces geodiversity indicators as well as those based on habitat. Based on whole catchment natural capital logic chains linking natural capital assets (quantity, quality and location) and the ecosystem services and benefits. Focuses on natural capital assets rather than monetary values to include factors affecting the long-term provision of ecosystem services. Utilised extensive expert multidisciplinary input. Consistent with CICES, ONS National Accounts. Already widely used, e.g, 25 YEP metrics and evidence annex, NE attributes of resilience, Defra Pioneer projects, Lake District National Park State of the Park report, Water Companies' business planning & performance commitments, MENE survey and an evaluation of the impact of agri-environment schemes on natural capital.	Recognises that there are other typologies to those based on broad habitats that exist, e.g. 25YEP asset list which includes ecosystems, species, freshwater, land, soils, minerals, air and seas. However, in the NE Indicator framework, these are included as component parts of broad habitat assets which avoids overlap between the assets (and double counting for accounting purposes). Recognises data gaps and challenges with fragmented broad habitat assets. Indicators were not identified for management interventions, pressures or drivers of change affecting natural capital assets, ecosystem services and benefits

Reference	Strengths for creation of LNCP	Limitations for creation of LNCP
Defra Measuring environmental change: Outcome Indicator framework for the 25 YEP: May 2019	Developed 66 indicators to describe natural capital change, arranged into 10 broad themes, allows users to select natural capital conceptual framework indicators and identify pressures acting upon natural capital assets, assess the condition of assets, and highlight the services and/or benefits that are provided by natural capital. Outcomes and Goals are consistent with 25YEP, Draft Environment Bill and therefore LNCP. Flexible, linked to international frameworks and consistent with the MEA, UN SDG, IPBES, TEEB, UK NEA and NCC	Focused on monitoring 25YEP rather than building evidence base. NCC have advised that less than 20% of the 66 proposed indicators provide a measure of natural capital assets and that even these are partial measures. Many indicators still require further development. Excludes external drivers of environmental change, such as the global economy and security; population growth and migration; emergent diseases, technological advances and climate change, although this is common to most approaches.
NCC Advice on an environmental baseline census of natural capital stocks: an essential foundation for the government's 25 Year Environment Plan	Links to the NCC workbook and updates and builds upon previous work. Propose organisation of baseline data across 8 asset types or themes: Atmosphere – recommends wider set of air quality parameters and modelling; Freshwater – recommends developing metrics for all water types – standing, rivers, streams and groundwater, as well as condition of invertebrates, plants, fish etc in water bodies; Land and ecological communities – recommends standardising extent and condition of land cover into one open access database; Species – agree data standards and species lists, and prioritise gaps; Soils – recommends SOC as priority indicator, with metrics for soil invertebrates, bulk soil density, pH and nutrients; Urban natural capital – recommends gathering range of scales and standardising existing data. Oceans are not relevant to OxCam LNCP All data in a centralised, open-source database and web-portal that could be managed by Defra Recommends incentivising the prevention of degradation of assets ahead of ever more detailed baseline measurements. Advocates 5 year trend analysis. Highlights the importance of including provision for using citizen science and increasing citizen engagement with the environment. Recommends that spatial scale is detailed enough to support asset registers for landowners, businesses and local authorities and sufficient to support scaling up and down of the data for multiple uses. Terrestrial datasets should resolve to a common spatial unit.	Although focused on a data census it recommends additional new data collection, including for soils, marine, biodiversity, ecological communities and urban areas to include data-capture resulting from the use of emerging technologies (e.g. Sentinel satellites and Landsat imagery, and smart phone apps) and by doing so encourages as wide a participation as possible in collecting this data including landowners, school children, public bodies and National Parks Recognises that a rigorous gap analysis of environmental data does not exist.

Reference	Strengths for creation of LNCP	Limitations for creation of LNCP
	Should enable enhancements to ONS natural capital accounts and enable HMT Green Book economic analyses	
Accounting for National Nature Reserves: Dec 2018 Natural England	Method which uses the NE indicators. Recommends natural capital accounts are built on key attributes of natural capital stock and not just services or benefits. Recognises monetary values are very partial. Based on the standard logic chain: Ecosystem Asset to Ecosystem Service to Benefits and Values with sub-components of each based on expert opinion. Introduces significance and confidence limits for different components indicators and parts of the logic chain, especially important where data sets are incomplete	Limited to National Nature Reserves
Natural Capital Metrics Phase 1 Final Report: Central components CEH Project (2017)	Valuable study which reviewed a variety of frameworks – Cascade model, Ecosystem Service Provision (FESP), Drivers-Pressures-State-Impact-Response (DPSIR) US-EPA FEGS, NCC, ONS natural capital accounting, Welsh Government frameworks for well-being goals, ecosystem services and natural resources, and IPBES. Recommended a conceptual evidence chain framework with linkages and interactions between natural capital or ecosystem assets (biophysical extent, condition and structure, often but not exclusively habitat based) through ecosystem services flows and processes to human socio-economic values and benefits and beneficiaries. Considered that the Drivers-Pressures-State-Impact-Response (DPSIR) framework, although often excluded, is critical to the framework. Discussed several case studies and metrics for these, developed through individual evidence or logic chains. Recommends online portal to groups of potential stakeholders/users providing access to datasets and project outputs, with visual presentation of natural capital chains of evidence.	Useful discussions on data sets and indicators but developed through a set of specific case studies only and as such no comprehensive datasets and metrics for the approach
TVERC developing a natural capital	NCC workbook framework study with 5 stages: Audit natural capital and ecosystem services, forecast the impact of change, Value the benefits, identify where to invest in natural capital to achieve net gain via	Introduces demand and attempts to calculate natural capital / ecosystem service deficit and/or surplus balance. Although interesting

Reference	Strengths for creation of LNCP	Limitations for creation of LNCP
investment plan 2018	Environmental Investment Plan (EIP) and monitor changes in natural capital and the impact of investment.	this is a challenging approach as it tries to model and balance a very highly complex set of scenarios.
Oxford to Cambridge Arc Natural Capital Indicator Maps July 2019 NE Natural Capital Indicator Atlas	Derived from the national natural capital atlas, this is an OxCam LNCP specific tool for early engagement. Based on 1 km^2 and developed logic chain. It defines an initial sets of Asset Quantity indicators: 8 for freshwater, 3 for grasslands & heath, 5 for urban, 4 for farmland and 4 for woodland. Asset Quality indicators comprise 3 for hydrology and geomorphology, 4 for nutrient and chemical status, 2 for soil/sediment process , 2 for vegetation, 2 for species composition and 5 for cultural. The evidence chains and indicators are consistent with many of the referenced approaches and form a useful starting point for the LNCP.	Limited only by the spatial atlas format, but supported by underlying spatial databases
Common International Classification of Ecosystem Services (CICES)	Widely used ES classification which follows EU MAES 2013 process and classifies final ecosystem services which give rise to benefits into hierarchy of: Section – Division - Group – Class. Has separate biotic and abiotic categories for each of the ecosystem service types Acknowledges that the boundary between biotic and abiotic ecosystem services is difficult to define in practice.	Does not address underpinning or supporting ecosystem accounts in terms of the structures, processes and functions that give rise to services measurement units have not been provided as part of the definition of the Classes

C.2 Comparison of key natural capital assessment approaches

Approach framework			
	Natural Capital Committee How to do it workbook	**Natural Capital Protocol**	**Green Book Natural Capital Screening and 4-Step Assessment Tools**
Vision	*Step 1 Setting out the vison* Structured discussion and deliberation. Involve a wide group. Documented goals and objectives	*Frame Stage* *Step 1 Get started* Consider natural capital impacts and dependencies What decisions would benefit? On what timescale Record engagement with stakeholders	*Screening questions* Identify potential effects on natural capital
Scoping	*Step 2 Where starting from* Desk based research and mapping on current state and condition of natural assets, services and benefits. Identify what is planned, by whom, over what scale and when. Identify stakeholders	*Scope Stage* *Step 2 Define objective* Define target audience, stakeholders, SMART objectives and resources needed *Step 3 Scope Objective* Define organisational focus, boundaries, value perspective, impacts and dependencies. Decide on qualitative, quantitative and/or monetary value for aspects. Identify baselines, scenarios, spatial and time boundaries and key planning issues Step 4 Determine impacts and/or dependencies List decision making requirements, potential impacts and dependencies, carry out materiality assessment to confirm most relevant natural capital issues	*Step 1 Identify the environmental context* Scope the biological and physical changes in natural assets Identify scale, location, outputs and spatial reach Identify types of land cover and natural systems that will be affected directly or indirectly

Evidence Base	*Step 3 Build evidence base* Detailed analysis (mapping, environmental and ecosystem modelling, economic modelling) of the natural assets, their services and economic and social benefits	*Measure and Value Stage* *Step 5 Measure impact drivers and/or dependencies* Map activities against drivers and/or dependencies Define what to measure Identify how to measure Collect data *Step 6 Measure changes in the state of natural capital* Select and apply methods, to measure and estimate changes in natural capital resulting from your drivers and dependencies	*Step 2 Consider Bio-physical effects on natural assets* Which natural assets are specifically likely to be affected? Look at physical sustainability of natural stocks. Identify multiple impacts which may need to be measured and valued
Valuation		*Measure and Value Stage (cont.)* *Step 7 Value impacts and/or dependencies* Select appropriate valuation technique(s) Undertake valuation Define consequences and the relative significance of costs and/or benefits	*Step 3 Consider social welfare implications of the bio-physical effects identified* Proportionately quantify and monetise the effects on environmental goods and services due to changes to the assets. Un-monetised factors should be included. *Step 4 Consider uncertainties and implementation* Quantify and cost risks, critical factors, monitor, intervention proposals to manage risks and optimise outcomes
Create Plan	*Step 3 (cont.)* Integrate with demographic and infrastructure plans and develop potential natural capital plans indicating needed inputs and outcomes for assets, benefits and beneficiaries. *Step 4 Identify and assess options* Scenario development, modelling and deliberative discussions to agree the nature of the plan. Generate new options	*Measure and Value Stage (cont.)* *Step 8 Interpret* Sensitivity analysis, who is affected by a decision, and how. Develop analytical approach or framework e.g. CBA, MCA, cost-benefit analysis, multi-criteria analysis, compare options, Output Key messages, caveats, assumptions, and uncertainties	

Implement and Evaluate	*Step 5 Implementation and evaluation* Develop practical, implementable and prioritised action plan that all partners buy in to with the necessary funding identified. Put in place governance, accountability and reporting arrangements Review and Update	*Apply Stage* *Step 9 Take Action* A communication plan Plan for making natural capital assessments part of how you do business	

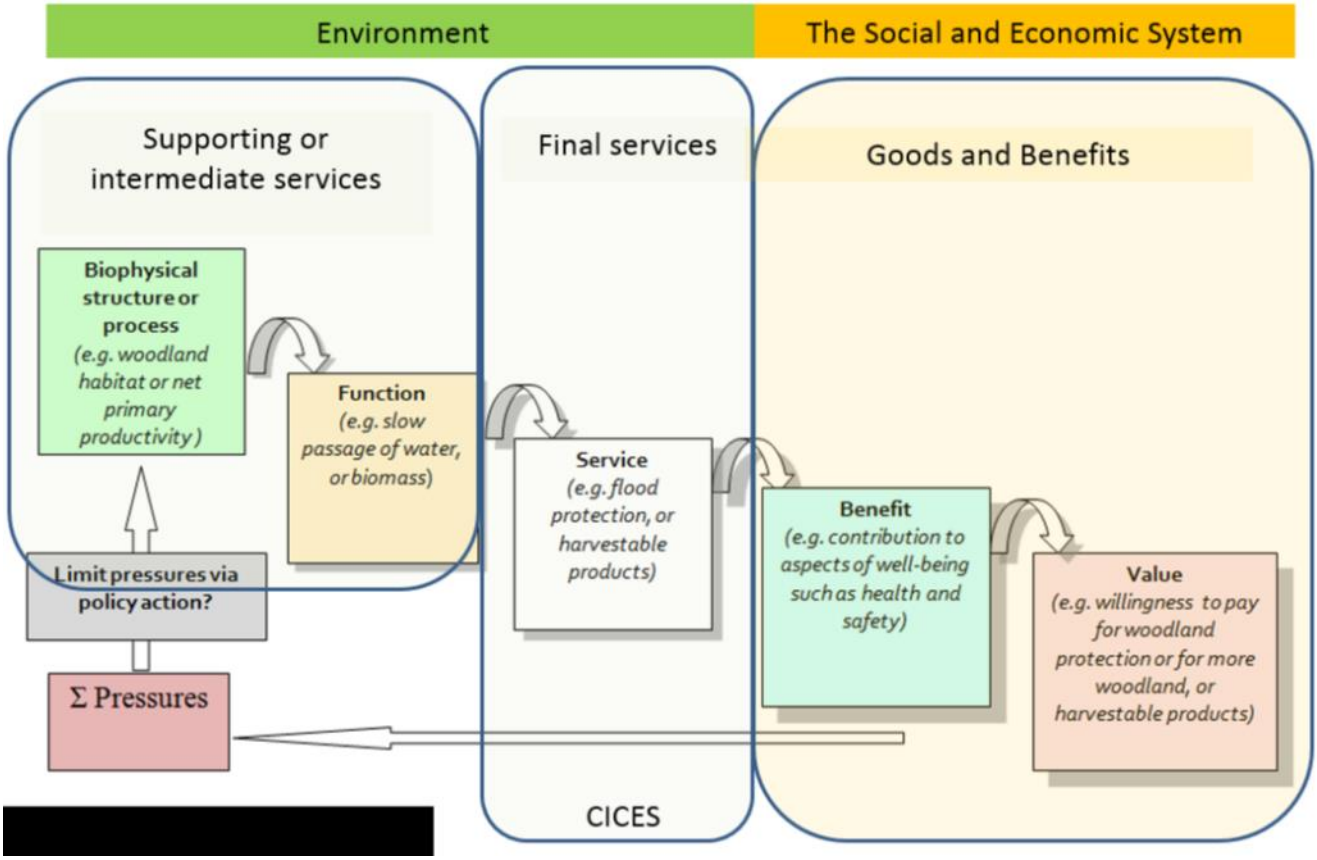
C.3 Broad Habitat Ecosystem Categories

NEA Broad Habitats (2008)	CEH 2015 class (21 total)	EA database (Corine 2012)	Biodiversity Broad Habitat Classification	NE Natural Capital Indicator Atlas
Mountain		Mountains moorland and heath	Montane habitats	Not present
Heathland	Heather		Dwarf shrub and heath	Grassland and Heath
	Heather grassland		Bracken	
Grassland	Improved grassland	Semi natural grasslands	Improved grassland	
	Neutral grassland		Neutral grassland	
	Calcareous grassland		Calcareous grassland	
	Acid grassland		Acid grassland	
Woodland	Broadleaved woodland	Woodland	Broadleaved, mixed and yew woodland	Woodland
	Coniferous woodland		Coniferous woodland	
Enclosed farmland	Arable and horticulture	Enclosed farmland	Arable and horticulture	Farmland
Open water	Freshwater	Freshwaters	Rivers and streams	Freshwater
		open waters	Reservoirs Standing water and canals	
		floodplains	Groundwater	
Wetland	Bog		Bogs	
	Fen, marsh and swamp	wetlands	Fen, marsh and swamp	
Inland rock	Inland rock		Inland rock	n/a
Urban	Urban	Urban	Built up areas and gardens	Urban
	Suburban			
Coastal	Supra-littoral rock	Coastal margins	Transition and coastal	Not present
	Supra-littoral sediment		Coastal dunes	
	Littoral rock		sandy shore	
	Littoral sediment		saltmarsh	
	Saltmarsh			
Marine	Saltwater	Marine	Deep sea	Not present
			Boundary and linear features	

Appendix D. Logic Chain Examples

Most logic chains can be traced back to the Cascade Model (Potschin and Haines-Young, 2011, 2016).

Natural England's natural capital Indicators project generic logic chain (2018)



Natural England 2018 logic chain for Urban – global, regional and local climate regulation

URBAN Global, regional and local climate regulation

Ecosystem Assets

(Factors affecting provision of ecosystem service)

Quantity – Extent (& number/density) of:

- Green space (not semi-natural)
- Semi-natural habitats
- Woodland scrub and hedge
- Wood pasture/historic parkland & veteran trees
- Urban/street trees, canopy cover
- Urban blue space: ponds, lakes, reservoirs rivers, canals, streams, SUDs and associated vegetation
- Open mosaic habitats

Quality

Soil/sediment processes:

- Soil depth
- Soil water retention
- Soil Type
- Soil erosion
- Degree of compaction
- Infiltration

Nutrient & chemical status:

- Soil carbon
- Soil N, P, K, , pH
-
- Atmospheric deposition: exceedance of critical loads : particulates; ozone; N; S; pH

Vegetation:

- Vegetation cover/bare soil/concrete or tarmac
- Plant growth rate
- Above and below ground biomass
- Surface roughness/microtopography
- Urban tree canopy (extent/height), age, density & health (including drought stress), species
- Building integrated vegetation: including green roofs & walls
- 'Naturalness': vegetation that arises & develops through natural processes (i.e. not planted/designed).
- Vegetation management i.e. maintained or not

Ideal indicators highlighted: short list & long list

Ecosystem Service Flow

- Local urban cooling
- Carbon sequestration by soil/vegetation and fixing of greenhouse gases

Quality continued:

Hydrology and geomorphology:

- Naturalness of water level regime

Geology & topography:

- Geology
- Altitude, slope, aspect , land form
- Catchment characteristics

Climatic:

- Air temperature
- Sunlight/cloud cover
- Precipitation (incl. distribution, seasonality, intensity)
- Snow cover and length of snow lie
- Wind (including localised effects due to buildings)
- Drought
- Length of growing season (for vegetation)
- microclimate – particularly reduced temperature from green space and street trees

Spatial Configuration:

- Position of habitats and trees to provide cooling to housing and buildings

Benefit

Equitable climate e.g. reduced risk of drought, flood & extreme weather events, lower summer temperatures, reduced health & safety risks, reduced flood risk, protection of infrastructure/lack of transport disruption

Management Interventions

- Cutting of grassland (including frequency/absence of)
- Removal of arising
- Enhancing grassland/woodland eg planting, seed sowing
- Fertiliser applications
- Gardening, including for food
- Grazing – including deer and under grazing
- Woodland creation & management, thinning/coppicing etc
- Land drainage
- Irrigation
- Land wetting
- Pesticide & herbicide use
- Hedge & tree management – frequency and type
- Increase in non-permeable surfaces, including paving front gardens
- Designed/retrofit green infrastructure
- Sustainable Urban Drainage Scheme
- Salt/de-icing roads/airports

Other drivers of change

- Demographic - increasing human population
- Climate change
- Market forces/ Commercial growth/decline
- Technological change
- New housing & transport needs
- Increased density of development
- Decline in heavy industry, dereliction
- Domestic traffic
- Public transport
- Water abstraction
- Atmospheric pollution – especially particulates & ozone
- Noise and artificial lighting
- Contaminated land
- Invasive non-native species
- Pests & disease
- Regulation/de-regulation
- Policy, local initiatives & targets
- Availability of funding & management for urban greenspace: public, private, lottery, charitable
- Awards/accreditation e.g. Green Flag
- Attitudes to greenspace & public health
- Recreational pressures
- Shift from burial to cremation

8

Natural England 2018 logic chain for Freshwater, Openwaters, Wetlands and Floodplains – Global, regional and local climate regulation

FRESHWATERS: OPENWATERS, WETLANDS & FLOODPLAINS Global, regional and local climate regulation

Ecosystem Assets
(Factors affecting provision of ecosystem service)
Quantity – Extent of (PH = Priority Habitat)
- Rivers
- Standing waters
- Groundwaters
- Coastal and flood plain grazing marsh
- Lowland fens
- Lowland raised bogs
- Reed beds

Quality
Soil/sediment processes:
- Peat depth
- Soil microorganisms/biota
- Soil organic matter
- Soil water retention/moisture
- Soil Type
- Soil integrity esp. peatland erosion;
- Degree of compaction
- Infiltration

Nutrient (& chemical) status:
- Soil carbon/organic matter
- Soil nutrient status N, P, , pH
- Nutrient status of water bodies (P, N, C, BOD, NH_3, etc.)
- Atmospheric deposition: exceedance of critical loads S, N
- Chemical status of water bodies, not nutrients

Vegetation:
- Aquatic macrophytes: submerged & emergent
- Phytoplankton & diatoms (lakes), phytobenthos (rivers)
- Vegetation cover/bare soil
- Type/composition eg root depth, transpiration, interception
- Plant growth rate
- Above and below ground biomass
- Surface roughness/microtopography
- Proportion of peat mass actively forming peat
- Riparian/hydrosere transition vegetation cover/type
- Litter, including debris dams

Italics shows factors not affected by management interventions
Ideal indicators highlighted: short list and long list

Ecosystem Service Flow
- Carbon sequestration by soil/vegetation and fixing of green-house gases

Quality continued:
Hydrology and geomorphology:
- Naturalness of lake hydrological regime
- Infiltration
- Lack of physical modifications
- Sedimentological regime: erosion & deposition
- Naturalness of flooding regime
- Naturalness of water level regime(esp. for wetlands)
- Water depth
- Flow regime
- Natural aquifer function: recharge & discharge
- Extent of artificial drainage
- Amount of surface water run-off/overland flow

Species Composition:
- Invasive non-native species
- Invertebrates: macro & micro
- Fish: populations, spawning & nursery grounds
- Bird populations: breeding; wintering; passage

Geology & topography:
- *Geology*
- *Altitude, slope, aspect , land form*
- *Catchment characteristics*

Climatic:
- *Air temperature*
- *Sunlight/cloud cover*
- *Precipitation (incl.type, distribution, seasonality, intensity)*
- *Snow cover and length of snow lie*
- *Frequency of freeze thaw*
- *Wind*
- *Drought*
- *Length of growing season (for vegetation)*

Spatial Configuration:
Not relevant to this service

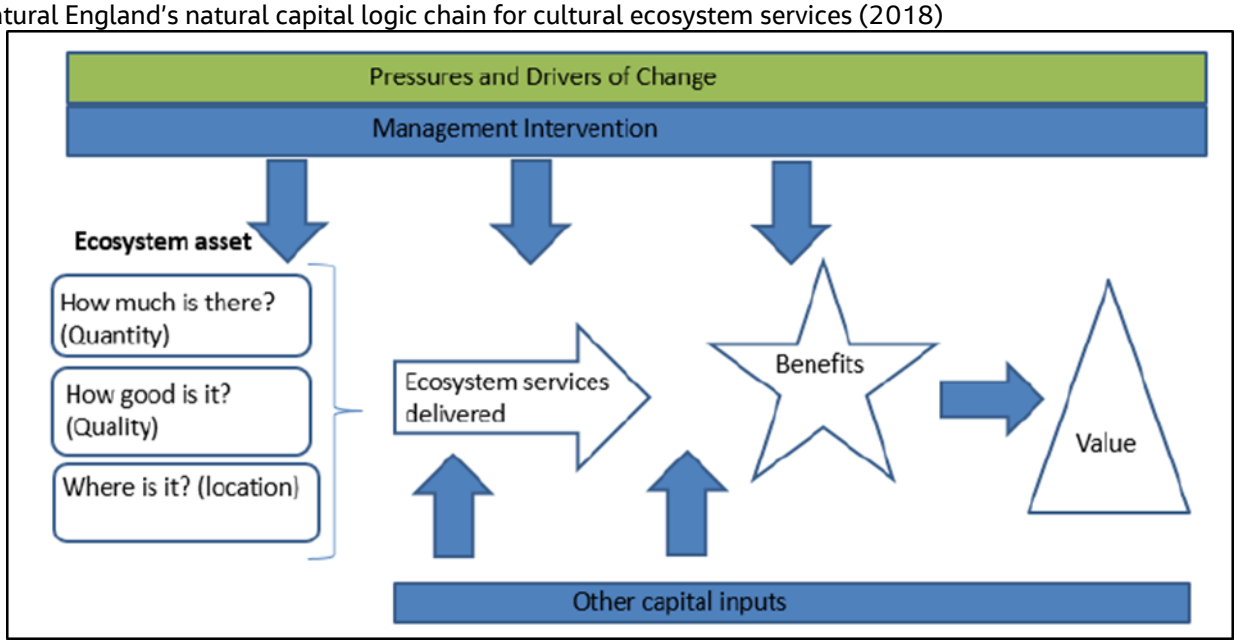
Benefit
Equitable climate e.g. reduced risk of drought, flood & extreme weather events, lower summer temperatures, reduced health & safety risks, reduced flood risk, protection of infrastructure/lack of transport disruption

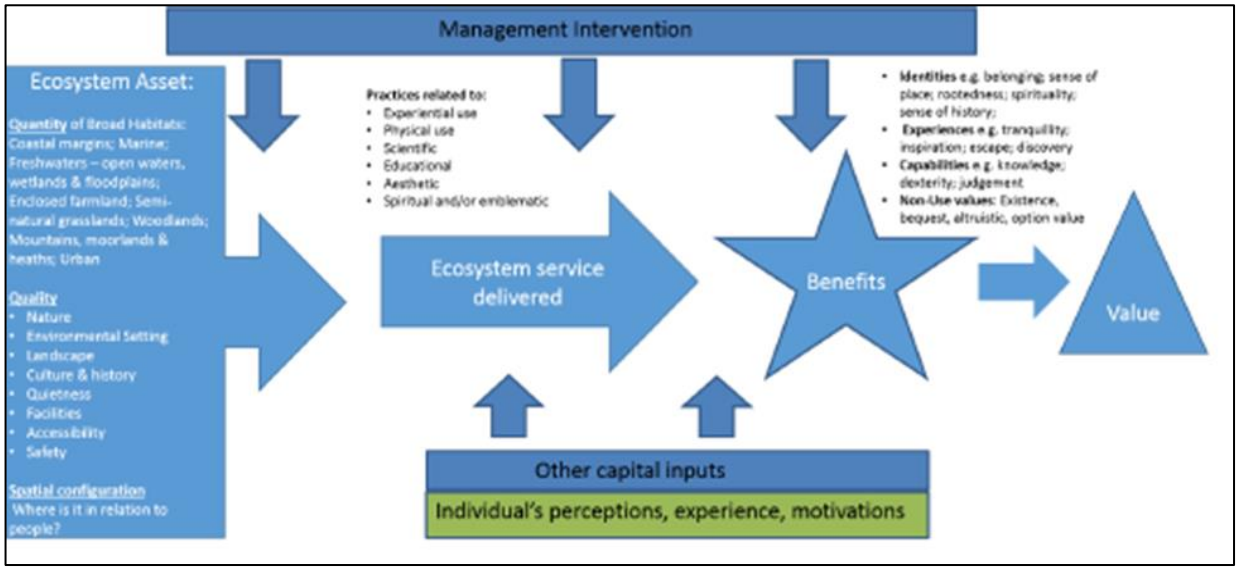
Management Interventions
- Water abstraction: surface & ground water
- Flow modification/ water level regulation
- Water impoundment & diversion
- Channel straightening, reprofiling, deepening
- In-channel structures: weirs; dams etc
- Bank reinforcements/flood defence schemes
- River restoration
- Squeezing/loss of freshwater-terrestrial transitions
- Land drainage and agricultural improvement
- Tilling, ploughing
- Grazing/trampling: livestock type; intensity; cessation
- Rotational burning: scale; pattern; frequency
- Aquaculture
- Afforestation
- Woodland creation
- Pond, bog and other habitat creation & restoration
- Scrub, bracken, gorse control
- Cutting aquatic & terrestrial vegetation, removal of wood
- Agricultural nutrient applications
- Pesticide use e.g. sheep dip
- Renewable energy: wind; hydro

Other drivers of change
- Climate change
- Point source pollution - sewage
- Industrial pollution
- Diffuse pollution (including from agriculture)
- New pollutants e.g. endocrine disruptors, nano particles
- Thermal discharges
- Soil erosion and landslips
- Regulation, including WFD
- Agri-environment schemes/cross compliance/changes in subsidy payments
- Peat extraction
- Recreational pressures (soil erosion)
- Atmospheric deposition (acidification, eutrophication)
- Urban development & infrastructure
- Increasing human population & demand for water Seasonal peaks in human population e.g. with tourism
- Invasive non-native species
- Pests and diseases

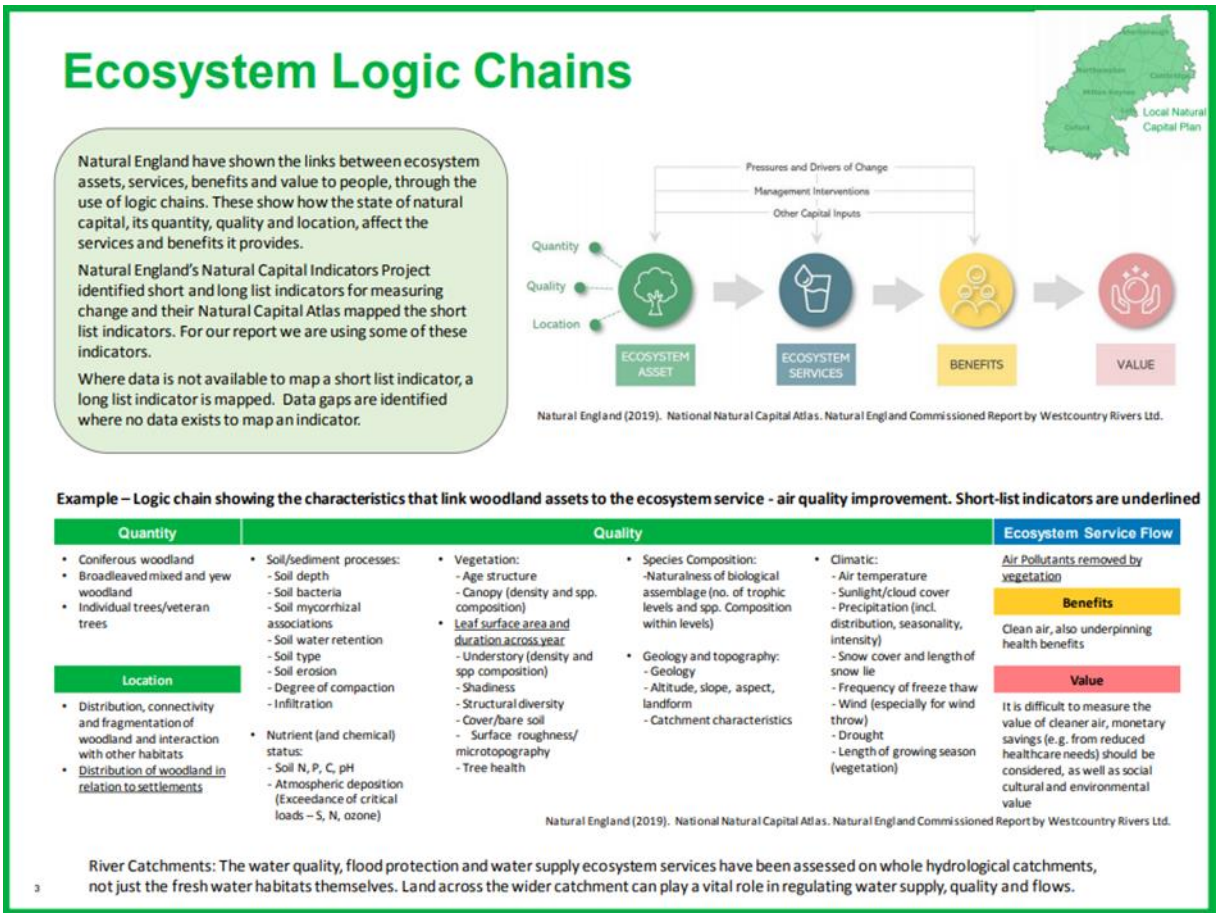
22

Natural England's natural capital logic chain for cultural ecosystem services (2018)





Logic chain from OxCam Natural Capital Indicator Maps which is taken from Natural England's National Natural Capital Atlas (2019)



Ecosystem Logic Chains

Natural England have shown the links between ecosystem assets, services, benefits and value to people, through the use of logic chains. These show how the state of natural capital, its quantity, quality and location, affect the services and benefits it provides.

Natural England's Natural Capital Indicators Project identified short and long list indicators for measuring change and their Natural Capital Atlas mapped the short list indicators. For our report we are using some of these indicators.

Where data is not available to map a short list indicator, a long list indicator is mapped. Data gaps are identified where no data exists to map an indicator.

Natural England (2019). National Natural Capital Atlas. Natural England Commissioned Report by Westcountry Rivers Ltd.

Example – Logic chain showing the characteristics that link woodland assets to the ecosystem service - air quality improvement. Short-list indicators are underlined

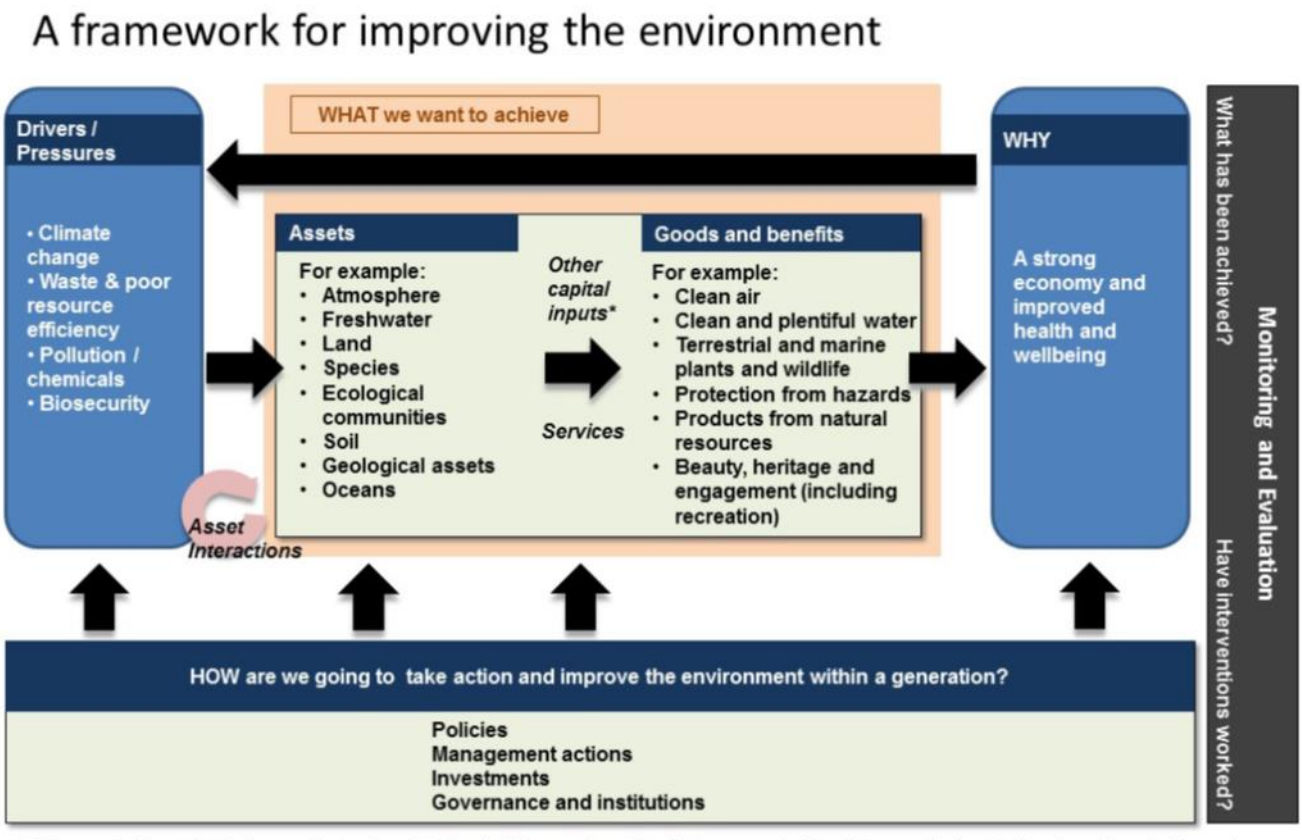
Quantity	Quality				Ecosystem Service Flow
• Coniferous woodland • Broadleaved mixed and yew woodland • Individual trees/veteran trees	• Soil/sediment processes: - Soil depth - Soil bacteria - Soil mycorrhizal associations - Soil water retention - Soil type - Soil erosion - Degree of compaction - Infiltration • Nutrient (and chemical) status: - Soil N, P, C, pH - Atmospheric deposition (Exceedance of critical loads – S, N, ozone)	• Vegetation: - Age structure - Canopy (density and spp. composition) • Leaf surface area and duration across year - Understory (density and spp composition) - Shadiness - Structural diversity - Cover/bare soil - Surface roughness/ microtopography - Tree health	• Species Composition: -Naturalness of biological assemblage (no. of trophic levels and spp. Composition within levels) • Geology and topography: - Geology - Altitude, slope, aspect, landform - Catchment characteristics	• Climatic: - Air temperature - Sunlight/cloud cover - Precipitation (incl. distribution, seasonality, intensity) - Snow cover and length of snow lie - Frequency of freeze thaw - Wind (especially for wind throw) - Drought - Length of growing season (vegetation)	Air Pollutants removed by vegetation **Benefits** Clean air, also underpinning health benefits **Value** It is difficult to measure the value of cleaner air, monetary savings (e.g. from reduced healthcare needs) should be considered, as well as social cultural and environmental value
Location • Distribution, connectivity and fragmentation of woodland and interaction with other habitats • Distribution of woodland in relation to settlements					

Natural England (2019). National Natural Capital Atlas. Natural England Commissioned Report by Westcountry Rivers Ltd.

River Catchments: The water quality, flood protection and water supply ecosystem services have been assessed on whole hydrological catchments, not just the fresh water habitats themselves. Land across the wider catchment can play a vital role in regulating water supply, quality and flows.

3

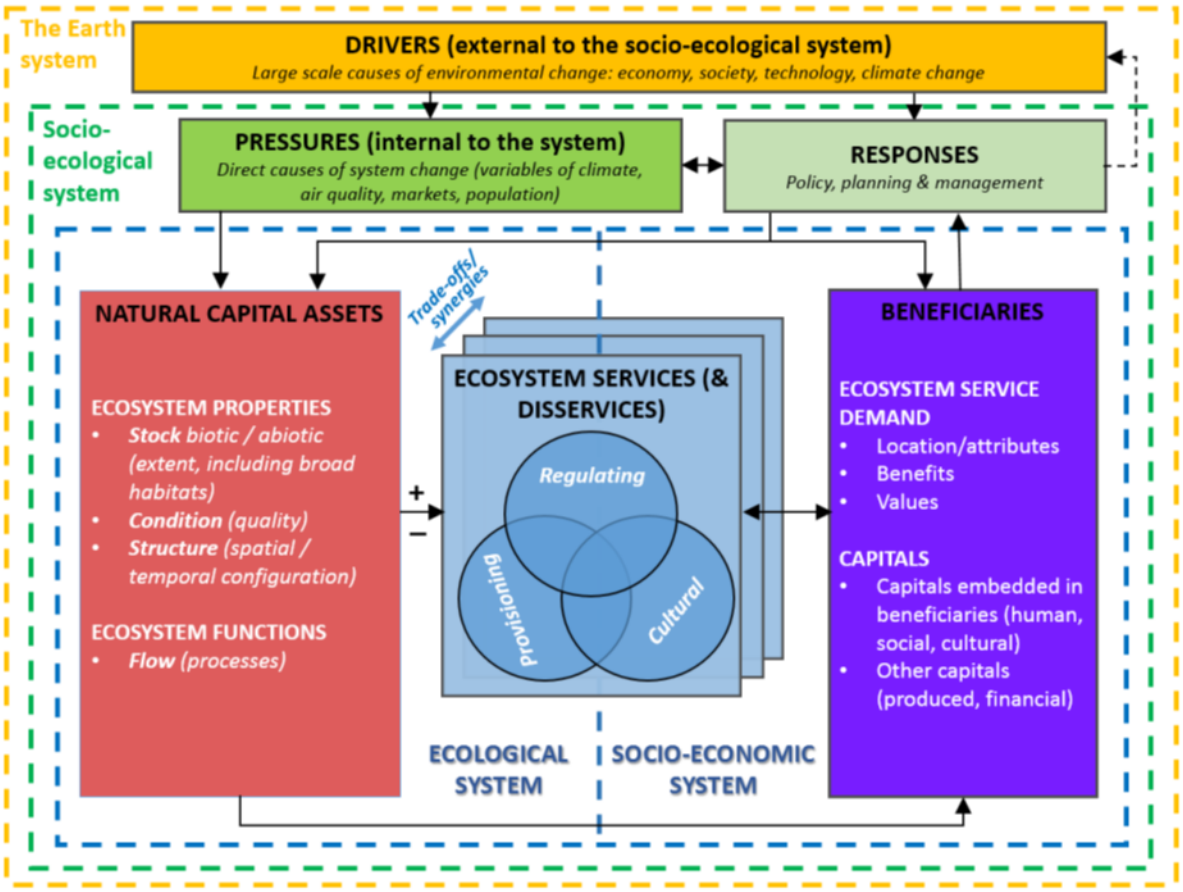
From Defra 2019 - 25 YEP Outcome indicators



A framework for improving the environment

*Other capital inputs include manufactured capital (eg. buildings and machines), human capital (eg. labour and education) and social capital (eg. rules and procedures)

NC Metrics project Conceptual Framework for a single socio-ecological system (CEH Metrics Project 2017)



Appendix E. Tools: additional information

E.1 Table 3 4: Summary of tools which underwent detailed analysis against LNCP applications

✓✓ Good coverage

✓ Covered

× Not covered

	Eco-metric 2.0	LUCI	InVEST 3.7.0	NEVO	SENCE	EcoServ-GIS 3.3
Spatial NC & ES baseline	✓	✓✓	✓✓	×	✓✓	✓✓
Risks/trends identification	×	×	✓	✓	✓	×
Opportunity mapping	✓✓	✓✓	×	✓	✓✓	✓✓
Trade-off analysis	✓	✓✓	✓	✓	✓	×
Monetary valuation	×	✓	✓✓	✓✓	✓	×
Access and resource requirements	Excel-based, simple to use. Requires access to GIS to gather input data. Expected to be free. Draft version in testing phase.	GIS-based, modelling skills required. Free for non-commercial use, on request of tool developer. Default input data available	GIS-based, advanced GIS skills required. Free to access, open source license. Can be explored with any GIS package e.g. ArcGIS, QGIS. Default input data available	Web-based interface. Users can create a login and run & save scenarios under 'My store' function. Free, cannot be customised and limitations to data that can be downloaded.	GIS-based. A WMS and an FME update tool allows ES maps to be updated by user. Proprietary tool – consultancy offering only.	GIS-based, ArcGIS 10.2 or later Free but limited support available.
Scalability	Excel-based, dependent on habitat/land use cover resolution.	Has been applied from national to sub-field level at high resolution e.g. 5x5m for GMEP, Wales	Can be run on spatial units of any resolution (Nelson et al, 2009) Resolution will be the same as the LULC input. Area of analysis supported: 0.1km2- 10,000,000km2 Temporal scale determined by inputs	Flexibility in the scale of enquiry available to users, including catchments, local authority areas, counties or countries (England and Wales) Smallest unit of analysis is 2km2 (400ha)	Has been applied at regional and national scales in published studies reviewed	Recommended for study areas between 1,500-5,000km2 (SNH, 2018) Recommends use of 10m raster.

	Eco-metric 2.0	LUCI	InVEST 3.7.0	NEVO	SENCE	EcoServ-GIS 3.3
Natural capital and ES coverage	Very comprehensive. 18 ecosystem services across provisioning, regulating and cultural service categories. Spatial factors must be applied through a series of multipliers.	Does not include models for cultural ecosystem services, or urban regulating services. Flow-based services are well captured.	Suite of standalone models. 9 terrestrial ES models.	Integrates suite of ES models developed by LEEP UK, Forestry Commission, JNCC, Aberdeen University and Forest Research	23+ ecosystem services, 7 commonly mapped (Medcalf, 2019) – natural flood management, sediment regulation, climate regulation, biodiversity, pollination, green infrastructure	Suite of standalone models. Does not assess water supply, pest regulation, biodiversity and geodiversity. Tool default is not to use soils data due to poor resolution of mapped boundaries
Treatment of ES values	Does not calculate absolute values of ES supply. Area of each habitat multiplied by the assigned score (0-10) for ability to deliver ES. Multipliers for condition and spatial location. ES cannot be monetised.	ES expressed in biophysical units. Some maps represented as index-based scores. Condition data not standard to running of the tool. Not within tool, but quantified units support monetisation.	ES expressed in biophysical units. Maps generally index-based scores. Condition data not standard to running of the tool. Some benefits can be monetised within the models e.g. carbon storage	ES expressed in quantity and monetary units. Map outputs for ES. Values generated are indicative and more sophisticated modelling may be required for specific types of decision-making	ES not generally monetised, but measurement units could support this (Medcalf, 2019)	Does not calculate absolute values of ES supply. Produces index-based scores (e.g. 0-1) of ecosystem services Ecosystem services are equally weighted.

	Eco-metric 2.0	LUCI	InVEST 3.7.0	NEVO	SENCE	EcoServ-GIS 3.3
Transparency, uncertainty and validation	ES cannot be validated against observed data but expert opinion and engagement with delivery partners has refined scores and multipliers Worksheets record data entry so can be reviewed, though GIS analysis done outside of worksheet.	Assessment of uncertainty not specifically included in tool but can be done through sensitivity analysis. Validation examples against other models and empirical data summarised in **Section 3.4.**	Technical guide published for each model. User guide provides guidance under each model on limitations. Validation examples against other models and empirical data summarised in **Section 3.4 Error! Reference source not found.**	Technical reports for each ES model provide data and method/calculations. Assumptions in-built into the component models need to be understood. Tool validation not known. User application can be easily reviewed as it is a web-based tool.	Tool validation not known.	Not suited to areas with uniform habitat or socio-economic conditions, as tool always grades 1-100 even when there is comparatively little variation in the study area. Levels of uncertainty are not estimated.
Future developments	Representation in GIS is being explored. Habitat scoring for cultural ecosystem services being reviewed – evidence base may support further differentiation	Urban services being developed. Collaborations with other researchers will develop and include ecological and groundwater modelling. Updates will not be available for LNCP.	Updated versions are released every 3 months. Data and modelling platform being developed called Urban InVEST ES will include: air purification, noise attenuation, mental health.	Not known. Guidance on the 'Select', 'Alter', 'Optimise' functions to complement the Technical Guides for each of the models would be useful.	Tool is adapted to suit project requirements, and rules bases and models are enhanced in line with improvements in scientific knowledge base. Has been applied to~30 projects around the world and in the UK.	Tool no longer being updated due to resource constraints. Natural Capital Solutions are working on a project for Defra to update elements of the tool.
Best for	Habitat-based natural capital asset register using a simple, replicable method.	Opportunity mapping and trade-off analysis, and biophysical values for ecosystem services, scalable to sub-field level.	Valuation and comparison of ecosystem trade-offs.	Analysis of trade-offs between traded goods (food, carbon, from changes to broad habitat types	Customised ES assessment incorporating comprehensive and bespoke natural capital baseline.	Opportunity mapping by experienced users who have the ability to customise/update elements of tool.

E.2 Further detail on tools against applications

E.2.1 Ecosystem services baselines

Table 5-8 summarises the approach, strength and limitations of tools to developing a natural capital and ecosystem service baseline, discussed in the main report. It draws on the available tool user guides, and Vorstius and Spray (2015), who compare and produce maps of the same ecosystem services, in the same area using InVEST, EcoServ-GIS and SENCE.

Table 5-8 Strengths and limitations of shortlisted tools to generating an ecosystem service baseline

Tool	Approach summary	Strengths	Limitations
Eco-metric	• Tool has been applied to Oxfordshire area by Smith (2019). Maximum scores, using Eco-metric multipliers, applied to habitat types to map ecosystem services. • Combined ES opportunity maps produced by mapping land parcels that contribute to regulating and cultural services in one colour, and provisioning (food) service in another.	• Recently developed by a working group of UK-based consultants and academics. • Comprehensive ES coverage emphasises that all natural and semi-natural land cover contributes to delivery of one or more (generally 5 or more) ecosystem services.	• Tool is in draft testing phase and some multipliers (e.g. for recreation, water supply) in relation to particular land uses are likely to be refined. Final report expected with Beta tool in 2020. • Not spatially explicit and does not generate unit values for ecosystem services.
EcoServ-GIS	• Uses readily available datasets to create a base map, assigning habitat types to each land parcel. • Each of the models is designed to support decision-making around the supply and (in some cases demand) for ES • Uses social indicator of 'need' for ES (Index of Multiple Deprivation – Health or Education) for Air quality regulation, noise regulation, education, accessible nature/recreation. • Does not take account of soil type in estimating ES provision.	• One of the few tools that is designed to assess both supply and demand and therefore provides an indication of the realised ecosystem services. • Can be run at fine (10x10m) resolution. • One of only a couple of tools that assesses 'urban' regulating services at larger scale than site-level (e.g. tools such as B$ST, GI-Val) • Recommends broad management practices – protect, maintain, improve, assess, provide access, change habitat type etc. Requires only intermediate level of GIS knowledge.	• Tool is no longer being updated and very limited user support is available from tool developer • A number of bugs complicate its use except for those involved in tool development (Rouquette, 2019) • Not suited to areas with uniform habitat or socio-economic conditions, as tool always grades 1-100 even when there is comparatively little variation in the study area (Winn *et al.*, 2018) • Level of reliability of the model varies (see Winn et al 2018). Water supply model in particular is less robust – and relies on some older formulas in which factors have since been updated e.g. the Universal Soil Loss Equation (USLE)

InVEST	• High flexibility in scale, data input and detail of assessments and mapping (Vorstius and Spray, 2015) • Consists of a series of 9 terrestrial ES models and several marine models (these were not reviewed due to geography of the LNCP area), (see Appendix **E3.1**) • Aimed at ES baseline development as requires a LULC map as a prerequisite to running the tool. • Does not take account of soil type in estimating ES provision.	• InVEST is in use in over 80 countries and has been kept up to date. • Tool outputs have been validated against other tools and empirical data in the UK – which can form the basis for further enquiry (see **Section 3.4**). There is work underway to expand the tool to cover urban regulating services (Natural Capital Project, 2019).	• The tool requires a high level of GIS and modelling capability which may not be available for LNCP development. • Several models have a small number of input parameters and are highly sensitive to decisions around these, which need to be specified by the user. • Assumptions behind the models need to be understood – for example carbon storage/sequestration model does not take account of natural succession and effect on carbon pools. If global default values are used (e.g. carbon in dead organic matter), these may not accurately reflect local conditions.
LUCI	• Habitat/land use map: compatible with Land Cover Map (Centre for Ecology and Hydrology) and CORINE (European Environment Agency) • Soils: compatible with Soilscapes and NATMAP (Cranfield University) • Can be applied at very fine (5x5m) resolution.	• Applied in the UK to inform targeting of land management payments in Wales (GMEP) • Tool outputs have been validated against other tools and empirical data (see **Section 3.4**). The tool is regularly applied to research projects including MSc and PhD students at Victoria University	• Regulating services important to urban areas are not included in the tool e.g. noise regulation, air quality regulation. Cultural services • Habitat classification level may not be sufficiently detailed for deriving ecosystem services depending on the intended uses.
SENCE	• Land cover map generated as part of consultancy service. Takes account of habitat type, geology/soil, position in the landscape and land management.	• As part of tool application, evaluates drivers and policies to understand the ES most valuable in each area. • Rule bases are developed for each relationship based on local knowledge and expert understanding. • A WebMap service (WMS) is provided to allow base maps to be updated.	• Consultancy service offering only. • Not a standardised/generalisable tool that can be repeated without clear instructions.

E.2.2 Risk/trend identification examples

Table 5-9 summarises the approach, strength and limitations of tools to developing a Risk Register, discussed in the main report.

Table 5-9: Examples of tools used to assess risks to natural capital and ecosystem services

Tool	Approach summary	Strengths	Limitations
Co$ting Nature	• Co$ting Nature is a web-based ES tool package and includes a Threats and Pressures Module • Calculates index of pressure as the combination of relative population, fire frequency, grazing intensity, agricultural intensity, dam density and infrastructure density. Index of pressure is given on a scale of 0-1 • Calculates relative threat index by combining threats of land use change, climate change and infrastructure change – all assumed to be related to accessibility to populations through the road network.	• Distinguishes between current pressures and future threats/drivers • Provides spatially-explicit assessment of actual ES according to population distribution, infrastructure and risk • Accessible Data supplied globally at 1km and 1ha spatial resolution – users can upload own data if better (WBCSD, 2013)	• As a global model several pressures are not relevant to the LNCP context (fire frequency, dam density, deforestation) • Represented spatially as an index of relative combined pressures and threats – i.e. these are not disaggregated. • Threats are given equally weighting by default.
InVEST	• One of the InVEST models – the Habitat Quality model – aims to take account of threats to terrestrial ecosystem services	• Relies on local/regional data that is likely to improve the accuracy of the assessment	• Requires a relatively large amount of information on distance between the habitat and threat, sensitivity to the threat, scale of the threat and level of existing protection. • Threats are assumed to be additive – risk of cumulative impacts is not captured. • Due to nature of information required does not appear to be able to take account of global or diffuse threats.
SENCE	• Matrix-based approach. Analysis has been adapted to suit different ecosystem services assessments. • One study (Parker et al, 2016) selects priority ES indicators by developing a matrix linking areas of economic activity to ecosystem benefits or to the status/trends in ES using social,	• Review of policies and socio-economic trends can identify gaps in protection of particular assets, or assets that are under pressure from multiple sources.	• Analysis is not spatially explicit – locations under greater pressure are not identified. • Examples reviewed do not assign an indication of the direction and magnitude of impact between drivers/pressures and characteristics of assets or services.

Tool	Approach summary	Strengths	Limitations
	economic and environmental data. • Another approach (Natural Resources Wales, 2016) developed a natural resource and wellbeing register, linking the diversity, extent, condition and connectivity of broad habitat types in Wales to 6 of the goals of the Well-being of Future Generations (Wales) Act 2015 - see **Appendix E.2.1** for example matrix.		

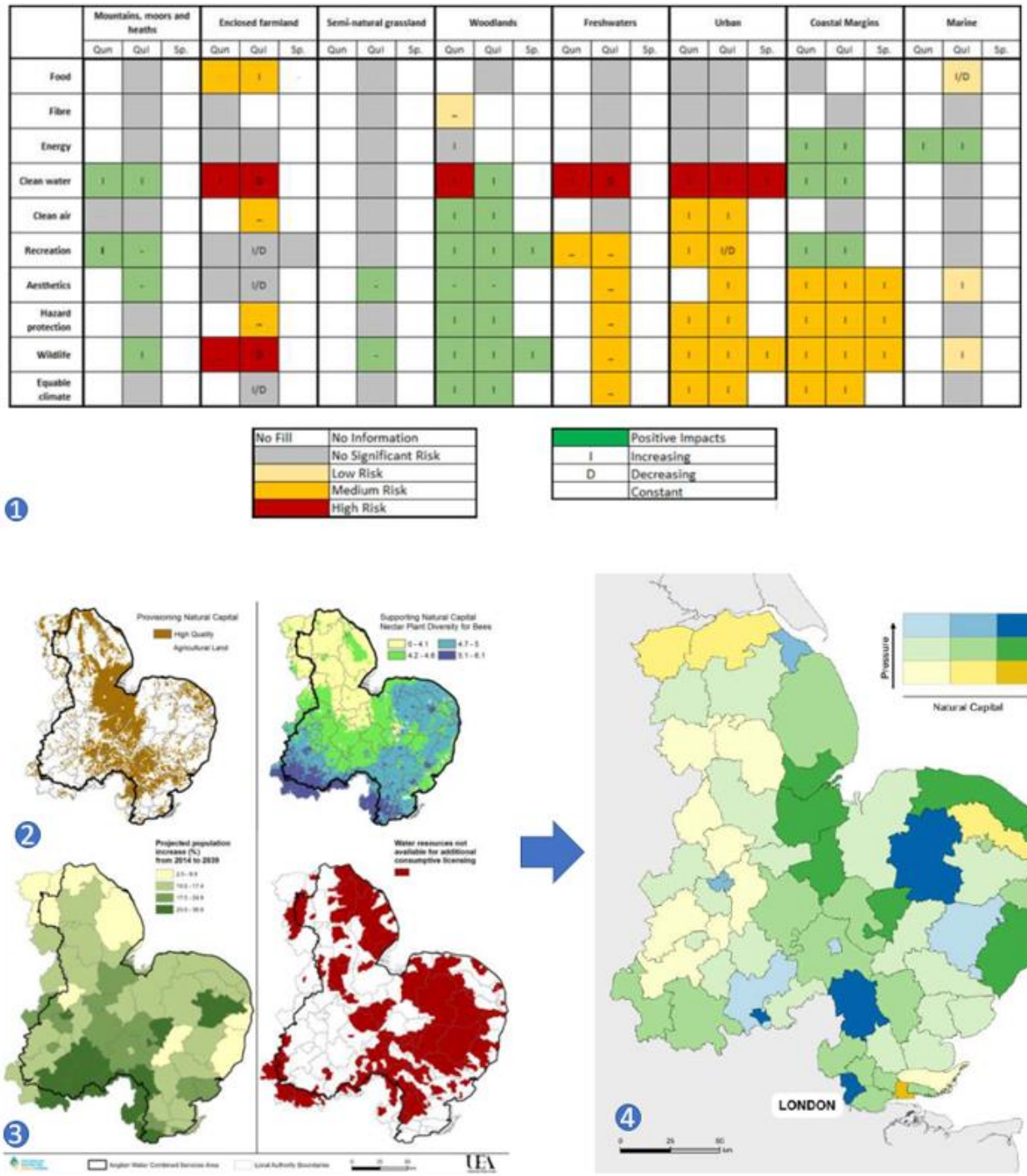


Figure 5-3: Risk Matrix (1) and Spatial Variation in Asset Indicators (2) and Pressures (3) in Anglian Water Services Area (CSERGE, 2018)

E.2.3 Opportunity mapping examples

Table 5-10 summarises the approach, strength and limitations of tools to opportunity mapping, discussed in the main report.

Table 5-10: Strengths and limitations of shortlisted tools to support opportunity mapping

Tool	Approach summary	Strengths	Limitations
Eco-metric	• Tool has been applied to Oxfordshire area by Smith (2019). Maximum scores, using Eco-metric multipliers, applied to habitat types to map ecosystem services. • Composite ES opportunity maps produced by mapping land parcels that contribute to regulating and cultural services in one colour, and provisioning (food) service in another.	• Recently developed by a working group of UK-based consultants and academics. • Comprehensive ES coverage emphasises that all natural and semi-natural land cover contributes to delivery of one or more (generally 5 or more) ecosystem services. • Approach requires GIS ability but not advanced modelling skills. • Guidance identifies potential for preliminary application of the tool where detailed information for multipliers is not available.	• Tool is in draft testing phase and some multipliers (e.g. for recreation, water supply) in relation to particular land uses are likely to be refined. Final report expected with Beta tool in 2020. • Current guidance does not cover opportunity mapping using the tool, though this could be developed.
EcoServ-GIS	• EcoServ-GIS is a toolkit to map ecosystem services at a county and region scale. The toolkit generates maps illustrating the need for each service as well as the capacity for service provision. • Includes the facility to overlay these maps to show how well demand and capacity coincide in space, highlighting those natural areas providing high levels of service delivery that should be conserved, as well as those that are most in need of measures aimed at improving single or multiple service delivery. • Uses social indicator of 'need' for ES (Index of Multiple Deprivation – Health or Education) for Air quality regulation, noise regulation, education, accessible nature/recreation.	• One of the few tools that is designed to assess both supply and demand and therefore provides an indication of the realised ecosystem services. • Can be run at fine (10x10m) resolution. • One of only a couple of tools that assesses 'urban' regulating services at larger scale than site-level (e.g. tools such as B£ST, GI-Val) • Recommends broad management practices – protect, maintain, improve, assess, provide access, change habitat type etc.	• Tool is no longer being updated and very limited user support is available from tool developer • A number of bugs complicate its use except for those involved in tool development (Rouquette, 2019) • Not suited to areas with uniform habitat or socio-economic conditions, as tool always grades 1-100 even when there is comparatively little variation in the study area (Winn *et al.*, 2018) • Level of reliability of the model. Water supply model in particular is less robust – and relies on some older formulas in which factors have since been updated e.g. USLE.

Tool	Approach summary	Strengths	Limitations
LUCI	Opportunity mapping is integrated into the trade-off analysis module and is reviewed in Table 5-11.		
NEVO	• Web accessible in-built GIS-based 'Optimise' mode to address 'what's best?' questions • User has the flexibility to specify the variable(s) to be altered: agricultural prices or area of land cover, models to run, discount rate to be applied, and maps to be produced.	• No data input or technical knowledge required from user. • Only tool reviewed in detail incorporating agent-based modelling. Includes in-built functionality to evaluate effect of agricultural price change (which can be specified by user) on land use decisions.	• Focus on opportunities for production of final end goods, and recreation, omits in particular regulating services. • Uses relatively broad land use categories (woodland, agriculture, semi-natural, urban, water) and returns opportunities at 2km grid level, not suited to finer scale analysis of opportunities. • Cannot increase or reduce area of land under water as part of the Alter function.
SENCE	• Multi-benefit maps created by combining various stock layers to highlight areas providing multiple benefits.	• Incorporates data on soils which is likely to improve the estimation of certain ES e.g. carbon.	• Consultancy service offering only. • Not a standardised/generalisable approach that can be repeated

The example outputs below (Figure 5-5, Figure 5-6) show that opportunity mapping using tools such as EcoServ-GIS, SENCE and LUCI can be carried out for large geographic areas (e.g. national scale applications) as well as fine-scale analysis that is suited to urban areas.

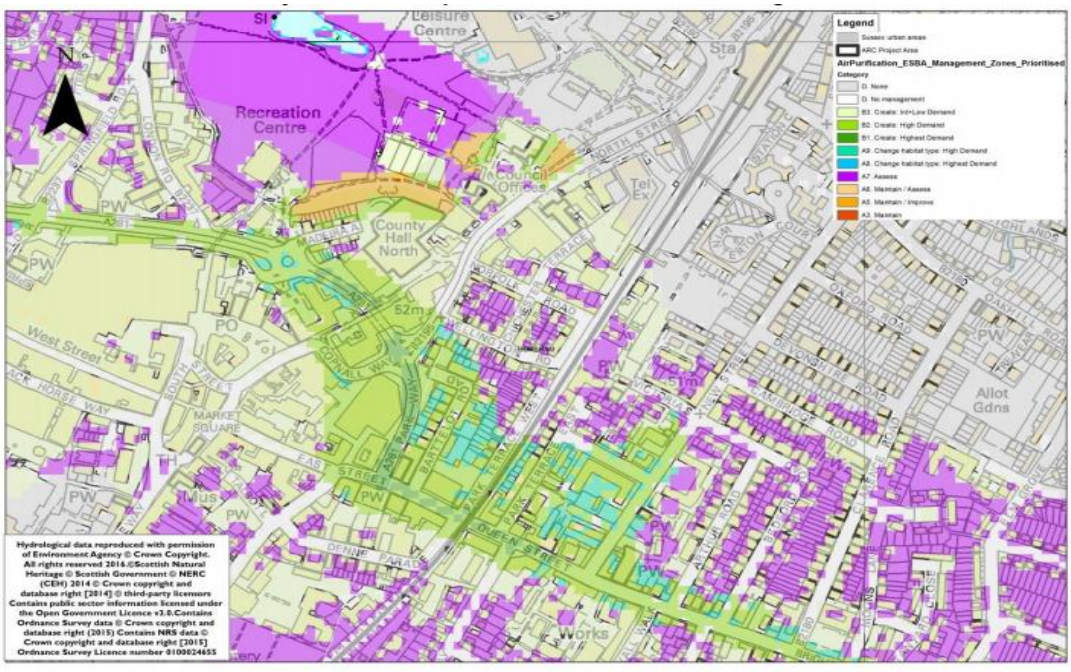


Figure 5-4: Air purification service map, Horsham using EcoServ-GIS (Southgate, 2016)

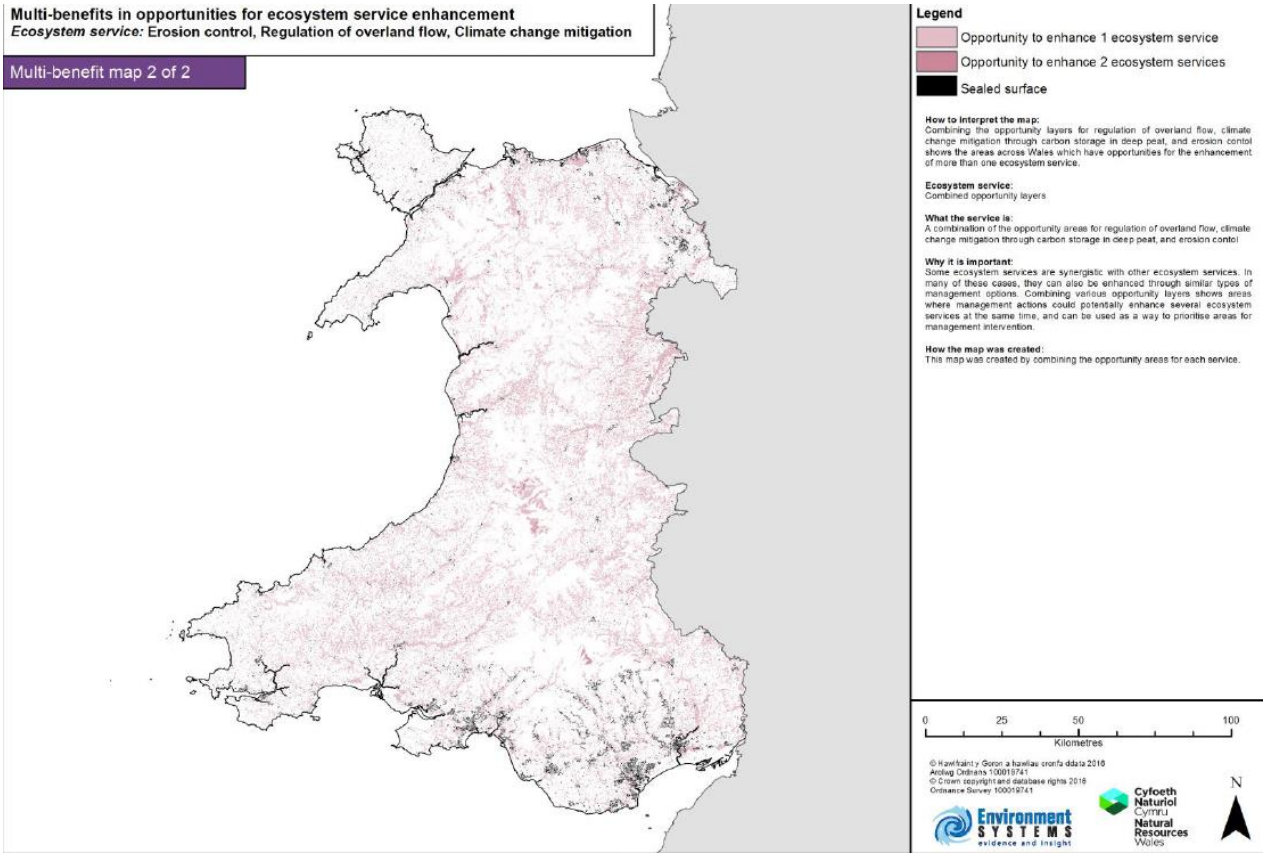


Figure 5-5: Application of SENCE tool to mapping provision and opportunities to enhance 3 regulating services in Wales (Natural Resources Wales, 2016)

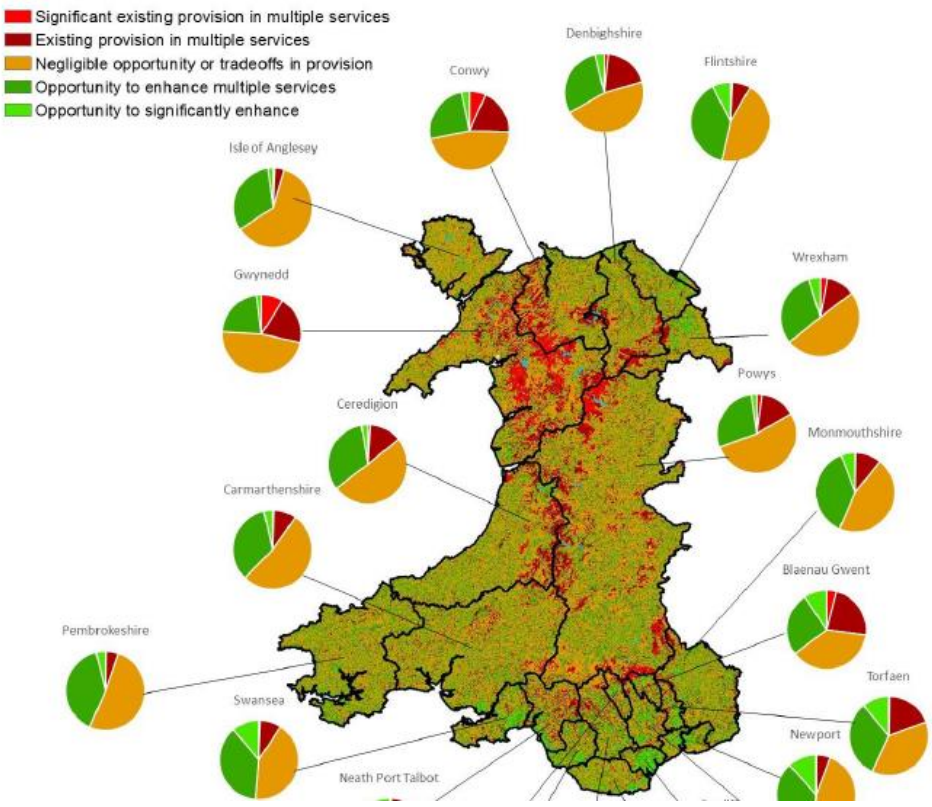


Figure 5-6: Opportunity mapping using LUCI tool of 7 ecosystem services by county, Glastir Environmental Monitoring and Enhancement Programme, Wales (CEH, 2017)

E.2.4 Trade-off/scenario analysis

Table 5-11 summarises the approach, strength and limitations of tools to conducting scenario planning and trade-off analysis, discussed in the main report.

Table 5-11 Strengths and limitations of shortlisted tools to assessing trade-offs

Tool	**Description**	Strengths	Limitations
LUCI	• GIS-based trade-off module. • Uses ES model outputs and algorithms to identify where management interventions could enhance or degrade multiple services.	• Flexibility in how tool evaluates trade-offs and assigns weightings between services (The LUCI team, 2019; Nayak and Smith, 2019). See **Appendix E.3.2** for details • Very fine resolution supports analysis down to sub-field level.	• Does not currently map cultural services (including recreation) or regulating services important to urban areas e.g. air quality regulation, noise regulation. • Does not take account of demand for ES. • Higher complexity modelling tool, requires models to be run before opportunities can be mapped.
NEVO	• Web accessible in-built GIS-based 'Alter' mode. • Enables analysis of how ES flows would change in an area if land use or agricultural prices were altered • Trade-offs traded services (timber, agricultural output, carbon) and recreation.	• No data input or technical knowledge required from user. • Flexibility in query parameters to analyse effect on land use allocation: - type of landcover - landcover to be replaced, - area of change - ES to be optimised - whether to prioritise values (£) or quantities - outputs that are mapped • Quick running time supports real-time scenario evaluation.	• Trade-offs are represented on a 2km grid (400ha), so fine scale analysis to land parcel level is not supported. • As a web-based tool, local data cannot be integrated directly into the tool, so validation against local data is important. • The assumptions underpinning the constituent models need to be understood, in order to understand the accuracy/representativeness of tool outputs

The LUCI trade-off module summarises qualitatively outputs from other ecosystem service models, showing in very fine detail areas where there is high existing ecosystem service provision (i.e. limited scope for improvement), areas where groups of services can be enhanced (with minimal effects on other services) areas where there would be trade-offs between services, and areas where there are significant opportunity to enhance ecosystem services (i.e. starting from a low base). Adjustments can be made to weightings and subsets or a full set of services can be compared.

The NEVO tool (Figure 5-7) expresses a land use change scenario as a change to land cover units (ha) and can also express this as changes in monetary terms to farm profits, timber revenues, GHG sequestration from forest and farmland, and recreational value.

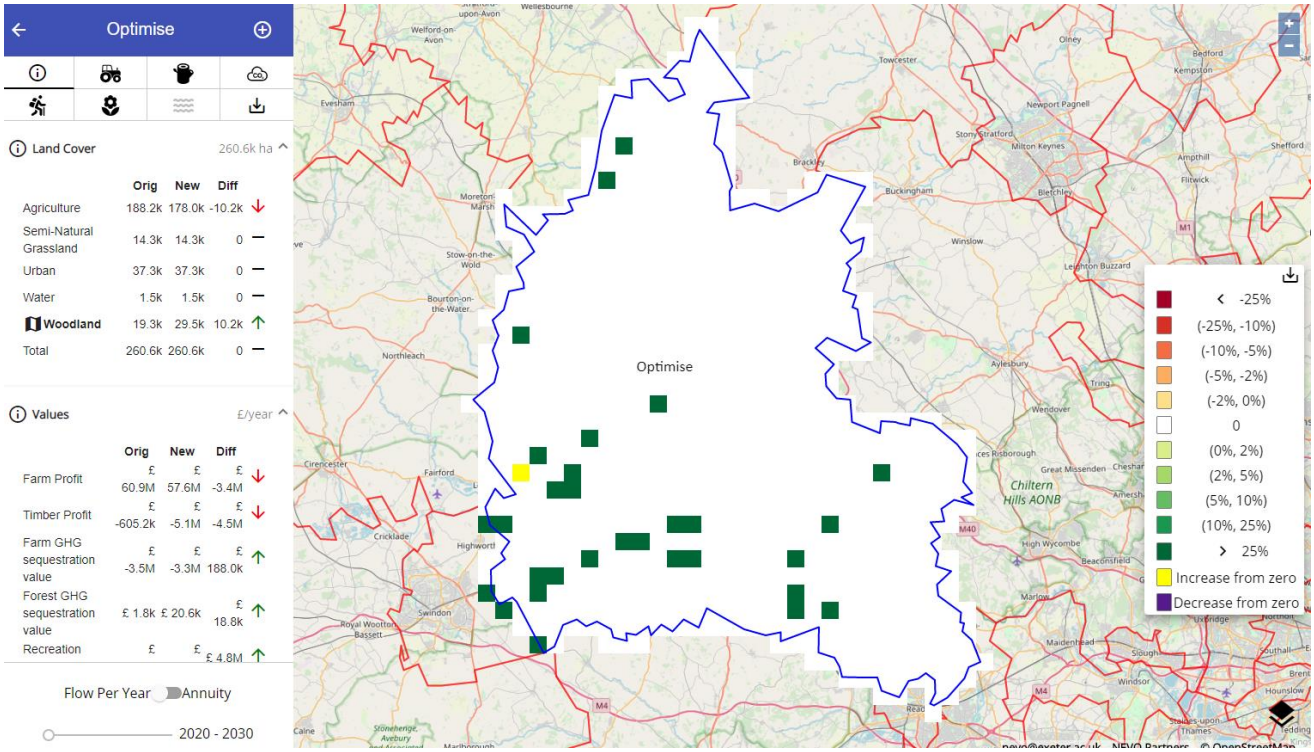


Figure 5-7: Opportunity mapping and trade-off analysis using NEVO tool for Oxfordshire, showing locations where GHG sequestration can be best enhanced if 5% of agricultural land was converted to woodland, and monetary valuation of the changes – left of screenshot (scenario run by author using NEVO, LEEP 2019)

E.3 Example tool review sheets

The following tool review sheets provide a comparison of how two different tools (InVEST and LUCI) assess ecosystem services – the indicators, input data, outputs of each tool. These considerations need to be taken into account in tool selection. This section draws strongly on the tool user guides, and the review by Nayak and Smith, 2019. The same type of analysis can generally be done for other tools.

E.3.1 InVEST

Note that as the LNCP area is landlocked, models focused on quantifying ecosystem services for coastal and marine ecosystems are not reviewed. This includes the Scenic Quality Model, Coastal Blue Carbon Model, Wave Energy Production Model, Offshore Wind Production Model, Marine Aquacultural Production Model and Coastal Vulnerability Model). The Annual Water Yield model is also not reviewed as it focuses on estimating the annual average quantity and value of hydropower produced by reservoirs. The $ symbol denotes where the model produces a monetary valuation of the service.

InVEST Models	Input data	Output	Summary/notes
Habitat Quality The model estimates the extent and threat (degradation) of vegetation and habitats and uses such information on habitat quality and rarity as proxies for biodiversity in a landscape. No economic value is placed on biodiversity.	Land-use/ land-cover map; Threat data (e.g. roads, agriculture, pollution); Source of threats; Habitat type and sensitivity to threat; Half-saturation constant. Optional: Land-cover map for future scenarios; Baseline / historical land-cover map; Relative protection against threats (0-1)	Habitat quality landscape score for baseline, current and future land use/land cover change scenarios.	Proxy for biodiversity, runs using raster data. Non-monetised, it is treated as attribute of natural systems rather than ecosystem service. Similar to Habitat Risk Assessment model, it is suited to assessing how human activities impact biodiversity
Habitat Risk Assessment The model estimates exposure to stressors and assesses the direct impact to habitat. Consequences of exposure are estimated on the habitat or species and	Multiple and dependent on user requirement.	Vector maps of area at no, low, medium, high risk, and stressor extent. Online visualisation tool is available for user to upload outputs to view results.	Based on exposure-consequence framework, model is suited to screening risks from human activities and prioritising management strategies to mitigate risks. Capacity to rank data quality and importance. Can be used in marine systems.

InVEST Models	Input data	Output	Summary/notes
give a score based on exposure and consequence. Allows users to visualise areas where impacts of climate change and human pressures may create trade-offs among multiple ecosystem services.			Model calculates risk at grid scale and summarises at sub-regional scale The impact of multiple stressor is considered additive (Nayak and Smith, 2019).
Pollination The model estimates insect pollinator nest sites, floral resource and flight ranges to provide an index of pollinator abundance. Can also create an index of the value of the pollinators to agricultural production.	Land-use/ land-cover map; Table of pollinator species; Table of landcover attributes (scaled 0 -1) e.g. nest information and flowering season Optional: Half-saturation constant; Land-cover map for future scenarios.	Pollinator supply, where pollinators originate from, based on available nesting sites and floral resources (0-1) Pollinator abundance, where pollinators are active on the landscape, attracted by floral resources (0-1)	Index-based model only estimating relative patterns of abundance and contribution of pollination to crop yields. Factors that influence bee populations, like habitat disturbances and typical population fluctuations, are not captured. All species are assumed to contribute equally based on their relative abundance and the half-saturation constant specified for each farm/crop. The model does not account for the sizes of habitat patches in estimating abundance.
Fish Production ($) The model is uses population dynamics modelling and estimates the harvest volume and economic value of single-species fisheries within a defined area.	Species information to fulfil model parameters.	Harvest for area of interest (number of individuals or weight) Total value of harvest to subregion (unit value)	Best suited for comparing fisheries production under different scenarios. A scenario could be a change in the amount of juvenile habitat, a change in the harvest rate in a particular subregion, or a change in survival due to other causes such as climate change. It is not intended to be a stock assessment tool.

InVEST Models	Input data	Output	Summary/notes
The value of earnings from fisheries can be estimated for population based on user-defined prices.			
Crop Production ($) The Crop Production Percentile and Crop Production Regression models estimate crop yield and nutrient value for a fixed set of crops, derived from user-supplied landcover information. Crop yield is primarily driven by climate and fertilizer rates. Estimates of yields from 175 crops (percentile based model) and nutrient information for 12 crops (regression model	Raster of land use/land cover (LULC); A .csv table that maps a Land-Use/Land-Cover integer code to a crop name. Optional: A .csv table that contains crop names, and application rates for nitrogen, phosphorus, and potassium in kilograms/hectare.	Production rate of crop per pixel (metric tonnes/pixel/year)	It is a global coarse model driven by climate, and (optionally) by management. Not able to capture variation in productivity across heterogeneous landscapes. E.g. A rocky hill slope and a fertile river valley, if they share the same climate, would be assigned the same yield in the current model. Not suited to decision-making on future habitat conversion, or where farming is most productive and least destructive.
Carbon Storage/Sequestration ($) The model estimates the current amount of carbon stored in a landscape and values the amount sequestered over time. Option to estimate economic value to society - market value or social cost of carbon, its annual rate of	Land-use/ land-cover map; Carbon stock values (carbon stored in above and belowground biomass, dead organic matter and soil). Optional: Harvest rates; Land-cover map for future scenarios; economic data.	Raster maps showing storage, sequestration (Mg of carbon/pixel) and value (unit per pixel). Net change in carbon storage and social value of sequestration	Evaluates carbon stored in four pools (aboveground biomass, belowground biomass, soil and dead organic matter). Valuation can only be done in the model with a future scenario. Assumptions are constant over time e.g. fixed storage level despite changes from natural succession within habitat.

InVEST Models	Input data	Output	Summary/notes
change, and a discount rate. Can perform uncertainty analysis.			May need to use global default values for certain parameters if data is not available e.g. regional estimates of carbon in dead organic matter.
Nutrient Delivery ($) The model maps nutrient sources from watersheds to their transport to the stream, to assess nutrient retention service. Uses data on water treatment costs to calculate the economic value contributed by each part of the watershed to water purification. Potential to model current and future land use scenarios to help inform conservation efforts / clean water supply.	Digital Elevation Model, LULC raster, nutrient runoff proxy, watersheds shapefile, biophysical table (nutrient loads for each LU class, maximum retention efficiency, distance decay and proportion of dissolved nutrients), threshold flow accumulation, Borselli k parameter, subsurface critical length (N or P), subsurface maximum retention efficiency (N or P)	Nutrient export map showing how much load from each pixel reaches the stream (kg/pixel) Total nutrient loads in the watershed (kg/year) Total nutrient export from the watershed (kg/year)	Small number of inputs and outputs have high sensitivity to these – errors in parameter values will have a large effect on predictions. Retention efficiency values are based on empirical studies. Factors affecting these values e.g. slope are averaged. No in-stream processes are captured (attenuation) Sensitivity analysis is recommended. Validation data requirements are relatively high (10 year time series to attenuate inter-annual variability, minimal seasonal data gaps etc)
Recreation/Visitation The model estimates the 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. If there is no empirical data, the model is parametrised using a	Area of interest map Optional: Additional predictor variables (e.g., population data, protected area data, protected habitats, land-use / land-cover map)	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	May be some recording bias in favour of younger generations so areas with higher proportion of young people may appear to have higher visitation rates.

InVEST Models	Input data	Output	Summary/notes
crowdsourced measure of visitation: geotagged photographs posted to the website Flickr.			
Urban Cooling The model estimates a cooling capacity index (0-1) of areas based on shade, evapotranspiration, and albedo, as well as distance from cooling islands (e.g. parks). Valuation of heat reduction service possible.	Land Cover map raster, biophysical table (land use, shade represented as proportion of tree cover, albedo, crop coefficient), evapotranspiration raster (in mm), shapefile of area, rural reference temperature, difference between urban and rural temperature. Optional: buildings shapefile (with integers for building type – residential, office etc.); energy consumption for buildings (kW/degC)	Cooling capacity rasters with average cooling capacity value, average temperature (C), avoided energy consumption ($), loss of light work ($), loss of heavy work ($)	Information is available about the Urban Cooling Model but it has not yet been released and available to apply. 2 methods provided by tool to value heat reduction: -energy savings from reduced electricity consumption, where A/C is prevalent -gain in outdoor worker productivity Could also value the decrease in heat-related morbidity and mortality – but not provided in model as effects vary dramatically across cities.
Urban Flood Risk Mitigation ($) The model calculates the runoff reduction, i.e. the amount of runoff retained per pixel compared to the storm volume. It also calculates, for each watershed, the potential economic damage, by overlaying information on flood extent potential and built infrastructure.	LULC raster map; biophysical .csv table with LULC code and values for each hydrologic soil group Optional: raster of flood-prone areas; population raster; built infrastructure raster; potential damage loss table ($/m2)	Amount of runoff reduction retained (m3) Potential economic damage per watershed (flood extent potential and built infrastructure) Map of runoff retention service	Flood risk mitigation valued as the avoided damage for built infrastructure (alternative approaches – morbidity, mortality, economic disruption) could be implemented.

InVEST Models	Input data	Output	Summary/notes
Seasonal Water Yield ($) The model computes spatial indices to quantify the relative contribution of a parcel of land to the generation of baseflow (flows during dry weather) and quick flow (during or shortly after rain events).	Monthly precipitation rasters, Evapotranspiration rasters, DEM raster, LULC, Soil group rasters, AOI/Watershed shapefile, Biophysical csv table, Rain events csv, threshold flow accumulation. Advanced model options: Climate zone table (csv file), Climate zone raster, recharge raster (local values)	Map of baseflow (mm), quick flow (mm), local recharge (mm), available water (mm)	The baseflow modelling is an extremely simplified, physics-based model for which there are no quantitative estimates only relative values. Quick flow is based on curve number, does not take topography into account.
Sediment Retention ($) The model estimates the capacity of a land parcel to retain sediment using information on climate, geomorphology, vegetation and management practice. The model can value the landscape in terms of water quality maintenance and determine the economic cost of sediment removal (e.g. from reservoirs).	Digital Elevation Model; Rainfall Erosivity Index; Soil erodibility; Land-use/ land-cover map; Watersheds; Biophysical table; Threshold flow accumulation; Hydrology and soil texture calibration parameters (defaults available). Optional: Drainage layer (e.g. roads, stormwater pipes).	Total amount of sediment exported from each pixel that reaches the stream, and by watershed Sediment retention index (relative values) Total amount of potential soil loss per watershed Difference in amount of sediment delivered by current watershed	The model works at the spatial resolution of the input DEM raster. Relies on USLE – only accounts for rill/inter-rill erosion, not gully erosion, streambank erosion and mass erosion (landslides). The equation can be adapted to reflect data from local studies Outputs are highly sensitive to most input parameters. Sensitivity analyses recommended to investigate confidence in input parameters.

E.3.2 LUCI

LUCI Models	Input data / parameters	Output	Summary/notes
Habitat connectivity *Assesses areas suitable for habitat expansion and protection, based on cost-distance approach to* species' movement for species of interest.	LULC data Species – currently broadleaved woodland focal species (default is 11) Minimum habitat area for species of interest (ha – default 2ha) Maximum cost distance through hostile terrain (km – default 2.5km)	RAG maps Areas are classified as existing habitat, other priority habitat to conserve, habitat of interest but exceeds maximum distance, areas currently accessible and with potential to extend existing habitat.	Automates the BEETLE cost-distance approach to evaluating habitat connectivity. Can be applied to generic focal and actual species. Parameterisation and accuracy of landcover data are important.
Flood mitigation *Models areas where overland and near surface flow may accumulate and the presence of mitigating features (sinks).*	Stream network data Hydrologically consistent DEM (consistent with stream network and local depressions removed) LULC data	RAG maps Shows mitigation of current soil/land use: either providing flow mitigation; receiving mitigation; or low permeability/storage areas Flood interception areas: classified as high contributing areas with no mitigation; areas with negligible flow concentration; areas acting as flow sinks providing flood mitigation	Applicability of the model to urban areas Not accounting for storage capacity of deep soils in non-wetland areas and the influence of paved surfaces in urban areas can reduce mapping accuracy.
Erosion/sediment delivery risk *Areas at risk of erosion and contributing significant sediment to water bodies*	Compound Topographic Index (CTI) threshold for moderate erosion risk (default value, 50) CTI threshold for high erosion risk (default value, 1000) LULC data	Maps, qualitative categories: Areas at risk from erosion: discrete classifications (either opportunity for change, where values exceed min CTI threshold or high opportunity for change, where values exceed max CTI threshold)	These 2 models assess the same ecosystem service slightly differently. The approach is currently being updated to use the RUSLE approach with elements of CTI to handle gully erosion. The RUSLE approach is that it more directly accounts for impacts of both land use and land

LUCI Models	Input data / parameters	Output	Summary/notes
		Sediment delivery mitigation priority (areas that would benefit from/suitable for mitigation efforts)	management change and enables outputs to be quantified more easily (pers.comms, Jackson, 2019)
Soil loss/sediment delivery *Estimates annual soil loss using the Revised Universal Soil Loss Equation (RUSLE) approach and sediment delivery,*	Lower threshold for medium erosion risk (default is 250 tonnes/km2/yr) Lower threshold for high erosion risk (default is 500 tonnes/km2/yr) Lower threshold for extreme erosion risk (default is 1000 tonnes/km2) Rainfall erosivity factor (R) Slope and length factor (default value is 26.6) LULC data	Maps, biophysical units or qualitative categories Soil loss (T/km2/yr) Erosion risk: bounded classifications, based on user-defined thresholds (low, medium, high) Sediment delivery vulnerability based on location on non-mitigated land. Bounded classification (mitigating features; negligible delivery to stream; moderate delivery to stream; water body)	
Nutrients *Accumulation of flow and cumulative N and P export calculated to provide estimated annual TN concentration*	LULC data Proportion of dissolved to assumed particulate (default 0.8 for N, default 0.3 for P) N/P critical accumulation threshold, below which considered to be of no concern (default 5mg/L for N, default 0.025 mg/L) N/P critical load threshold, below/above which load is of no/significant concern (default for N: 0.1kg/yr and 1.0 kg/yr; default for P: 0.01 kg/yr and 0.1 kg/yr)	Maps, biophysical units or qualitative categories N or P load: load generated by any point in the landscape (kg/ha/yr) N or P load accumulated accounting for uphill sources (kg/ha/yr) In-stream N or P concentration (mg/L) [The accumulated load and in-stream load indicators can also be classified as very low to very high. Additional indicators are available for loads to	Nitrogen and Phosphorus are separate models but use the same method so are assessed together. These could be used as an indicator for risk to water quality. The cumulative N/P export is computed for every point in the landscape, based land cover and/or land management classification for each grid cell.

LUCI Models	Input data / parameters	Output	Summary/notes
	In-stream attenuation factor: proportion of N/P in-stream that remains in water and not attenuated (default value 0.5)	surface water features (lakes, streams, watersheds)]	
Carbon stocks and fluxes	LULC data	Maps, biophysical units or qualitative categories for – Estimated carbon stock in biomass and soil (1m and top 30cm) (tonnes/ha) Rate of emissions or sequestration (tonnes/ha/year) Provision of storage and sequestration: Discrete categories (good performance – high carbon, no loss; moderate – low carbon, no sequestration; bad – loss of carbon, potential to gain or low carbon)	Peats are not well accounted for spatially in soil or land use data. Actual carbon storage strongly affected by site variation from national average conditions.
Agricultural productivity *Potential productivity and optimal utilisation according to slope, fertility, aspect and drainage.*	LULC data Slope threshold for very productive and somewhat productive land (degrees – default values are 5 and 15) Elevation threshold for improved and all agriculture (default values are 350m and 3000m) Fertility relative to national standard (standard, low, very low) Aspect (optional)	Maps, qualitative categories for – Current utilisation: 5 discrete categories (very high to no production capacity) Predicted optimal utilisation: accounting for all characteristics except land cover Relative utilisation (optimal minus current): over-utilisation, under-utilisation or appropriately utilised	Model outputs dependent on user thresholds and weightings. Confidence relates strongly to the soil and land use dataset accuracy. Can be weighted to account for land management measures on soil fertility.

LUCI Models	Input data / parameters	Output	Summary/notes
		Status: same as above but in 2 discrete categories: (preservation or change in utilisation).	
Trade-offs *Selected or all ES models can be run to identify opportunities to improve delivery of ES while protecting areas that deliver high levels of service.*	LULC data Weightings for the services can be specified (default is 1) Reporting option – selected by user, see notes Selected services for trade-off analysis Lowest or highest level of calculation (minimum 2)	Maps; qualitative categories Proportion of study area that have the following characteristics: - Excellent service provision - Moderate service provision - Negligible service or trade-offs - Opportunity to improve service - Excellent opportunity to improve service	4 reporting options available: overall trade-off/synergy map; information on each pixel on total # of 'wins', 'losses' and 'negligible impacts'; information on individual service 'wins' and 'losses'; combined - information on both total # and individual service 'wins' and 'losses'

E.4 LIMITATIONS AND UNCERTAINTIES

There are uncertainties with the replicability of results using different modelling methods and data for spatially-explicit modelling tools to generate biophysical ES values. Researchers have pointed to the need for comparative studies to test how sensitive models are to decisions about input data and the spatio-temporal resolution (Bagstad et al, 2018; Sharps et al, 2017). For certain ecosystem services, testing of model outputs can be done against observed data. Only a few studies that have performed this analysis in the UK were identified

- Vorstius and Spray (2015), comparing InVEST, EcoServ-GIS and SENCE outputs for mapping Carbon Storage, Water Purification and Pollination.

- Sharps et al. (2017), comparing InVEST, LUCI and ARIES for mapping Water supply, Carbon and Nutrient retention

A brief summary is presented below.

Table 5-12: Findings from comparison of tools applied to the same services and study area

Observed results
Vorstius and Spray (2015) • **Water purification** – marked differences between SENCE and EcoServ-GIS, agreeing only on level of service provision from woodland. Most significant divergence was for steep slopes mapped in the catchment. This was mapped as dry dwarf shrub heath habitat with high water purification capacity by SENCE but grassland with low water purification capacity by EcoServ-GIS. Differences likely to be due to differences in the approaches to determining service delivery. EcoServ-GIS puts more emphasis on slope in mapping the service, and combines mapping of nutrient and sediment regulation, where these are mapped separately in SENCE, and places greater emphasis on habitat type and soil type to service delivery. • **Pollination** – Some correspondence between SENCE and InVEST maps. Key difference between tools is in the selection and integration of factors considered important to the presence of pollinators. SENCE displays presence of suitable habitat and pollen bearing species with the assumption these have a high likelihood of supporting pollinators, whereas InVEST uses the habitat type approach as a basis for floral resources and therefore presence of pollinators but not species information although it does additionally take account of potential nesting habitat such as woodland edge.
Sharps *et al.* (2017) • **Water yield** - models performed well against measured data. • **Nutrient retention** - outputs were not directly comparable for LUCI and InVEST and were both considerable underestimates as compared to the annual average load calculated from measured nutrient concentration and flow data. • **Total carbon stock** - estimates were broadly comparable between InVEST and LUCI (estimating carbon in biomass and soil at 30cm and 1m depth) but were overestimates when total carbon in the catchment was considered. This is considered to be due to the use of generalised inputs (data extracted from a variety of literature) and national scale soil data being used that did not correspond to the observed land use or soil type for all points.

E.5 Further information on tools

The longlist of tools has been compiled from a review of available documentation on each tool, and existing tool reviews – in particular: Bagstad *et al.,* 2013; IUCN, 2017; Howard *et al.*, 2016. The ecosystem services assessed by the key tools is summarised in **Appendix E.2**.

Tool	Type	Scalability	Spatial baseline	Access	Link to tool
ARIES	Biophysical	Watershed or landscape	Yes	Free	http://aries.integratedmodelling.org/?page_id=632
B£ST (5.1.1)	Valuation	Site	No	Free	http://www.susdrain.org/resources/best.html
CAVAT	Valuation	Site	No	Free	https://www.ltoa.org.uk/documents-1/capital-asset-value-for-amenity-trees-cavat
Co$ting Nature (3.0)	Biophysical and valuation	Landscape	Partial	Free/ at cost (use-dependent)	http://www.policysupport.org/costingnature
Defra Biodiversity Metric (2.0)	Biophysical	Site	Yes	Free	http://nepubprod.appspot.com/publication/5850908674228224
Eco-metric (2.0)	Biophysical	Site	No	Free	https://ecosystemsknowledge.net/ecometric
EcoServ-GIS	Biophysical	Regional/landscape	Yes	Free	https://drive.google.com/drive/folders/0B_v9QO2jyC4eNlVUbzY1UUstZU0
EVL	Valuation Look-up tool	All	No	Free	http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19514
EVRI	Valuation	All	No	Free	https://www.evri.ca/en/content/about-evri
GI-Val	Valuation	Site applications	No	Free	https://www.merseyforest.org.uk/services/gi-val/
HEAT	Valuation	Site	No	Free	http://www.euro.who.int/en/health-topics/environment-and-health/Transport-and-health/activities/guidance-and-tools/health-economic-assessment-tool-heat-for-cycling-and-walking
The Helliwell System	Valuation	Site	No	Free	https://www.trees.org.uk/Book-Shop/Products/Guidance-Note-4
HydroloGIS	Biophysical	Site to basin level	Yes	Proprietary	https://viridianlogic.com/#ourwork
InVEST	Biophysical	Watershed or landscape	Yes	Free	https://naturalcapitalproject.stanford.edu/software/invest
i-Tree Eco	Biophysical Valuation	Site or local authority	No	Free	https://www.itreetools.org/tools/i-tree-eco
LEED	Guidance Toolkit	Strategic planning	No	Free	https://ecosystemsknowledge.net/apply/local-economy/LEED
LUCI	Biophysical	Sub-field to landscape	Yes	On request	https://www.lucitools.org/
MIMES	Biophysical	Local to global	Yes	Free in principle	http://www.afordablefutures.com/orientation-to-what-we-do

Tool	Type	Scalability	Spatial baseline	Access	Link to tool
NEATree	Guidance Toolkit	Any assessment	No	Free	http://neat.ecosystemsknowledge.net/
NCPT	Biophysical	Site-level	No	Free	http://ncptool.com/about-the-ncpt/
NEVO	Biophysical and valuation	2km grid, catchments, administrative scales	No	Free	https://www.exeter.ac.uk/leep/research/nevo/
ORVal	Valuation	Local authority area or catchment	No	Free	https://www.leep.exeter.ac.uk/orval/
PGIS	Participatory	Local, Regional	Part	Free	http://web1.adas.co.uk/pgis_algol/
SENCE	Biophysical	Landscape	Yes	Proprietary	https://www.envsys.co.uk/sence/
SolVES 3.0	Participatory	Watershed or landscape	Part	Free	https://www.usgs.gov/centers/gecsc/science/social-values-ecosystem-services-solves?qt-science_center_objects=0#qt-science_center_objects
SustainFARM Public Goods Tool	Biophysical and participatory	Site	No	Free	http://www.organicresearchcentre.com/manage/authincludes/article_uploads/SustainFARM%20PG%20Tool%20user%20manual%20v1.1.pdf
TESSA 2.0	Participatory /Biophysical	Site	Yes	Free	http://tessa.tools/
Woodland Valuation Tool	Valuation	Any	No	Free	https://forestry.gov.scot/publications/680-woodland-valuation-tool

Appendix F. Key Study Review Summaries

F.1 List of studies reviewed

Studies considered in the review are identified below. The studies reviews are summarized in **section 4** in relation to use of natural capital and ecosystems services approaches and tools and other components relevant to LNCP development. Summary review tables are also provided in **Appendix F.1**.

Studies reviewed for valuation and accounting approaches are addressed and covered in **section 6**, with key case study examples also provided in **section 6**.

Ref. No	List of Studies Reviewed	High level review on NC approach and tools Section 4	Summary Review Table Section 4 & Appendix F.2	High level Review for valuation Section 6	Summary Review Table for valuation Section 6
Within OxCam Arc area					
1	Habitat Opportunity Mapping in Northamptonshire and Peterborough, Natural Capital Solutions (May 2018) NCS for Wildlife Trust for Beds, Cambs and Northants, Northants County Council, Peterborough City Council, North Northants JPU, West Northants JPU, River Nene Regional Park, Natural England, Environment Agency	✓	✓	×	×
2	Mapping natural capital and ecosystem services in the Nene Valley (2016) Nene Valley, University of Northampton, Natural Capital Solutions Ltd	✓	✓	×	×
3	Bicester and Beyond (A Framework for Planning Green Infrastructure Green Spaces, Healthy Places (A.Smith, 2018) Tools for Planning and Evaluating Urban Green Infrastructure: Bicester and Beyond: A Framework for Planning GI Presentation to TCPA Land-cover scores for ecosystem service assessment Alison Smith and Rob Dunford, Environmental Change Institute	✓	✓	×	×
4	Natural Capital Investment Planning for the Oxford-Milton Keynes-Cambridge Growth Corridor (Growth Corridor Natural Capital report) (2018) Bedfordshire Local Nature Partnership with partnership of Local Nature Partnerships and Oxfordshire Local Authorities, supported by Defra	✓	×	×	×

Ref. No	List of Studies Reviewed	High level review on NC approach and tools Section 4	Summary Review Table Section 4 & Appendix F.2	High level Review for valuation Section 6	Summary Review Table for valuation Section 6
5	Jacobs and Cranfield University's natural capital assessment and ecosystem service mapping for the Expressway (2019 draft)	✓	✓	×	×
6	Oxford University's Environmental Change Institute's natural capital mapping in Oxfordshire (Draft)	✓	×	×	×
7	Natural Capital Assessment Proposal; Thames Valley Environmental Record Centre (TVERC) Oxfordshire Investment Plan	✓	×	×	×
8	Natural Capital Valuation in the Cam and Ely Ouse Catchment Vivid Economics / Cranfield University (2017)	✓	✓	✓	✓
9	Management of the Otmoor Protected Area, Oxfordshire; An Evaluation of Values, Impacts and the Application of the Ecosystem-Based Approach: Wildfowl & Wetlands Trust, Defra	✓	×	×	×
10	Spatial Evidence Base to improve Regulating Ecosystem Services in Central Bedfordshire Central Bedfordshire Council, Cranfield University Central Bedfordshire Development Strategy Ecosystem Services Report Publication January 2013	✓	×	×	×
Outside OxCam Arc area					
11	A Natural Capital Asset Check and Risk Register for the Anglian Water Combined Services Area CSERGE/Anglian Centre for Water Studies UEA for Anglian Water Services	✓	✓	×	×
12	Cumbria Catchment Pioneer: Phase 1 Cumbria Catchment Pioneer Pilot Project: Natural Capital Assessments for Braithwaite, Glenridding and Staveley. Natural Capital Solutions, Environment Agency, CWT	✓	✓	×	×

Ref. No	List of Studies Reviewed	High level review on NC approach and tools Section 4	Summary Review Table Section 4 & Appendix F.2	High level Review for valuation Section 6	Summary Review Table for valuation Section 6
13	Greater Manchester Pioneer & related work Urban Pioneer Natural Capital Accounts: Greater Manchester. Greater Manchester Natural Capital Group, Manchester LNP Natural Capital Account for Greater Manchester, Eftec (2018)	✓	✓	✓	✓
14	North Devon Landscape Pioneer Natural England The North Devon Pioneer is one of 5 natural capital pioneer projects initiated by Defra. It uses an engagement-based approach to identify key issues for priority assets and ecosystem services and assess strategic options that cross-cut across identified problems.	✓	✓	×	×
15	Natural Capital Investment Plan for Surrey: Surrey Nature Partnership (2018) High level Implementation plan setting out benefits and objectives for a natural capital approach for investment, identifying use of mapped Biodiversity Opportunity Areas and potential future use of Nature Recovery Network.	✓	×	×	×
16	Beam Parklands Natural Capital Account	✓	×	✓	✓
17	London Borough of Barnet corporate natural capital account	✓	×	✓	×
18	Natural Capital Accounts for Eycott Hill National Nature Reserve	✓	×	✓	×
19	A study to scope and develop urban natural capital accounts for the UK. Eftec (2017)	×	×	✓	×
20	Benefits and costs of ecological restoration: Rapid assessment of changing ecosystem service values at a U.K. wetland. Peh et al. (2014)	×	×	✓	×
21	Forest Enterprise England corporate natural capital account. Eftec (2016)	×	×	✓	×

Ref. No	List of Studies Reviewed	High level review on NC approach and tools Section 4	Summary Review Table Section 4 & Appendix F.2	High level Review for valuation Section 6	Summary Review Table for valuation Section 6
22	Natural Capital Accounts for public green space London (GLA) – Vivid Economics (2017)	×	×	✓	×
23	The Tresham Garden Village Natural Capital Account and Natural Capital Assessment. Natural Capital Solutions (2017-2019)	✓	×	✓	✓
24	The quantification and valuation of the environmental, social and economic impacts of the Forest of Marston Vale. Natural Capital Solutions (2017)	×	×	✓	×
25	Accounting (studies) The value of Peterborough City Council's trees. Natural Capital Solutions (2018)	×	×	✓	×
26	Accounting for National Nature Reserves: A Natural Capital Account of the National Nature Reserves managed by Natural England (Natural England, 2019)	×	×	✓	✓
27	Benefits and costs of ecological restoration: Rapid assessment of changing ecosystem service values at a U.K. wetland (Peh et al., 2014)	×	×	✓	×
28	Accounting for Nature: A Natural Capital Account of the RSPB's estate in England (RSPB, 2017)	×	×	✓	×
29	A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Bagstad, K.J. et al (2013) Not reviewed as a case study as is based on US values and considered limited relevance for LNCP	×	×	×	×
30	Benefit Transfer and Use Estimating Model Toolkit (Loomis et al., 2008) Not reviewed as a case study as is based on US values and considered limited relevance for LNCP	×	×	×	×

F.2 Summary Tables for Key Studies

The following table provide a summary of the reviews for key studies within and outside the OxCam Arc and referenced in **Section 4**.

<table>
<tr><th colspan="3">Bicester and Beyond (Smith, 2018) (A Framework for Planning Green Infrastructure Green Spaces, Healthy Places (2018); Tools for Planning and Evaluating Urban Green Infrastructure (2017))</th></tr>
<tr><td colspan="3">Context/purpose:
Aim was to map current Green Infrastructure and the ecosystem services it provides; identify opportunities to enhance existing Green infrastructure and create new areas that fill spatial and functional gaps and improve connectivity for wildlife and people. Consider design and planning for net gain. Evaluate the benefits of existing and planned GI, in monetary terms where appropriate, to compare different options and make the business case for investment. Produce a toolbox and guidance to allow the approach to be applied elsewhere.</td></tr>
<tr><td>Area/scale Town and setting

Data: spatially explicit base mapping
Included TVERC and local authority data and stakeholder input
Includes urban green infrastructure and land cover categories</td><td>Approach
Baseline mapping of existing assets and ES including results of ES scoring grouped and averaged. Tools: scores, EcoServ-GIS • ANGSt • Participatory maps • Network mapping
Opportunities mapping tools: NCPT • Eco-metric • Green factor scores
Design/ net gain analysis of proposals comparison tool - Tools: NCPT • Eco-metric • Green factor scores
Valuation comparison Tools: GI-Val • BEST • iTree • ORVal • Participatory maps</td><td rowspan="2">Relevance for LNCP
Covers comprehensive range of ES associated with land use and habitats using eco-metric scoring approach complimented by tools for specific aspects. Included use of simple accessible tools and those needing expert support.
Participatory mapping - analysis of provision of local priorities for green infrastructure and potential to inform eco-metric scoring.
Clear outputs from mapping, scoring, quantitative analysis for comparison with other areas and valuation of benefits of GI for planning and development design.
Example of urban area approach using detailed land use information with focus on recreation, biodiversity and air quality regulation and application of a range of tools to inform identification of opportunities for improvement and compare performance and value of development proposals to deliver ES.
Data and approach likely to be too detailed for Arc wide plan but LNCP would provide context and much of the baseline information and potential to use as example of how information and analysis could be built upon locally.</td></tr>
<tr><td colspan="2">Limitations/ gaps
Habitat/land use assets as basis for ES as this was focus for study, Other NC assets not covered for example soils, minerals, water.</td></tr>
</table>

Habitat Opportunity Mapping in Northamptonshire and Peterborough, Natural Capital Solutions (May 2018)

Context/purpose: Aims to identify possible locations where new habitat can be created that will be able to deliver particular benefits, whilst taking certain constraints into account focusing on 3 broad habitat types. Follow on study to the Mapping natural capital and ecosystem services in the Nene Valley.

Area/scale

County wide

Data:

OS MasterMap/ OS vector maps

Open space data from 9 councils

BAP/PH habitat data wildlife trust and NE data

Corine European habitat data / CEH Land Cover Map 2007

Ancient Woodland Inventory data

Approach

Habitat opportunity mapping uses EcoServ GIS to identify potential area for the expansion of 3 key habitats.

Ecosystems service opportunities included 1) enhance biodiversity 2) reduce surface runoff 3) reduce soil erosion and improve water quality 4) ameliorate air pollution 5) increase access to natural greenspace

A step wise approach was applied to identifying each service drawing on referenced methodologies. This included considering biodiversity connectivity, constraints to opportunities and, for recreation and air quality, demand.

Constraints data including infrastructure, water bodies, existing habitats, scheduled monuments, flood risk zones.

Demand data included urban areas and analysis of proximity.

Combinations of service provision were also analysed.

Relevance for LNCP

Data requirements highlighted the need for considerable preprocessing especially for open space data from different local authorities.

Use of EcoServ GIS tool which requires specialist expertise with the tool's use, and it is currently unsupported.

Provided opportunity maps showing top 10% of areas to enhance water retention, water quality, air quality, and accessible natural greenspace provision. They highlight areas that can be targeted to enhance natural capital with respect to individual services or in combination to where multiple objectives can be delivered at the same location.

Recommendations for next steps included stakeholder involvement in ground truthing and comparison of mapping and to develop priorities to take forward. Mapping outputs are noted to be a starting point for considering location of habitat creation and restoration rather as end in themselves.

Limitations/ gaps

Based on 3 broad habitat assets and the ecosystems deriving from them. Study noted that opportunity areas for the three habitats often overlap, and no attempt was made to ascertain the most suitable habitat at a particular location.

Mapping natural capital and ecosystem services in the Nene Valley (2016)

Context/purpose: Undertaken for the Nene Valley NIA Project, this study aimed to identify, map and value natural capital and ecosystem services across the Nene Valley. The aims were to highlight the key benefits provided by the natural environment, to increase understanding of the interdependencies between the natural environment, people and the economy, and to help planners and decision makers protect, enhance and restore the natural environment for the benefit of both people and wildlife.

Area/scale

River valley NIA

Data:

OS MasterMap/ OS vector maps

Nature conservation designations

Rivers and water body classification

BAP habitat

Agricultural Land classification

Agri-environmental schemes

Creation of phase 1 habitat mapping and hedgerow and tree line maps.

Mapping of 275,000 biological records for species richness and density maps

CPRE tranquility mapping

Approach 3 step approach taken

- Mapping natural assets – extent and distribution of assets
- Mapping ecosystems services - level and distribution of key ecosystem services identifying hot and cold spots
- Mapping value of benefits - distribution in the values of benefits derived from ecosystem services

Maps were developed for 11 different ecosystem services: carbon storage, noise regulation, local climate regulation, air purification, water flow, water quality, pollination, agricultural production, tranquility, accessible nature, and green travel.

Capacity of the natural environment to deliver those services (the current supply) was mapped and, wherever possible, the local demand (beneficiaries) for each service was also mapped.

Mapping based on the EcoServ GIS toolkit developed by the Wildlife Trusts, but with a number of modifications to better suit the situation in the Nene Valley.

Bespoke models were created for several ecosystem services – all at a fine scale of mapping across the area.

Outputs are indicative – relative values (showing that certain areas have higher capacity or demand than other areas) and highlight areas of high and low provision and the pattern of capacity (supply) and demand for each ecosystem service. Maps were also generated of the overall supply and demand of all services.

Valuation of selected services where information was sufficient and methodology available.

Limitations/ gaps: habitat/ land based ecosystems and surface water assets. Ground water and minerals not covered. Soil and carbon data from EcoServ-GIS. Outputs based on relative scoring for ES value mapping.

Relevance for LNCP

Detailed baseline mapping preparation included:

- Development of phase 1 habitat mapping and hedgerow mapping using range of sources including manual identification from aerial photography
- Historical habitat mapping to identify change and loss.

The supply maps highlighted the importance of woodlands and the River Nene corridor at delivering multiple ecosystem services.

The river corridor is also effective at bringing habitats delivering high levels of ecosystem services right into the heart of urban areas, and this is particularly prominent in Peterborough, Northampton and Kettering.

The demand maps clearly highlighted the importance of the urban areas in driving demand, with the very highest demand from parts of Northampton and Peterborough

Monetisation of value undertaken for 1) Agricultural and orchard production 2.) Greenhouse gas balance, considering emissions from agriculture and carbon sequestration 3.) Pollination 4.) Expenditure on recreation

Scoring system used to identify high to low value (1-100) for non-monetized ES but also monetary values were also mapped high to low as heat map-various scales.

Oxford University's Environmental Change Institute's natural capital mapping in Oxfordshire ((Draft) (2019)

Context/purpose: Method used to generate preliminary Natural Capital maps for Oxfordshire developing evidence on natural capital to feed into development of the Oxfordshire Plan to 2050 based on habitat scoring adapted from an eco-metric scoring tool in development.

Area/scale

Regional within Arc area

Data:

OS MasterMap/ OS

Phase 1 habitat mapping for Oxfordshire

OS hedge data

Tree data

Urban green space identified as one land use

Approach

Natural capital mapping developed using a habitat scoring system as a simple and rapid method to allow spatial patterns to be identified.

Method adapted from work being carried out by Natural England to develop an eco-metric scoring tool for assessing net gains or losses in natural capital due to land use change.

Scores are based on stakeholder input, literature, expert workshops and peer review and are mainly indicative 1-10 scale scores apart from carbon storage and air quality regulation where scores are proportional to measured values.

Limitations/ gaps :

Analysis focused on habitat ES and area-based services. Scoring is not weighted so combining scores across ES requires caution. Considerable preparation work on habitat and land use baseline involved to capture detail.

Relevance for LNCP

Provides a comprehensive basis for mapping 18 habitat based ES using an eco-metric scoring approach.

Analysis included mapping of high value habitats to identify areas for protection, and also strategic network and low value areas where opportunities for improvement could be targeted.

Explored approach for grouping the ES using maximum scores to avoid averaging.

Stakeholder input to methodology.

Simple approach as an initial step and recognised not to provide a detailed natural capital assessment, or a basis for monetary values that can be compared across different services. It is intended to be a first step that can be extended into more detailed assessments in future. Useful mapping comparisons to existing biodiversity opportunity areas and to strategic planning scenarios.

Next steps:

Improve base map of land cover
Refine matrix of scores
Consider demand for services, based on needs of local population (present and future)
Integrate natural capital with Nature Recovery Networks
Continue to input to assessments for the OP2050 and Ox-Cam Arc
Test and evaluate with stakeholders

Jacobs and Cranfield University's natural capital assessment and ecosystem service mapping for the Expressway (draft) 2019

Context/purpose: Study undertaken for Highways England in response to the National Infrastructure Commission recommendations (NIC, 2017) and Chancellor's autumn 2018 and spring 2019 statements (HM Treasury, 2018 and 2019) which set out the Government's intention for the policy for the wider Oxford - Cambridge corridor to embody the 25 Year Environment Plan and be based on a natural capital approach. Objectives include: to carry out a high-level natural capital assessment (NCA) of the PCF Stage 1 route options for the expressway; develop an understanding of the potential net gain opportunities, develop an approach for including natural capital in route selection decision making and provide a basis for taking natural capital assessment into future options assessment and consultation stages.

Area/scale	**Approach**	**Relevance for LNCP**
Regional within Arc area **Data**: OS MasterMap/ OS CEH land use and crops data Phase 1 habitat data – semi automated mapping from aerial photography NatMap soils data Nature conservation designations River network and Water body WFD classification Flood risk zones Minerals safeguarding areas Agricultural Land classification Landscape sensitivity mapping and designations CPRE tranquility and night sky mapping Biodiversity opportunity areas Recreation open areas – local authority information	Based on the steps of the How to do it: a natural capital workbook' (NCC, 2017) and Natural Capital Protocol (Natural Capital Coalition, 2016), included 1. A natural capital baseline asset register to capture the extent of natural capital stock affected by each option 2. Ecosystem services assessment – two approaches considered. • Ecosystem services modelling – combination of GIS spatial analysis and specialist Tools INVEST and Circuitscape 4.0 • Eco-metric 2.0 draft version made available to trial covering 18 ecosystems services 3. Potential for opportunities/ net gain associated with the route options based on stakeholder feedback and existing work on natural capital in the OxCam Arc. Natural capital stocks were grouped by type/theme into habitat, water, soils and minerals, landscape, land use and atmosphere. Indicators were selected to cover each type and to reflect extent and proportion of higher value potentially affected. The asset stock assessment focused on the potential change in the extent of natural capital lost or affected by a route option. Focus on assets was on direct loss. Wider indirect effects, for example on species connectivity, water and sediment flow were also considered within a catchment based study area through ecosystem service modelling. Quantitative GIS analysis of change was used to generate a comparative assessment of options by using a statistical measure of standard deviation difference from group mean - Z scores.	Asset indicators representative of all relevant natural capital themes. Limited consideration of condition as high level and large area. Only water quality and air quality condition covered. Detailed habitat mapping with phase 1 habitat information was available for the study. Biodiversity value was identified through application of distinctiveness scores including an irreplaceable habitat category and high to low distinctiveness which brought together a range of data for high level analysis. Analysis included: Spatial analysis GIS based– combined datasets (for agricultural production, carbon storage in soils and biomass); InVEST- Services modelled nutrient delivery, pollination, ecological connectivity, sediment delivery, recreation and seasonal water yield (baseflow and quick flow). Circuitscape 4.0 models for ecological connectivity applied to two indicator species. Initial consideration of a draft version of the Eco-metric tool but given high level of assessment with no design basis and scale of area the Eco-metric tool could only be applied in the simplest exploratory way, focusing on habitat extent, without adjustment for condition or location. The tool was used with total area of each habitat type for each route multiplied by the ES value scores to compare the relative importance of land directly affected and presented in a colour coded matrix with potential to provide an initial comprehensive overview for 18 ecosystem services. Analysis focused on option comparison and provided quantitative analysis through bar charts, comparative z scores matrices, and heat mapping,

Limitations/ gaps: Linear habitats not fully captured in semi-automated phase 1 habitat mapping – limited by aerial photography resolution. Found that existing tools not set up for assessing large scale linear infrastructure options. Open space data definition and terminology variability.	Potential types of opportunities for consideration in future net gain were explored largely based on stakeholder suggestions and the investment planning report and initial analysis of recreation demand and supply and existing mapping of biodiversity opportunity areas.

Cam and Ely-Ouse Catchment

A valuation of the natural capital of the Cam and Ely-Ouse catchment – Final report prepared for WWF UK (Vivid Economics, Cranfield University, 2017) - Appendix 2

Context/purpose: A high-level assessment of the value of natural assets in the Cam and Ely-Ouse (CamEO) catchment, to help inform a catchment-based approach to prioritizing improvements in natural capital. Proof of method for application of NCA to a catchment. This summary focuses on the assessment of drivers and pressures and the mapping carried out as part of the project. The focuses on impact of intensive agriculture on compaction, erosion and soil carbon loss and includes modeling by Cranfield University of soil degradation risks. Valuation of damage costs is provided for provisioning services, carbon, water quality and flood risk. Analysis of ES flows also highlights the range of NC beneficiaries.

Area/scale: Catchment (rural/urban)

Data:

Habitat data: LCM 2007 (CEH)

Ecological condition (freshwater): WFD status (Environment Agency). Metric used: % meeting this criteria

Biodiversity indicator: numbers of SSSIs (and condition), presence of priority habitat (National Water Environment Benefit Survey, Environment Agency)

Access: numbers of visitors/annum (Forestry Commission); recreational uses

Agricultural output: Farm Business Survey for E of England (2016)

Water abstraction (National Abstraction Licensing Database, Environment Agency)

Carbon sequestration

Recreation (ORVal)

Approach:

Physical natural capital account of extent of Broad Habitats in the catchment. Partial indicators for asset condition (freshwater only), access (freshwater and woodland only) and biodiversity (woodland and priority habitat)

Natural capital mapping to illustrate distribution of land uses (agricultural production, rivers and flood risk, groundwater)

Pressures identified as climate change, population growth and increasing food production.

Applies DPSIR framework which is recommended as a way of organizing analysis of pressure and threats to prioritise possible responses and investment.

Logic chains presented for key ES showing drivers and pressures → natural assets → ES → economic value (and relevant human capital and manufactured capital inputs)

ES assessed: crop production, water abstraction, timber production, carbon sequestration in soil and biomass, water purification, flood risk regulation, recreation and biodiversity (non-use value)

Relevance for LNCP

Stated preference values from NWEBS (Environment Agency) could potentially be used as partial valuation of non-use value of SSSIs in the OxCam Arc

Logic chains present clearly the cause and effect linkages between pressures, stocks, services and value, and could be an important tool in engaging stakeholders around natural capital.

The partially monetised assessment attributes ecosystem service values across beneficiaries (farmers, water company, household/society, other businesses) – which could help to identify future funding for NC investment.

Limitations/ gaps:	Asset typology is at high level of aggregation due to data limitations (more detailed habitat classifications could be used). The analysis of ES value to beneficiaries is a useful step but could go further e.g. value of food production is attributed solely to farmers and could also consider value to society. Study area Location of beneficiaries is not assessed	

<table>
<tr><td colspan="3">Anglian Water A Natural Capital Asset Check and Risk Register for the Anglian Water Combined Services Area (2018)</td></tr>
<tr><td colspan="3">Context/purpose:

Aims to apply the NCC 2017 steps. Focuses on the Anglian Water combined water and used water services area and for this geographical region characterises the natural capital assets and then compiles a risk register for them. Spatial data on pressures and assets are then used to classify local authorities in the region and highlight those locations where there is likely to be a need for particularly careful spatial and resource planning in the future.

Key features are the compilation of a natural capital risk register at a regional rather than national scale and the second is the spatial analysis of pressures and assets to determine where different combinations of conditions exist.</td></tr>
<tr><td>Area/scale
Regional but Local authority based analysis 63 authority areas

Key points on data:
Data used was limited to open data sources so Corine land use categories were used, but also used was Priority Habitat data

Agricultural land classification used as an indicator for soil

OS open spaces data and national recreation data</td><td>Approach
Natural capital approach encompassed within a so-called DPSIWR (Drivers-Pressures-State-Impact-Welfare-Response) framework. The Natural Capital Committee (2017)

Selection of small set of asset indicators including some condition indicators such as SSSI condition status and WFD status.

Included some ecosystem services such as pollination and carbon sequestration in analysis so not just assets.

Demand and pressure mapped through population data, population trends and economic data

EA data on water body classification at low flow Q95 details were used to identify where abstraction might be restricted

Natural capital risk register aimed to highlight those natural capital assets whose current condition was such as to put at risk a sustainable flow of ecosystem services into the future. This was based on service from broad habitat types and include analysis of change in habitat data and projected population growth and expert judgment and literature in many cases based on the national information.</td><td rowspan="2">Relevance for LNCP

Quantitative analysis comparing asset extent and selected condition indicators for whole region with national data.

Natural capital risk register for ecosystems associated with the habitat types based on data and judgement or the whole study area:

Regional trends in pressures were mapped by local authority covering:

Grade 1 and 2 agricultural land important for food production, Nectar plant diversity as an indicator of habitat quality for pollinators Carbon storage in soils, and Land used for amenity or recreation purposes; Biodiversity: Areas of priority or designated habitats that are important for delivery of a range of benefits and

Z scores were used to compare the difference between authorities on same basis.

Approach for identifying demand and pressures at a local

Further steps recommended included potential to apply at catchment level.</td></tr>
<tr><td colspan="2">Limitations/ gaps: Local authority level analysis

Resolution limited due to data sources used but appropriate for level of analysis

Soil carbon data including limited soil depth assumptions</td></tr>
</table>

North Devon Landscape Pioneer

Root Cause Analysis of problems affecting ecosystem services in the Landscape Pioneer (North Devon) – Final Report for Natural England (Eftec, 2018). A Natural Capital Strategy for North Devon – Draft Summary for Comment (Thomson, 2019). Evaluation of the 25 Year Environment Plan Pioneers: Final report (ICF Consulting, 2018)

Context/purpose: The North Devon Pioneer is one of 5 natural capital pioneer projects initiated by Defra. Uses an engagement-based approach to identify key issues for priority assets and ecosystem services, and assess strategic options that cross-cut across identified problems.
Selected outputs[1] of the work were reviewed including the *Root Cause Analysis* (RCA) report, setting out a cause-effect chain for each priority ES of problem/pressures, causes and possible interventions and an *evidence spreadsheet* recording data collection and information gathered from key partners. The subsequent draft *Natural Capital Strategy* puts forward 4 priorities (water quality, flood risk, carbon capture/storage and recreational pressure) for targeting via land use and land management changes.

Area/scale: Protected area (Biosphere Reserve) **Data**: Primarily relied on partners' knowledge (including evidence from previous projects) and national guidance or research literature on causality and effect. North Devon Biosphere reporting (Annual Report; Strategy for Sustainable Development, State of Reserve) WFD water body ecological status (Environment Agency)	**Approach** *RCA:* cause and effects chains developed for each of the key ecosystem services, identifying root cause/driver and the immediate causes. 27 interventions identified across all problems. Preliminary qualitative evaluation of the interventions against set criteria (including the extent to which different from current practice, extent to which would have positive effect on NC assets, ES and biodiversity. Analysed the balance of costs and benefits for each intervention, including potential barriers and existing drivers (e.g. regulation) *Natural Capital Strategy:* Strategic changes to be selected on multifunctionality, benefit to biodiversity and affordability criteria. Analysis on Government spend on NC, disaggregated by asset type, organisation as well as whether responding to policy driver or whether improvement/maintenance costs.	**Relevance for LNCP** The North Devon Pioneer places considerable importance on engagement and knowledge capture via series of teleconferences to define problems and potential interventions. Helps to leverage available resources and build consensus. Particular focus on specific intervention options to address current and future problems. Other reviewed examples of trends/risk analysis tend to focus on mapping out causality and do not assess the merits of various solutions. Identifies where the same intervention could address multiple problems e.g. more stringent enforcement of existing regulations for water quality, which can help to identify efficiencies and basis for further work. Future work may include engagement with national and local partners (engagement), development of NC spatial plan (NC and ES mapping) and investment cases (NC investment plan). Evaluation and lessons learned also expected. The North Devon Pioneer have also engaged with South West Water to discuss the potential of a Payment for Ecosystem Services type scheme (ICF/eftec, 2018)
Limitations/ gaps	Preliminary consideration given to other factors e.g. administration/enforcement costs and distributional effects of interventions, but these would need to be further evidenced. Analysis of asset condition is limited – except for water body ecological status. No spatial analysis of where threats/pressures to assets/ES are greatest, or where risks/threats coincide.	

Cumbria Catchment Pioneer (CCP)

Natural Capital Assessments for Braithwaite, Glenridding and Staveley sub-catchments – Cumbria Catchment Pioneer Pilot Project. Phase 1 (Holt, 2017)

Evaluation of the 25 Year Environment Plan Pioneers: Final report (ICF Consulting, 2018)

Context/purpose: The CCP set out 3 objectives: informing farming and land management strategies (including shaping and testing elements of the future Environmental Land Management (ELM) scheme), building a common understanding of system interactions to steer investment towards innovative catchment solutions and engaging communities for sustainable catchment management.

Phase 1 of the project developed Natural Capital summaries for the 3 sub-catchments. The future phases of work referred to in Phase 1 documentation including engagement (phase 2), investment and intervention plans (phase 3) and sourcing investment and commissioning delivery (phase 4) have not been published.

Area/scale: Rural Catchment, sub-catchments

Data (Phase 1):

LCM 2007 (CEH)

Priority Habitats (NE)

Cumbrian Peat survey

Flood risk areas, river network, lake water bodies, groundwater (Environment Agency)

Environmental Stewardship agreements (NE)

Ancient Woodland (NE)

National Forest Estate Woodland (FC)

Countryside Rights of Way (NE)

Above-ground carbon, nitrogen/phosphorus, pH, invertebrates concentration in topsoil (NERC/CEH)

Separate hydrological modelling identified opportunities for NFM (woodlands for water planting).

Approach

Partnership working between Lake District NP Partnership, United Utilities, Environment Agency, Forestry Services, local universities, Local Community Development Group and Local Authorities.

Phase 1 NC assessments evaluated some condition indicators - e.g. peat condition (derived from aerial imagery), grazing intensity, SSSI condition.

Other workstreams of the Pilot included:

Co-designing ELM test and trial with Defra /trialing the universal payment scheme.

Merging and development of 2 existing projects exploring NC trading and investment (3keel, Green Alliance, National Trust, Nestle, UU, BITC).
In the Eden catchment Business in the Community are using landscape enterprise network analysis to assess the importance of natural capital to businesses and potential for shared commercial interests (WRAP.

Relevance for LNCP

CCP has a strong focus on land management (including establishing pilots) and evaluating how partnership working arrangements can be improved for more integrated decision-making.

Limitations/ gaps (Phase 1)

Natural capital and ES mapping is derived from relatively coarse resolution national scale maps (1x1km)

Some key threats identified but are not assessed in detail (pollution from abandoned mines, invasive species for water bodies).

Preliminary mapping

Manchester Urban Pioneer / Irwell Management Catchment (IMC)

IMC: Natural Capital Account and Ecosystem Service Opportunities Mapping report (TEP/GMCA, 2018). Greater Manchester (GM) Natural Capital Investment Plan (NCIP). Final Report from Eftec, Environmental Finance and Countryscape to Greater Manchester Combined Authority (Eftec et al., 2019). Evaluation of the 25 Year Environment Plan Pioneers: Final report (ICF Consulting, 2018)

Context/purpose: The Urban Pioneer objective had a series of clear objectives including an integrated approach to planning and delivery, developing an evidence base, testing new tools and methods, developing an NCIP for GM and demonstrator project to evidence the benefit of a natural capital approach to project funding.

The earlier IMC project, with EU Life IP funding) had a strong water quality focus. The objective was to assess natural capital value and ES investment opportunities for each of the waterbodies in the study area. One of the key project outputs was capacity building and development of an interactive GIS mapping tool, which was extended across GM and hosted on MappingGM online portal.

Area/scale Urban and Urban Catchment Priority Habitats 2007 and 2015 LCM (CEH) AQMAs (Defra) Water body classifications (Environment Agency) Provisional ALC (NE) IMD at LSOA level (ONS) Active Lives Survey Small Area Estimates at MSOA (Sport England) Strategic Housing and Employment land Availability Assessment (GMCA)	**Approach** GM Urban Pioneer Established 'logic models', setting out the goal, rationale, assumptions, inputs/outputs and impacts for key activities Combined asset data, quality indicators, social indicators and development areas to generate GM wide opportunity map (each layer scored 0-1 for investment opportunity, on 1km^2 grid) Evaluated trends in land use change using LCM 2007 against LCM 2015. Developed asset register, physical flow account and monetary account. Developed biodiversity net gain policy and mechanism, including a Net Gain task group Developed a Natural Capital Investment plan Tested the Environment Agency Natural Capital Score Card Communications and engagement including support to a Green Summit event.	**Relevance for LNCP** GM Urban Pioneer The most developed natural capital programme of work reviewed (more stages than other studies in Table Strong emphasis on partnership working and communications with environmental, health and economic stakeholders. Established Natural Capital Group with engagement of a range of partners, including Chamber of Commerce and Public Health Stakeholder workshops supported natural capital implementation plan. Visible legacy and signposting to current projects and publications via the Nature Greater Manchester website Comprehensive Investment Plan that provides platform for partners to take forward opportunities. The Plan reviewed track record in each investment priority area (e.g.), examples of financing vehicles used elsewhere, types of investors, capacity and expected returns to assess readiness to invest. Approach to compiling and analyzing the NC account useful for LNCP where multiple local authorities are involved. The NC account developed is for GMCA but account and metrics can be disaggregated for the 10 districts.

IMC MasterMap (OS) MasterMap Greenspace/ Open Greenspace (OS) National Forest Inventory Environmental designations (various) European Soil Database 2.0 Cycle Routes (TfGM/Sustrans) GM Tree Audit WFD Surface Water Operational Catchment Cycle 2 (Environment Agency) Middle Super Output Areas (ONS	IMC Partnership approach Developed NC Account for 11 ES. Created land surface model from high-resolution LIDAR to identify flow paths and pooling areas for mapping several ES Used data from existing modelling studies[2] e.g. for flood mitigation opportunity mapping Produced summaries for each ES: monetized value, mapped value for all affected MSOAs, criteria and scores used for opportunity mapping, and summary of priority interventions and limitations/areas for further work.	IMC Used only open data to compile habitat and ES opportunity maps and provided with comments in the report. Aim was for NC valuation to estimate level of ES at highest level of disaggregation as possible. Detailed approach to mapping protocols and attribute scoring for ES opportunity