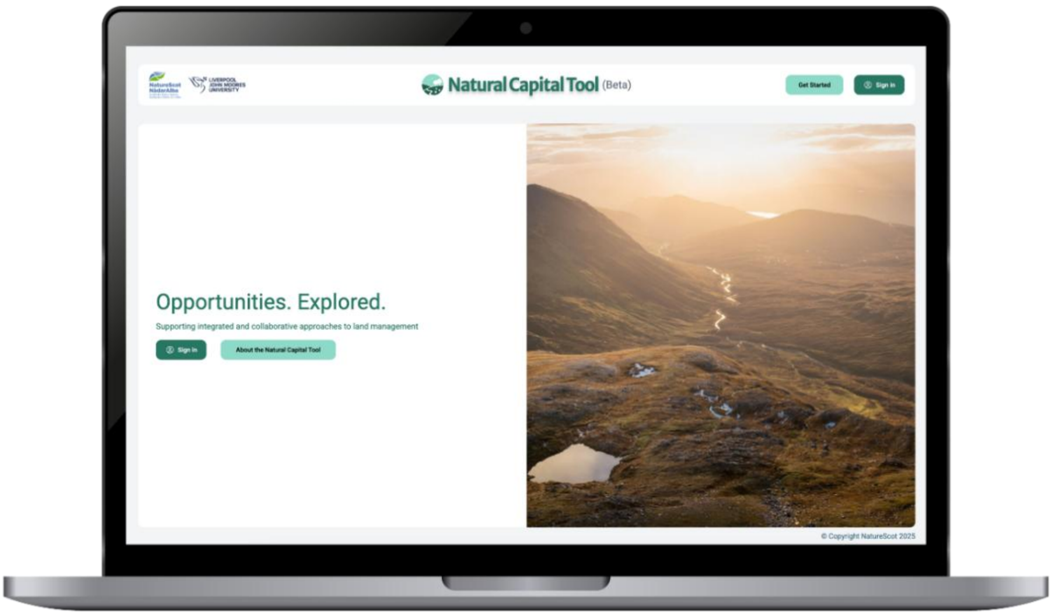
Natural Capital Tool

Natural Capital Tool (Beta) Version 1.2: Methodology Report Version 1.4 – April 2026

This active report has been prepared by the Natural Capital Tool team at NatureScot and the Natural Capital Hub at Liverpool John Moores University. It outlines the development process and methodology of the Natural Capital Tool (Beta).

Please note that as the tool is currently in Beta testing, both this methodology report and the tool are subject to ongoing refinement and active updates based on testing outcomes, user feedback and further development. As such, the methodologies and outputs described herein may be subject to change.

Should you have any queries, please contact natcaptool@nature.scot.



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Introduction

Land use change is a primary driver of biodiversity loss, with Scotland being in the bottom 15% of countries in terms of the Biological Intactness Index (Pakeman et al., 2023). Despite nature providing vital services, such as pollination and flood mitigation, economic and political decisions often overlook both the market and non-market values associated with the benefits we receive from nature, otherwise known as ecosystem services. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) published the Assessment Report on the Diverse Values and Valuation of Nature, which stated that the way nature is currently valued in political and economic decisions is both a key driver of the global biodiversity crisis and a vital opportunity to address it. Understanding the true value of the habitats and ecosystems that hold social, environmental, and economic value, i.e., natural capital, is essential for tackling the twin crises of biodiversity loss and climate change, and it can help Scotland secure a resilient, inclusive, nature-rich and low-carbon economy for our future.

The NatureScot Farming with Nature Programme (previously known as the Natural Capital Pilot Programme (NCAPP)) is a suite of projects to test natural capital approaches at landholding, landscape and national scale in order to inform future rural policy and land management support schemes and ultimately contribute to wider biodiversity targets. A natural capital approach captures the full range of benefits that nature provides in the decision-making process. At a landscape scale, a natural capital approach can help decision makers make best use of their natural assets to improve sustainability and maximise benefits for people and nature. This approach enables us to understand the role of our natural environment, alongside its intrinsic value, as an asset that underpins both our economy and society.

In order for the benefits that we receive from nature to be included within decision making, we need the methods and tools to quantify them. By mapping and modelling how certain land use changes might impact the ecosystem services they provide, decision makers will be able to identify interventions that deliver for both people and nature. As part of this programme, NatureScot is leading on the development of the Natural Capital Tool (NCT), a free and easy-to-use spatial tool that enables decision makers to take a natural capital approach to land management in Scotland. The NCT aims to support land managers and decision makers to:

- Access relevant datasets and evidence by democratising natural capital information and making it accessible for all;
- Save time and money through improved decision making, allowing users to take a strategic approach to land management;
- Prioritise interventions so that the environmental benefits from nature can be provided to the communities, habitats and wildlife that need it most;
- Examine the gains and losses in ecosystem services and habitat connectivity associated with different land use interventions; and
- Align with emerging nature finance markets by helping users to collaborate at the landscape scale, allowing them to aggregate investment opportunities.

Based on EcoservR, an R language rewrite of the ArcGIS tool EcoServ-GIS (Winn et al., 2018), the NCT is among the first of its kind in Scotland. In partnership with Liverpool John Moores University (LJMU; the authors of EcoservR), the NCT was developed with Scotland's habitats and ecosystem services at the forefront. Details of EcoservR and how NatureScot formed this partnership with LJMU can be found in section 2 of this report.

In order to ensure the NCT aligns with user needs and expectations, its development was co-designed with relevant stakeholders across multiple sectors. Working with a co-design group consisting of over 160 individuals across 64 organisations, stakeholders were able to directly influence the functionality, content, and ethos of the NCT. This approach ensured that the NCT would better match user needs and expectations. Details of the engagement strategy can be found in section 3 of this report. Through the co-design group, NatureScot was able to develop and confirm the key features of the NCT:

- Natural capital baseline mapping;
- Ecosystem service capacity and demand mapping;
- Habitat network mapping;
- Landscape-scale opportunity mapping;
- Scenario planning;
- Ecosystem service uplift prediction, in relative, biophysical, and economic terms; and
- Contribution to existing habitat networks.

The NCT presents users with the current mix of habitats in an area of interest through the habitat baseline map: a bespoke habitat map covering the whole of Scotland and generated specifically for the NCT. The habitat baseline is created by assigning habitat types to features in the OS MasterMap Topography Layer. Landcover datasets with national coverage (e.g., Scottish Landcover Map, Scottish Crop Map) are incorporated to improve the accuracy of the mapping. A full list of datasets that informed the habitat baseline are provided in section 4. The NCT also allows users to explore other open access maps, referred to as context layers, that can be used to create a more in-depth picture of the landscape, such as peat depth and riparian planting. Please see Appendix 2 for an overview of the context layers used in the NCT and their associated licenses.

Ecosystem services are benefits that flow from natural capital (Figure 1). There are four groups of ecosystem services:

- **Provisioning services** provide material benefits to people (e.g., timber production)
- **Regulating services** enable ecosystem resilience and protect against adverse impacts (e.g., flood regulation)
- **Cultural services** provide non-material benefits to people through interactions with nature (e.g., recreation)
- **Supporting services** underpin other ecosystem services (e.g., nutrient cycling)

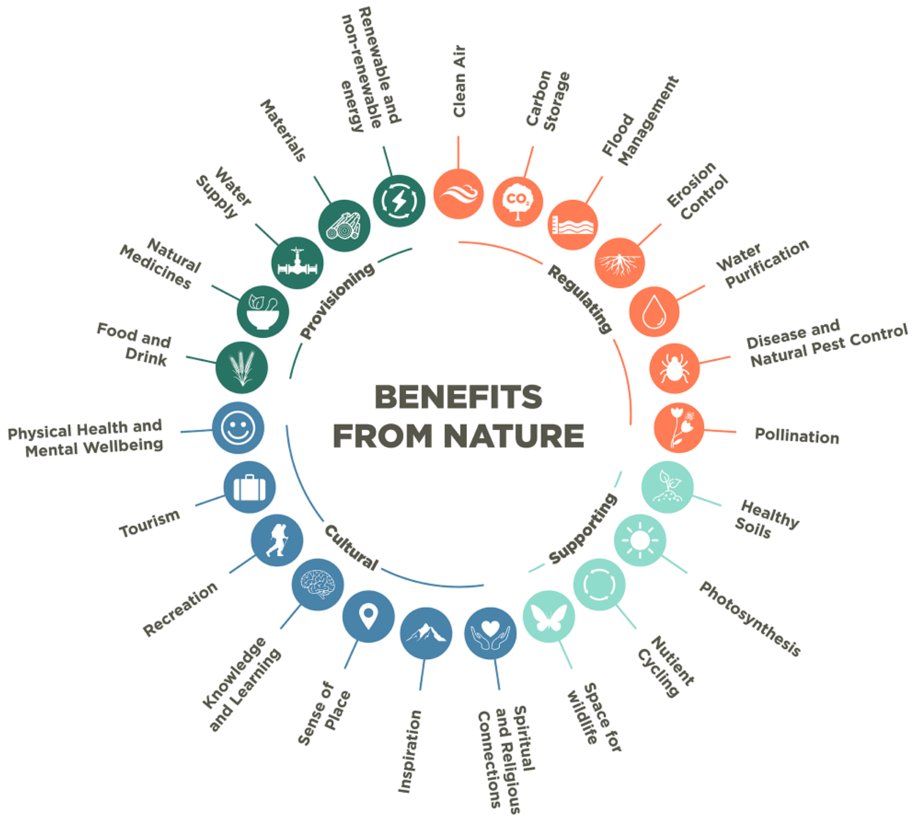

Figure 1. The four categories of ecosystem services. Examples of each ecosystem service are embedded within the wheel.

Taking a natural capital approach to land use requires identifying both the ecosystem services that are currently being provided by an area of land and opportunities to develop or enhance ecosystem services. This approach can inform users of the nature-based solutions and economic opportunities their land can provide through targeted land use intervention. The NCT draws from a robust and open source range of socio-economic and ecological datasets that underpin ecosystem service models, developed alongside LJMU. Seven ecosystem service models are currently included in the tool: carbon sequestration, insect pollination, inland flood mitigation, climate regulation, access to nature, air quality improvement, and noise regulation. These models show users: 1) the existing capacity of a target area to provide an ecosystem service (e.g., to what extent an area of land is providing land users with pollination services); and 2) the demand that exists for certain ecosystem service provision (e.g., the need for increased access to nature). The parameters used to generate capacity are based on national, open access datasets and values acquired through consultation with experts and literature reviews. The demand models use socio-economic datasets, such as census data and the Scottish Index for Multiple Deprivation (SIMD), to indicate areas where the provision of an ecosystem service would benefit local communities. Detailed descriptions of each ecosystem service model are provided in section 5.

In addition to mapping habitats and ecosystem service provision currently present on a target area of land, the NCT provides land managers and decision makers with the ability to map potential opportunities to enhance the natural capital present on their target area. Users can explore opportunities to boost a particular ecosystem service, explore specific habitat networks, or view opportunity areas that provide multiple benefits for people and nature. These opportunities are threefold to allow users to customise their experience in line with their specific goals. Opportunities to boost an ecosystem service occur in areas that have a low capacity to provide the service and a high demand for the service to be provided. Infrastructure, historic sites, playing fields, ancient woodlands, and areas of freshwater are excluded as opportunities. This ensures that the opportunities presented consider both people and nature and present realistic and feasible areas for nature-based interventions.

These opportunities can be viewed alongside the habitat networks currently present in an area of interest. Habitat networks are generated using cost distance analysis, the output of which presents areas of 'useable space' that species associated with a particular habitat can move through. Details on the habitat network models can be found in section 7 of this report. Opportunities to enhance habitat networks exist in areas adjacent to existing patches of habitat (buffer opportunities) and areas within the dispersal distance of species associated with that habitat (stepping stone opportunities).

Finally, users can highlight pinch-points in the landscape by viewing opportunities to provide multiple benefits. These are areas where a particular intervention would provide positive uplift across several ecosystem services. For example, planting broadleaved woodland in a particular area might contribute to air quality improvement, noise regulation, and carbon sequestration (i.e., three benefits). This allows land managers to prioritise areas that will provide greater return on investment in terms of benefits for people and nature.

Alongside viewing where opportunities to increase ecosystem services exist on a target area of land, users can quantify the impact that planned interventions will have on ecosystem service provision. This change, when positive, is referred to as ecosystem service uplift. Uplift is presented in the NCT in relative, biophysical, and economic terms. Relative uplift refers to the percent change in ecosystem service capacity based on standardised scores (0-100). Biophysical and economic valuations are calculated using methodology from Natural Capital Register and Accounts Tool (NCRAT; Lenane et al., 2023) adjusted to Scotland data, where appropriate. Biophysical refers to changes seen in ecosystem service provision in the units in which those ecosystem services are measured (e.g., carbon sequestration is measured in tonnes of carbon per year (tC/y)). The economic valuations are based on the value of societal benefit rather than values that can be traded for biodiversity or carbon credits. Therefore, these are not to be used as exact measures of profit for land managers. Details of how biophysical and economic valuations for each of the ecosystem services were calculated can be found on page 41.

As well as ecosystem service uplift, users can also quantify their contributions to habitat networks in hectares. Once users have simulated their interventions, the NCT reruns the habitat network models and shows how interventions will have expanded or reduced existing habitat networks across three levels of dispersal. More information can be found on page 45.

Once users have received their uplift results, they can download an html document that provides them with an overview of their target area, the extent of existing habitat networks in their target area, a visual reproduction of their planned interventions and information as to the impact of said interventions on wider ecosystem service provision. By providing a downloadable report, users can present what planned interventions might look like and the impact they might have when engaging with relevant stakeholders and pursuing funding opportunities. Furthermore, mapping, scenario planning and reports of this kind often require the investment of capital from land managers, whether that be through accessing licensed datasets and software or paying consultants/advisors; whilst this does not replace a bespoke survey of a user's target area, the NCT provides them with a free, easily accessible first step when planning nature-based interventions.

It is worth highlighting that the NCT is a decision support tool rather than a decision-making tool. The NCT acts as an initial scoping tool when exploring potential options for nature-based interventions on a target area of land. While the models and outputs of the NCT are based on a robust scientific methodology, there are several reasons why recommendations provided by the NCT require further evaluation from those familiar with the target area of land:

- Habitat data has not been widely ground-truthed, and as a result, may not identify all habitat patches accurately;
- Habitat condition is not taken into account, and condition will inevitably affect the ability of a habitat to provide ecosystem services; and
- The NCT does not consider the impact of interventions on a temporal scale – valuations are made under the assumption that habitats are mature.

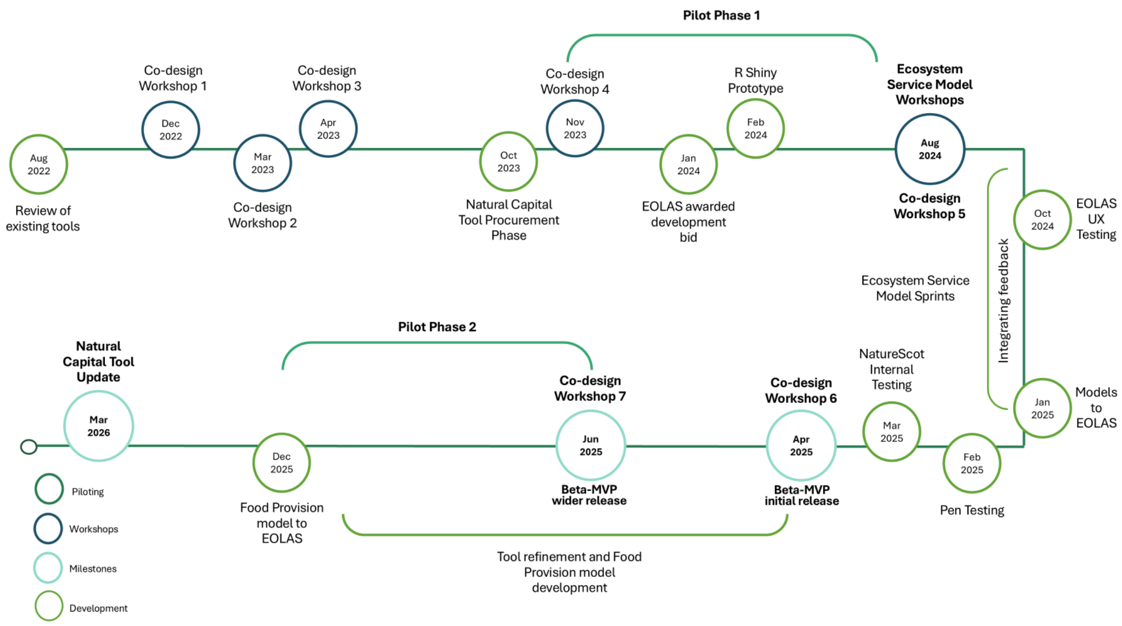

Figure 2. Development timeline of the Natural Capital Tool (2022-2026).

Applying EcoservR to a Scottish context

Prior to developing the NCT, NatureScot conducted a review of existing natural capital tools that aimed to address similar gaps in the natural capital tool market. This initial review found that no tools were both applicable in Scotland and fulfilled the key criteria:

- Open access and free to use, without requiring initial capital investment;
- GIS-based, so users can clearly visualise spatial priorities;
- Useable at the landscape scale to encourage collaboration across catchments and attract nature finance;
- Based on a transparent and robust methodology, backed up by existing knowledge;
- Simple and easy to use, without requiring prior expertise; and
- Developed using a co-design process, so that it meets the needs of the end user.

Following the review, NatureScot planned to develop a tool that would meet the above requirements and be applicable to Scottish decision makers, land managers and landowners. The review identified that this tool could be built on EcoservR (previously known as EcoServ-GIS), an existing open access tool produced by LJMU to assist landowners and managers in assessing the impact of nature-based interventions on their land. The NatureScot team was familiar with EcoservR through experience with the Edinburgh Nature Network, a project run by the Scottish Wildlife Trust using the EcoservR approach. For an in-depth assessment of EcoServ-GIS, see this report produced for NatureScot (Winn et al., 2018).

The NCT is a derivative of EcoservR which has been modified for use in Scotland. LJMU developed EcoservR for use in England, where data availability and habitat types differ from Scotland; both the habitat baseline and models have been updated to reflect this. Scotland is also less urbanised than England, and model parameters have been adjusted with this in mind.

Both the NCT and EcoservR produce intuitive statistics and spatial outputs (i.e., maps). However, EcoservR requires the use of R and (typically) GIS software to produce and visualise outputs. The NCT addresses this issue by providing a user-friendly interface that can be used to create and view these same outputs without any specialist training.

Following a request for the scripts, NatureScot formed a formal partnership with LJMU given the shared goals for the NCT: to produce a tool that does not require technical expertise and has an easy to use, ergonomic front-end. Since inception, LJMU have been heavily involved in the technical development of the NCT and have contributed to the NCT both in terms of providing original scripts and prototypes, as well as actively working together with NatureScot to apply these to a Scottish context. The development bid was awarded to EOLAS and Dev Major, app development specialists, who have been working on the tool interface since January 2024.

Both EcoservR and the NCT are built upon a habitat baseline, which is a composite of habitat datasets and the OS MasterMap Topography Layer. Before the NCT was developed, EcoservR scripts were only set up to create a habitat baseline for England, meaning the models could not be run in Scotland. The first task was therefore to create a new baseline for Scotland, initially by finding equivalents for each dataset included in the England baseline, but then by supplementing these with datasets for Scotland. Notably, EcoservR uses the Phase1 habitat classification as inputs, but the majority of habitat data available in Scotland uses the EUNIS classification. Therefore, an additional piece of work involved translating EUNIS codes into Phase1, using a combination of existing correspondence tables and expert opinion.

From this point, some of the EcoservR models would technically run in Scotland. However, many models required further datasets (e.g. health indicators), and so the second component involved finding equivalent Scottish datasets for the model parameters outwith the baseline.

In addition to the baseline, the habitat lookup table is a key part of EcoservR. This contains values for each Phase1 habitat, such as carbon sequestration estimates and cost distance values. In most cases, the existing values were deemed to be relevant in a Scottish context and were kept. If newer or Scotland-centric values were available, these replaced the existing values. This can be found in the 'About' section of the Natural Capital Tool.

Almost every model was changed to some degree. The models with the least changes were air quality improvement, climate regulation, and noise regulation. The insect pollination models were completely rebuilt from scratch using a cost distance approach, rather than focal statistics. Almost all of the opportunity models were overhauled to follow a standard approach (areas of high demand, low capacity, minus constraints). Details of the changes made to EcoservR models are outlined in section 5.

Engagement strategy

In order to meet the aims of the NCT, NatureScot used a co-design approach that involved stakeholders in the design and development of the tool. This co-design approach was delivered through a robust engagement strategy that identified key stakeholders and established a mechanism to integrate their feedback into the NCT's development. The engagement strategy was underpinned by three pillars of co-design: the co-design group, pilot phases, and tool development (Figure 3). The co-design group, comprised of 64 organisations representing Scotland's industries and sectors relevant to land management, was assembled to advise and steer the NCT's development to ensure it was accessible, relevant and useful in a wide range of land management situations. Pilot phases entailed testing the tool with landowners and land managers to gather and integrate their feedback regarding its performance in a variety of live-use scenarios. Ecosystem service workshops brought together internal and external subject matter specialists to advise and input on the development of the NCT ecosystem service models.

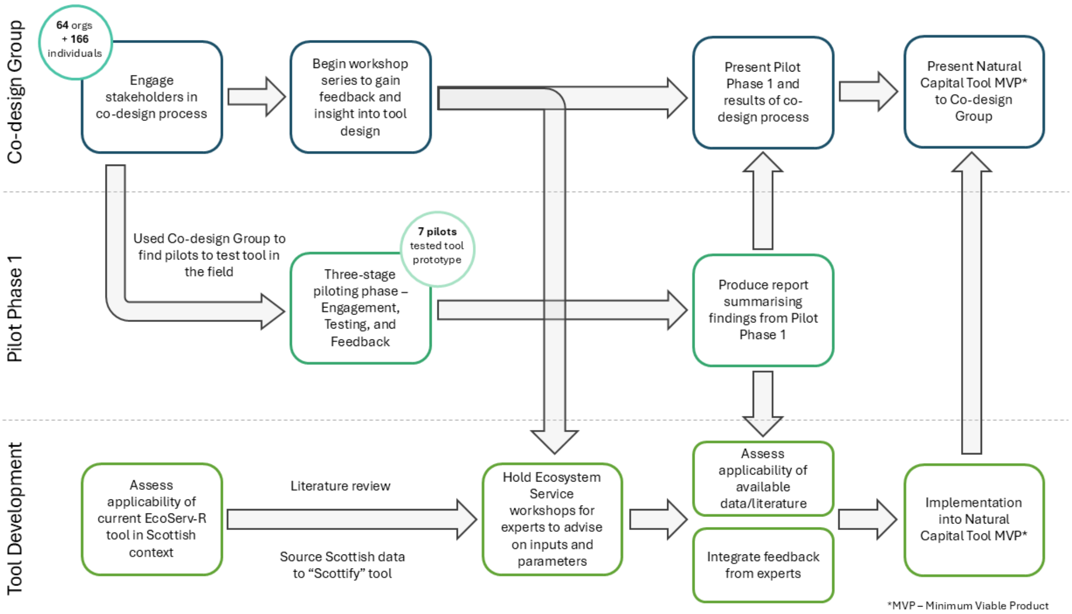

Figure 3. The strategic framework that underpinned the Natural Capital Tool engagement and development strategy (2022-2026).

Co-design group

The co-design group is the main mechanism through which the co-design approach was conducted. The co-design group was assembled in 2022 through an initial stakeholder mapping exercise that highlighted organisations from different sectors with whom NatureScot had a working relationship. The membership expanded as the project developed and additional organisations were engaged with. In total, the co-design group comprised 64 stakeholder organisations and 166 individuals (Appendix 3).

Across five workshops, the co-design group were asked to: 1) give feedback to ensure that the features and functions of the NCT would represent a variety of sectors and land uses; 2) sensecheck new ideas and developments presented by the technical development team; and 3) hold the team to its original aims and commitments (Figure 2; Table 1).

Table 1. The aims and outputs of each of the seven co-design workshops.

Workshop	Date	Aims of workshop	Outputs
1 – Introduction to co-design	12/2022	• Define 'co-design' • Introduce piloting • Outline timeline	• Engaged co-design group • Gauged stakeholders' level of interest
2 – Identifying user needs and tool functionality	03/2023	• Provide context for the NCT – relevant definitions • Outline aims and objectives of the NCT • Discussion of NCT features and functions	• Identified challenges and opportunities • Given feedback on stakeholder priorities for tool functionality
3 – Valuing the benefits from nature	04/2023	• Address questions from previous session • Define ecosystem services • Discussion of ecosystem services and stakeholder priorities	• Priority ecosystem services • Opportunities and challenges associated with quantifying ecosystem services • List of desirables
4 – Progress update	11/2023	• Update on what feedback has been incorporated from workshops 2 and 3 • Update on ongoing partnerships (e.g. with University of Exeter) • Introduction to datasets and basemaps • Outlining Pilot Phase 1 structure	• Feedback on progress so far – what they like, what we could do differently, etc. • List of desirables • Opportunity for stakeholders to ask questions directly of the team
5 – Progress update	08/2024	• Demonstration of prototype • Updates from technical development team – ecosystem service models • Outlining aims of ecosystem service model workshops • Pilot Phase 1 findings	• Feedback on progress so far – what they like, what we could do differently, etc. • List of desirables • Gauged interest of stakeholders with regards to user testing

6 – Beta Natural Capital Tool Initial release	04/2025	• Demonstration of Beta Natural Capital Tool • Overview of ecosystem service methodology • Introduction to front-end design of tool interface • Timeline for 25/26	• Members of co-design group signing up for early access to the tool • Feedback on Beta Natural Capital Tool
***Beta Natural Capital Tool – Wider release**	09/2025	• Release of the Natural Capital Tool to the public • Hosted with Scottish Forum on Natural Capital • Demonstration of Beta Natural Capital Tool • Overview of tool functionality and methodologies	• Members of the wider public signing up for access to the tool • Feedback on the tool from a larger group than we had previously presented to • Broader engagement led to more use cases
7 – Progress update	03/2026	• Update on feedback incorporated since Co-design Workshop 6 and the wider release • Overview of new features and functionality added and to be added (April 26) • Update on Pilot Phase 2 • Plans for 26/27	• Priority ecosystem services/functionality to be included in 26/27 • Desirables for future development

*The wider release of the Natural Capital Tool was advertised outside of the co-design group, but co-design group members were invited.

The first co-design workshop (December 2022) introduced the key aims of the project, the co-design process, and organisations who were willing to be active stakeholders within the project were identified. This was followed by a second co-design workshop (March 2023) which identified user needs and the key functions of the NCT. Stakeholders identified the need for the tool to clearly identify and visualise opportunities to develop ecosystem services in a manner that was accessible and without the need for extensive expertise. Participants also identified the importance of a standardised approach to developing ecosystem service models that was relatable to other tools and used commonly understood datasets, and they suggested the NCT should also support access to nature finance. See Appendix 4-6 for outputs of Co-design Workshop 2.

The third co-design workshop (April 2023) focused on the features requested by stakeholders: the ability to view political boundaries; map forestry and agricultural grants; identify subsurface features; provide connectivity to other tools; opportunity mapping; link to the biodiversity metric; incorporate land ownership boundaries; and show habitat changes over time. Additional requests included the ability to upload localised data and export maps, and to simplify the user interface. This workshop also identified insect pollination, carbon sequestration, soil health and erosion mitigation, and space for nature as desirable ecosystem service models.

The fourth and fifth co-design workshops shared key updates on the development of the NCT based on feedback from the first three workshops and findings from the Pilot Phase 1. The sixth co-design workshop (April 2025) featured the formal launch of the first iteration of the NCT in June 2025. Co-design workshops will continue to be held across 2025-26 in conjunction with the release of additional features developed for the tool.

Pilot testing

Pilot testing involves testing features of the NCT with its users, including those in the co-design group. The aim of pilot testing is to gather feedback on how the tool is used, how it performs, and what additional features or recommendations pilots would like to see integrated into its development. This feedback is analysed using a mixture of qualitative and quantitative data analysis by the engagement team and shared with the technical team.

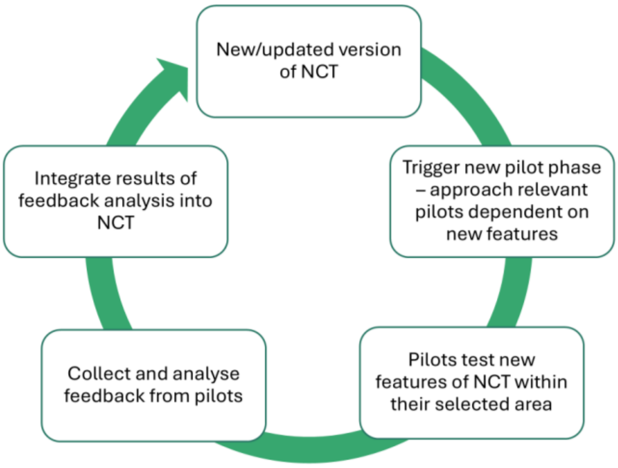

Figure 4. Piloting and development cycle of the Natural Capital Tool (NCT).

Pilot testing occurs in phases throughout the project's lifetime. This enables the NCT team to develop new features; it lets pilot partnerships test the NCT and provide feedback; and it allows for this feedback to be analysed and integrated before another pilot phase is initiated (Figure 3). Pilot phases comprise three one-hour sessions:

- Engagement session 1 – Introducing the project and broader themes of natural capital and ecosystem services, clarifying what piloting entails, and learning about the pilots' holdings, priorities, and expectations of the NCT. This is followed by a questionnaire gathering data about the pilots' holdings, sectors, key land uses, and familiarity with natural capital;
- Engagement session 2 – Demonstrating how the NCT works and Q&A. This is followed by a testing period of two-three weeks where pilots are encouraged to use the NCT on their land and complete a second questionnaire detailing how they used the tool and their impressions of its different features and functions; and

- Engagement session 3 – A pilot-led feedback session facilitated by themes generated from the second questionnaire and discussing in depth the pilots' experience testing the tool.

Feedback is then analysed according to sector and holding type to explore how pilots from different backgrounds used and perceived the NCT; this is done according to each feature and function of the tool. A report is then compiled synthesising this feedback and identifying actionable areas for the technical team to appraise and integrate into the NCT's development. A detailed Pilot Phase 1 – Executive Summary and Pilot Phase 1 Questionnaire 1 and 2 can be found in Appendix 7-9, respectively.

Ecosystem service workshops

Ecosystem service workshops drew upon subject matter specialists to critically review and contribute to the development of a selection of the ecosystem service capacity models included in the NCT. The NatureScot team held six ecosystem service workshops overall: access to nature, carbon sequestration, coastal flood mitigation, insect pollination, river cooling, and inland flood mitigation (listed in chronological order). Feedback gathered from these workshops was synthesised into actionable reports for the NCT technical team. Workshops comprised three steps: Step 1) the establishment of relevant parameters considered useful in quantifying specific ecosystem services; Step 2) collation of evidence of the usefulness of including the parameters; and Step 3) assessment of the feasibility and importance of the parameters collected in step 1. Reports were generated for each of the workshops, which were then distributed externally to participants and used internally as guides during tool development.

In Step 1, participants were asked to list parameters that they considered to impact the capacity and demand of habitats in relation to each ecosystem service model. This allowed for the establishment of a baseline of parameters which informed the course of the workshop and discussion. These parameters were then voted on by participants to establish popularity. The most popular choices were clustered thematically to inform the discussion later in the workshop. The less popular choices were not actively discussed, but they were included in the final research outputs of the workshops.

Once the priority parameters were established, participants were then asked to list data, evidence, and comments that they felt were most relevant for each of the suggested parameters. The synthesis of these discussions guided the NCT technical team in how they researched relevant literature, grey literature, and datasets according to each parameter, and ultimately dictated which parameters would be included in the NCT.

Finally, participants were asked to place all priority parameters, as decided upon in step 1, along two axes: feasibility and importance. This step was included to allow participants to elaborate on why particular parameters should be included beyond their relevance to the ecosystem service (i.e., whether it would be appropriate within the context of the tool). Again, comments and discussion points were documented and used to highlight points for further consideration during tool development. An example of a report generated from the Pollination Ecosystem Service Workshop can be found in Appendix 10.

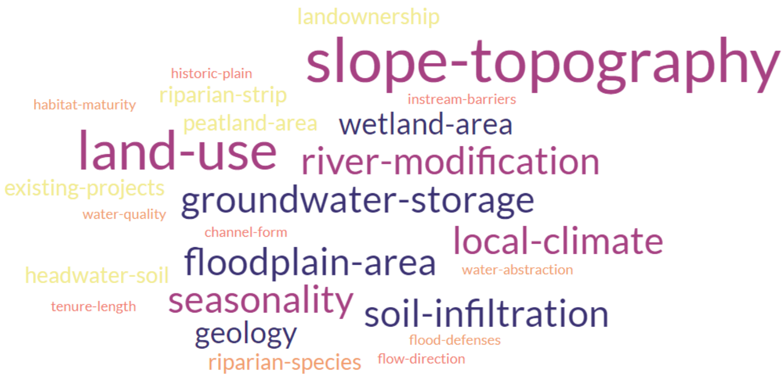

Figure 5. An example of a word cloud generated from the list of parameters produced by participants at the Inland Flood Mitigation ecosystem service model workshop.

<u>General themes of feedback</u>

Throughout NatureScot's initial engagement process (2022-2024), feedback gathered across the workshops was significant in driving the development of the NCT. Feedback was analysed using several methods: 1) asking stakeholders to prioritise feedback in workshops to ensure the team were applying the feedback that was most widely agreed upon; 2) cross-sector analysis of feedback to establish the themes that were most present across the board; and 3) carrying out literature reviews to gauge the feasibility of addressing particular pieces of feedback, particularly with regards to proposed parameters and datasets.

In initial stakeholder meetings with the co-design group, feedback was framed along two axes – challenges and opportunities – to ensure that the NCT was addressing neglected areas of the natural capital tool market. Outputs from this exercise can be found in Appendix 4. The most prevalent challenges were found to be accessibility of data, the integration of natural capital tools, and unclear/unstandardised metrics. As a result, addressing these three challenges was an ever-present feature throughout the development of the NCT. With regards to data accessibility, the team exclusively uses open-access datasets that require no capital investment or permit. This will ensure free-to-use access for users and will make it so that anyone who wants to develop a tool for themselves using the NCT's scripts will be able to do so without the requirement for specific permits. The remaining two challenges – integration of natural capital tools and unclear metrics – overlap somewhat in that they refer to the generally unstandardised approach to natural capital tool development. The reasons for this are numerous, but are mainly the result of natural capital tools often being developed by private institutions who have access to different datasets and methods of analysis. While the NCT does not have any formal integration with other natural capital tools, NatureScot has engaged with organisations who have developed natural capital tools and the team is keen to provide better and more intuitive signposting between natural capital tools on the market. With regards to unclear metrics, NatureScot is providing metrics in relative, biophysical, and economic terms. In this way, the team hopes that all users will be provided with metrics that they can understand and that they want/require for specific purposes.

In terms of opportunities, two emerged that were linked to the challenges discussed above – accessibility and standardisation. Furthermore, following discussions about current gaps in the natural capital tool market, two other opportunities were raised by stakeholders – access to finance and opportunity mapping. Firstly, access to finance was raised due to emerging opportunities as a result of increased capital investment in nature-based interventions, and stakeholders felt that current natural capital tools were not facilitating this access. Additionally, stakeholders highlighted that they did not have the capacity to identify and visualise ecosystem services and opportunities. These two opportunities formed the basis on which the NatureScot team drove tool development, ensuring that the NCT offered new opportunities within the natural capital tool market. As a result of this feedback, opportunity mapping now forms a core part of the NCT and frames the intervention stage by highlighting areas in which there are opportunities to boost ecosystem services. This particular feature solidifies the NCT's aim of providing a service that other natural capital tools do not provide, a key finding from NatureScot's review and stakeholder engagement.

Embedding the NCT within the green/nature finance market was a priority of the co-design group, and the team believed it to be an important step in connecting new sources of funding and farmers, land managers, and landowners. NatureScot has addressed this opportunity in multiple ways:

- Providing users with economic valuations of uplift in ecosystem services as a result of interventions; in providing economic valuations, investors would be able to see the returns to be expected following the implementation of certain interventions
- The report generated upon completing each stage of the NCT: users will be able to evidence expected uplift to funders in a printable, HTML format, allowing for better communication between users and funders

There is yet to be formal links between the NCT and sources of funding, and this will be a focus of the NatureScot NCT project following the tool's launch in summer 2025.

Environmental baseline

The NCT relies on publicly available, national datasets for mapping and modelling. Underpinning the tool is the habitat baseline, a bespoke nationwide habitat and land cover map. The habitat baseline was created from the OS MasterMap Topography Layer and augmented with additional data sources: CORINE Land Cover; Scotland Habitat and Land Cover Map (SLAM); Habitat Map of Scotland (HabMoS); OS MasterMap Greenspace Layer; OS Open Greenspace; National Forest Inventory (NFI); and the Scottish Crop Map (Appendix 1). The OS Terrain 50 digital terrain model (DTM) is incorporated to add slope and elevation data, and the 2011 Census of Scotland and 2020 Scottish Index of Multiple Deprivation (SIMD) are used to assign household population, heath scores, and risk groups. Users are currently unable to import personal/local data sources into the tool.

Habitat classification

To create the habitat baseline, a series of classification steps are applied to identify the most likely habitat in an OS MasterMap polygon. A first pass is made using only OS MasterMap Topography information. This is the authoritative mapping for Great Britain and is very accurate in the built-up environment. However, it lacks detail in the natural environment, so broad habitat categories (e.g. grassland, heath, agricultural land, etc.) are assigned based on the descriptive term attributes.

Subsequent steps use more specialised datasets to conditionally update relevant habitats. Refinements are made when the broader, first-pass category is compatible with the new information. For instance, a copse of trees categorised as woodland by OS MasterMap will not change if CORINE or SLAM indicates arable land – these datasets are coarser in resolution and likely to miss small features. The national datasets in the baseline have different strengths:

- SLAM and HabMOS: most habitats come from these datasets and they play a key role in classification, but they are not allowed to override codes already assigned with precision by MasterMap (e.g., built-up areas and water)
- NFI: applies to woodland codes only
- CORINE and Scottish Crop Map: distinguish arable land from pasture
- OS MasterMap Greenspace Layer and OS Open Greenspace: identify and distinguish uses of greenspace

After assigning a possible habitat type, the final step is to improve the classification through a set of heuristic rules. For example, grasslands on steep slopes are classified as unimproved grassland rather than arable, and heath at high elevation is classified as montane heath.

OS MasterMap offers very fine resolution in urban and peri-urban areas, but polygons often cover very large areas in the uplands. To improve resolution and allow for more granular identification of habitats, the SLAM map was used to divide large upland OS MasterMap polygons into smaller polygons based on SLAM habitat type. 'Large polygons' were defined as having an area of 1 km^2 or greater. This excluded the following broad habitat categories: "Inland Water", "Tidal Water", "Trees" and "Agricultural". The minimum size for a SLAM geometry (after polygonising/vectorising) to be considered for intersection was 4000 m^2, which is equivalent to 10 raster grid cells. This threshold was selected to avoid the intersection of very small individual polygons within the final basemap.

The baseline classification was applied following the intersection of OS MasterMap and SLAM. This means that SLAM-derived geometries/polygons in the baseline will not always receive a SLAM classification; all polygons go through the same habitat classification process as the original OS MasterMap polygons. This produced a more realistic habitat mosaic containing patches of exposed rock, bog/fen, and grassland. Because SLAM data is created in a raster format, upland polygons that were subdivided based on SLAM have a 'rasterized' or blocky appearance.

The broad habitat type of each polygon appears when users hover over the habitat baseline in the online tool interface. These are derived from the HabBroad category of the habitat lookup table. In addition to habitat type, users can also see median peat depth for each polygon. The median depth value from the 'Scotland soil carbon & peat depth' raster dataset (Aitkenhead & Coull, 2020) was extracted to each baseline polygon, along with the percentage coverage of peat at different depths.

<u>Habitat codes</u>

Each dataset comprising the habitat baseline was assigned a Phase 1 habitat code, regardless of the original habitat or land use classification system. EcoservR models were originally written to accept Phase 1 habitat codes, but in the future these models will be rewritten to accept EUNIS codes. Under the INSPIRE Regulations 2009, the use of EUNIS and Annex 1 habitat codes is required to align with the Q-FAIR principles (Quality, Findable, Accessible, Interoperable, Reusable). In most instances, habitats are displayed in the NCT as broad descriptive categories rather than using a specific habitat classification system.

<u>Socioeconomic data</u>

The habitat baseline attribute table also contains metrics specific to each polygon, which are derived from Scotland's Census 2011 or the Scottish Index of Multiple Deprivation (SIMD) 2020, or both. These are:

- 'HousePop' - Population estimates at postcode level were taken from Scotland's Census 2011, with results aggregated at Output Area level. SIMD 2020, which is at Data Zone level (broader than Output Area level), was joined to Output Area with a lookup (so several neighbouring Output Areas can have different population estimates but same the SIMD values).
- 'Health' - The health index taken from SIMD is HlthCIF, the Comparative Illness Factor (CIF). CIF is a combined count of the total number of people claiming one or more of: Disability Living Allowance, Attendance Allowance, Incapacity Benefit (not receiving DLA), Employment and Support Allowance, Severe Disablement Allowance, Income Support with disability premium, Personal Independence Payment, and Universal Credit claimants with an accepted restricted ability to work.

- ‘Riskgroup’ - Age estimates were taken from Scotland's Census 2011, with ages 65 considered groups at risk (for example, in the context of heat stress). A proportion of these age groups was calculated at the Data Zone level.

Socioeconomic data cannot be updated to the 2022 Census of Scotland until the newest SIMD is published in 2026. The 2020 SIMD dataset is based on the 2011 census Data Zones; the next iteration of the SIMD will be based on the 2022 census Data Zones (Office of the Chief Statistician, 2024).

Ecosystem service models

The habitat baseline, in conjunction with other national and publicly available spatial and non-spatial datasets, is used to model the provision and demand for ecosystem services across Scotland. Ecosystem services are the benefits people receive from the environment, and these can be boosted using a natural capital approach. The tool currently evaluates the impact of land use change on seven ecosystem services:

- Air quality improvement
- Access to nature
- Carbon sequestration
- Climate regulation
- Inland flood mitigation
- Insect pollination
- Noise regulation

These ecosystem service models originated in Ecoserv-GIS and EcoservR, and it was confirmed during the co-design process that they should be adapted for use in the NCT. Coastal flood mitigation, river cooling, and food provision were identified by the co-design group as additional ecosystem service models to include in future iterations of the tool.

The outputs of the ecosystem service models are three types of ecosystem service layers: capacity, demand, and opportunity layers. Capacity layers display the modelled ability of land to provide ecosystem services, while demand layers display the modelled need for ecosystem services in a given area. Opportunity layers display modelled opportunities to increase the provision of ecosystem services through a change in habitat type. Opportunities typically represent areas of lower capacity and higher demand for an ecosystem service.

The potential for development of coastal flood mitigation and river cooling models that follow the capacity/demand/opportunities framework of the NCT is being explored; currently, spatial data from the NatureScot Dynamic Coast project and the Scotland River Temperature Monitoring Network (SRTMN) are available in the tool as ‘context layers’. These pre-existing, publicly available datasets can be added to maps in the tool to provide additional context to support a natural capital approach to decision making.

<u>Ecosystem service model types and outputs</u>

The outputs of the capacity and demand models are score maps, often in the form of a heatmap. Scores are relative values that represent areas of high and low capacity or demand for an ecosystem service. Models that incorporate focal statistics output heatmaps, while other models output score maps that are more closely tied to habitat types. The scores do not relate to biophysical or economic values of natural capital.

All baseline capacity and demand layers can be viewed in Step 2 of the NCT under the Advanced tab. These layers have a generic colour scale showing low to high capacity or demand for the service. The scale is generated relative to the study area, with the lowest and highest values for a specified service in the study area set as the minimum and maximum values of the scale.

Opportunity models also output a score map. Most opportunity models output scores of 0 or 1, where a score of 1 is a potential opportunity to increase the provision of the ecosystem service through an intervention. Scores of 0 represent areas that may be less suitable for an intervention to provide the service; they are not displayed in the layer.

After making interventions in Step 3 of the NCT, the capacity models are re-run to calculate uplift of the ecosystem services. The average capacity values (or in the case of carbon sequestration, the sum) are calculated for the study area before and after the interventions are made, and the values are displayed in the Results table in Step 4 of the tool. Uplift is calculated as the percentage change in the capacity of the study area to provide the ecosystem service. The baseline and post-intervention capacity heatmaps are displayed in Step 4 under the Score Maps tab.

Additional models in the tool allow for the calculation of biophysical and economic values for select ecosystem services. These are not directly related to the capacity and demand models of the same name, and they do not follow the capacity/demand/opportunities framework or produce spatial outputs. Biophysical and economic values are modelled for the study area and displayed in the Results table of Step 4 of the NCT. Like the ecosystem service capacity models, the biophysical and economic values are calculated from the habitat baseline before and after habitat interventions are made. The resulting uplift is presented in the Results table as a conservative estimate of the social (community) benefit delivered by each ecosystem service.

Ecosystem service model parameters

Each ecosystem service model takes in a number of parameters, including the habitat baseline, additional datasets, and other fixed parameters (Tables 2 and 3). Habitat-specific parameters, such as carbon sequestration values and movement costs, are drawn from the habitat lookup table (see the About section of the NCT). All other parameters are supplied to the ecosystem service models as datasets or fixed default values. These default values can be adjusted if running the models independently with the *natcaptool* R package. Some model parameters were adopted from EcoservR, if appropriate within a Scottish context and in line with current knowledge, and others were brought forth in the ecosystem service model workshops by subject matter experts.

The ecosystem service capacity models use a variety of approaches to model ecosystem service provision, including cost distance modelling, focal statistics, and applying literature-derived values to the landscape. The ecosystem service demand models, with the exception of insect pollination, take a more standardised approach: a series of “indicators” are generated, and the sum of the weighted indicator scores is the overall demand score. Indicators of demand typically include the population density, mean health deprivation score, and distances from a feature of interest (e.g., roads, greenspaces, noise sources; Table 3). The score for each pixel is calculated using focal statistics, with a focal window of 300 m representing the local area (Winn et al., 2018).

Opportunity models require three main inputs: the spatial outputs of the corresponding capacity and demand models; threshold values of ‘low’ capacity and ‘high’ demand; and locations of land use types that should be excluded as opportunities for land use change. The model locates areas where low capacity and high demand for the ecosystem service overlaps, then eliminates areas that are not suitable for interventions.

Constraints

Land use types that are not suitable for interventions are referred to as constraints. The following constraints are identified in the baseline or from additional datasets, and these areas are excluded from the opportunity models:

- Built-up areas
- Railway, roads, paths, pavements
- Power lines
- Monuments and battlefields
- Ancient woodland
- Freshwater, intertidal, saltmarsh
- Gardens and allotments
- Tennis courts, bowling greens, playing fields

This is not an exhaustive list of habitats and land use types that may be unsuitable for interventions. Likewise, areas of land in some of these categories may be suitable for interventions in some instances. While large areas of land may be highlighted as opportunities, it is not implied that the entire area could or should be converted to a new land use type; opportunities are starting points for taking a natural capital approach to land use change.

Table 2. A summary of the parameters and datasets/maps used to model the capacity of an area to provide an ecosystem service ('capacity').

Ecosystem service	**Parameter**	**Dataset / Default values**
Access to nature	Protected areas	NatureScot Protected Areas WMS[1]
Access to nature	Core paths	Improvement Service Core Paths[2]
Access to nature	Path buffer: distance (m) of buffer around paths	100 m
Access to nature	Minimum area requirement (m^2) for which a patch can provide a service	100 m^2
Access to nature	Radius (m) for focal stats at local range	100 m
Air quality improvement	Maximum distance (m) from habitats to define areas where service occurs	100 m

[1] https://opendata.nature.scot/maps/snh::naturescot-protected-areas-wms/about
[2] https://data.spatialhub.scot/dataset/core_paths-is

Ecosystem service	Parameter	Dataset / Default values
Air quality improvement	Radius (m) for focal stats at short range	20 m
Air quality improvement	Radius (m) for focal stats at local range	100 m
Air quality improvement	Minimum area requirement (m^2) for which a patch can provide a service	100 m^2
Carbon sequestration	Carbon sequestration rates (t CO_2 equivalents ha^{-1} y^{-1})	Natural England Carbon Storage and Sequestration by Habitat[3]
Climate regulation	Radius (m) for focal stats at local range	300 m
Inland flood mitigation	Soil Percent Run-off (SPR)	Map of runoff risk (partial cover)[4] National soil map of Scotland (disaggregated)[5]
Inland flood mitigation	Minimum area requirement (m^2) for which a patch can provide a service	500 m^2
Inland flood mitigation	Habitat roughness	0-1 scale derived from Manning coefficient[6]
Inland flood mitigation	Terrain slope (DTM)	OS Terrain 50
Insect pollination	Minimum area requirement (ha) to be source habitat	0.5 ha
Insect pollination	Maximum pollinator travel distance	2214 m
Insect pollination	Distance into a habitat that is considered a source habitat of pollinators	20 m
Noise regulation	Radius (m) for focal stats at short range	20 m
Noise regulation	Radius (m) for focal stats at local range	100 m
Noise regulation	Minimum area requirement (m^2) for which a patch can provide a service	500 m^2

[3] Gregg et al., 2021
[4] Lilly & Baggaley, 2018
[5] Gagkas & Lilly, 2024
[6] Liu & Smedt, 2004

Table 3. A summary of the parameters and datasets/maps used to model the demand for an ecosystem service to be provided in a given area ('demand').

Ecosystem service	**Parameter**	**Dataset / Default values**
Access to nature	Minimum population density	5 people / hectare
Access to nature	Indicator weights	Distance to greenspace = 1 Population = 0.5 Health = 0.5
Access to nature	Radius (m) for focal stats at local range and threshold for distance to greenspace	300 m
Air quality improvement	Radius (m) for focal stats at local range	300 m
Air quality improvement	Indicator weights	Distance to roads = 1 Manmade surfaces = 1 Population = 1 Health = 1
Air quality improvement	Minimum population density	5 people / hectare
Air quality improvement	Source of pollution	OS Open Roads
Air quality improvement	Road type	OS Open Roads
Climate regulation	Radius (m) for focal stats at local range	200 m
Climate regulation	Built-up areas	OS Built Up Areas
Climate regulation	Minimum area (km^2) for a built-up area to have a heat island effect	10 km^2
Climate regulation	Minimum population (number of residents within 'local' distance) for which there is a demand	50
Climate regulation	Indicator weights	Distance to roads = 1 Manmade surface = 1 Population = 1 Health = 1
Inland flood mitigation	Flood risk	SEPA[7] River Flooding

[7] Scottish Environmental Protection Agency

Ecosystem service	Parameter	Dataset / Default values
Inland flood mitigation	Radius (m) for focal stats at local range	300 m
Inland flood mitigation	Minimum population density	5 people / hectare
Inland flood mitigation	Indicator weights	Flood extent = 0.5 Asset ranking = 0.25 Population = 0.25
Insect pollination	Minimum area requirement (ha) to be considered as having demand	0.5 ha
Insect pollination	Distance from habitats requiring pollination	2214 m
Insect pollination	Habitat type (high demand areas, i.e. arable land)	Scotland Crop Map[8]
Noise regulation	Distance threshold (m) for noise attenuation from noise sources	Motorway = 800 Dual carriageway = 600 Primary = 550 Railway = 650 Airport = 1500
Noise regulation	Radius (m) for focal stats at local range	300 m
Noise regulation	Minimum population density	5 people / hectare
Noise regulation	Indicator weights	Distance to roads = 1 Population = 0.5 Health = 0.5

Access to nature

Access to nature is defined in the NCT models as natural areas present within a short walk from dwellings. The capacity of an area to provide access to nature is dependent on natural environments connected to local dwellings by paths and pavements. The capacity model first identifies greenspaces, areas of foreshore, and protected areas within 100 m of a path network. Greenspaces are defined as any polygons assigned a Green Infrastructure designation of 'Natural' in the baseline (Winn et al., 2018). Foreshore includes most areas of the coast, identified from baseline polygons with 'Foreshore' listed as part of the Term attribute. Protected areas include Geological Conservation Review sites, Local Nature Reserves, National Nature Reserves, Ramsar Wetlands of International Importance, Sites of Special Scientific Interest (SSSIs), Special Areas of Conservation, and Special Protection Areas (Appendix 2). 'Paths'

[8] Rural and Environmental Science and Analytical Services (RESAS), 2021

include paths and pavements derived from the habitat baseline and core paths identified in the Core Paths dataset.

Any greenspaces and protected areas within a 100 m buffer of paths are considered to provide access to nature as an ecosystem service. The model then applies focal statistics at the local (300 m) range to determine the spatial extent of this benefit in the landscape. Patches of accessible greenspace below 500 m^2 are identified and masked out, as they are not considered large enough to provide the service (Winn et al., 2018). While core paths, pavements, and accessible shoreline are selected as a measure of access, these paths may vary in their degree of accessibility. Conversely, not all 'paths' may have been captured in the habitat baseline.

Demand for access to nature is modelled from three indicators: distance to greenspace, population size, and population health. Areas further from greenspaces with a high population and low mean health score will have very high demand for access to nature. Greenspaces are defined in this model as public or restricted green infrastructure (GI; habitat baseline *GI* values of "Public" or "Restricted") and non-private undetermined greenspace (*GI* value of "Undetermined Greenspace" and *GIpublic* value of N/A). The following land use types comprise public and restricted green infrastructure:

- Amenity
- Public Park Or Garden
- Cemetery
- Play Space
- Religious Grounds
- Camping Or Caravan Park
- Bowling Green
- Golf Course
- Tennis Court
- Other Sports Facility
- School Grounds
- Allotments Or Community Growing Spaces

Undetermined greenspaces are all other greenspaces that are not classified as green infrastructure (e.g., woodlands, grasslands, etc.). Only undetermined greenspace not classified as private is considered accessible; this excludes areas identified as "Agricultural Land" in the habitat baseline field *Term*. While access rights often allow for walking along field margins in Scotland, this model considers greenspace as natural areas where people may come to spend time. The demand model searches for 2 ha greenspaces within a 300 m radius, which is representative of a 5-minute walk (Handley et al., 2003; Winn et al., 2018).

Opportunities to increase access to nature exist in places with high demand for the service and low capacity to provide it, where paths are already a short distance away. The model first identifies where demand values in the top quartile nationally intersect with areas where there is no capacity to provide the service. A mask of the existing path network, with a 100 m buffer, is applied to find opportunities for improving or adding natural areas with good access. Finally, areas designated as constraints are removed.

<u>Air quality improvement</u>

Air quality capacity reflects the ability of vegetation to trap particulate matter (i.e., acting as a physical barrier between sources of pollution and people). Each habitat is assigned a value from a lookup table which describes the ability to trap particulate matter (Winn et al., 2018).

Habitats with a score of 0 are removed, while habitats with a score greater than 0 are buffered by 100 m; this distance represents the area in which air quality may be improved by the proximity of a natural habitat. The focal sum is calculated at a short (20 m) and local (100 m) range, and these values are summed to create a capacity score. A functional mask is then applied to remove patches that likely do not provide the ecosystem service: those with an area less than 100 m^2, and those where 10% of pixels in a 100 m radius have a capacity score of less than 10. This model does not consider the potential dispersion effects of vegetation presence, therefore, it is important to consider the local air quality demand and wider context when utilising these values (DEFRA, 2018).

Demand for air quality improvement is determined by four equally weighted indicators: distance to major roads, proportion of man-made surfaces, population, and health. To create the distance to major roads indicator, roads classified as either 'Motorway' or 'A Road' in OS Open Roads are selected and buffered by 40 m. This selection is then used to filter major roads from the habitat baseline by searching for intersections with road polygons (habitat code J511). A raster is created by calculating the distance of each pixel to a major road, up to 300 m from the road. These scores are then rescaled and transposed to reflect that areas closest to major roads have the highest demand for air quality improvement:

$$distance\ to\ major\ roads = 1 - \frac{log_{10}(distance\ to\ road + 1)}{log_{10}(300\ m)}$$

The proportion of man-made surfaces indicator is created from the *HabClass* field of the habitat lookup. Habitats classified as either 'Urban' or 'Infrastructure' are selected from the baseline and assigned a value of 1. The proportion of land identified as one of these classes within a 300 m radius is calculated from the focal sum.

The population indicator is created by summing the household population of each house in a pixel. Houses are identified as habitat code J360 (domestic buildings), and household population is assigned from the *housePop* field of the habitat baseline. The final population indicators score is the focal sum of the household population within a radius of 300 m. This score is then rescaled with a square root transformation as values from 0-1, where 1 is the highest value of the score nationally.

The health deprivation indicator is created by calculating the mean health deprivation score for all houses in a pixel. Like the population indicator, the health deprivation score for each household is assigned from the *health* field of the habitat baseline. The final score is the focal mean of the health deprivation score, calculated over a radius of 300 m. This score is then rescaled with a min/max transformation as values from 0-1, where 1 is the highest value of the score nationally.

The final demand score for air quality improvement is a sum of the four indicator scores. The co-design group identified that demand for air quality improvement may be highlighted along major roads in sparsely populated rural areas, despite air quality there being very high. To prevent these areas showing high demand, a mask is applied to remove areas where the population density is less than 5 people per hectare.

Opportunities for improving air quality follow the standard approach: areas where there is overlap with demand scores in the top quartile and capacity scores in the bottom quartile are selected. Constraints are excluded.

Carbon sequestration

Carbon sequestration is the ability of land to capture and store carbon dioxide (CO_2). Each habitat in the baseline is assigned a carbon sequestration value (tonnes of CO_2 equivalents emitted or sequestered per hectare per year); this forms the basis of the capacity layer. Carbon sequestration rates are converted to tonnes of CO_2 emitted or sequestered per pixel per year, and the total carbon sequestration capacity is the sum of the annual carbon sequestration for each pixel in the study area.

Most carbon sequestration rates are based on those compiled by NatureScot or Natural England (Gregg et al., 2021; NatureScot, 2025). Mean carbon sequestration rates for woodlands were calculated based on the Woodland Carbon Code (Woodland Carbon Code, 2025). For any habitats missing from these sources, carbon sequestration rates are assigned NA (equivalent to 0).

There is no corresponding demand layer for carbon sequestration, as demand for this service is considered to be universal. An opportunity layer was created to enable the inclusion of carbon sequestration as a benefit derived from woodland, but it is not displayed in the tool. The layer does not represent spatially optimised opportunities for carbon sequestration, instead highlighting areas of land where tree planting may increase the rate of carbon sequestration. In addition to the standard constraints applied to other opportunity layers, the Carbon and Peatland 2016 map was also used to exclude areas of soil classes 1, 2, and 3 as opportunities for tree planting. These areas of carbon-rich soils, deep peat, and peatlands are already good carbon sinks, and disturbing carbon-rich soils with planting can lead to carbon emissions (Scottish Natural Heritage, 2016; NatureScot, 2025).

Climate regulation

Climate regulation capacity reflects the ability of vegetation to reduce air temperatures in the immediate area. To calculate the capacity score, habitats identified in the habitat lookup table as being in *HabClass* “Woodland and scrub” or “Water” are assigned a score of 1; all other habitats are assigned a score of 0. The focal sum is then calculated using a radius of 200 m to produce a capacity score. However, patches of habitat will likely not provide climate regulation as a service over a distance of 200 m. To account for this, a series of masks is created:

- Patches < 20,000 m^2 are buffered by 20 m
- Patches from 20,000-50,000 m^2 are buffered by 40 m
- Patches from 50,000-100,000 m^2 are buffered by 80 m
- Patches > 100,000 m^2 are buffered by 100 m

The width of the buffer reflects that smaller patches of habitat likely only have the capacity to regulate temperate over short distances (Winn et al., 2018). Capacity scores outside of these buffers are set to 0.

Climate regulation demand is determined by three equally weighted indicators: proportion of manmade surfaces, population, and health. To determine the proportion of manmade surfaces, habitats of the *HabClass* “Urban” and “Infrastructure” are selected from the basemap and assigned a score of 1; all other habitats are assigned a score of 0. The focal sum is then calculated with a radius of 200 m. The resulting raster shows the proportion of manmade surfaces within a 200 m radius of each pixel.

Unlike other demand models, the population indicator for this model is weighted by the proportion of the population that are 65 and older. This group has a greater risk of health problems related to high temperatures. The indicator is created from two raster layers: the sum of the household population per pixel, and the mean risk score per pixel. Like in the air quality improvement and noise regulation models, the population is obtained by summing the household population for each house in a pixel; the household population is stored in the *housePop* field of the habitat baseline. To obtain the mean risk score, the *riskgroup* value is assigned from the habitat baseline to each house, and the mean value per pixel is calculated. The population score is the focal sum of the household population, and the health risk score is the focal mean of the risk scores, both calculated at a radius of 200 m. To limit demand in sparsely populated areas, population scores of less than 50 are dropped. The population score is then multiplied by the health risk score to create the final version of the population weighted by risk group indicator. These scores are rescaled from 0-1 using a min/max transformation, where 1 is the highest value nationally.

The third indicator, the health deprivation score, is calculated in the same manner as described in Air Quality Improvement. The focal mean is calculated for a radius of 200 m.

Each of the three demand indicators are masked to built-up areas greater than 10 km^2. This reflects the need for cooling where manmade surfaces could create a heat island effect (Winn et al., 2018). The OS Open Built Up Areas dataset is used to identify built-up areas; patches of built-up areas greater than 10 km^2 comprise the mask. The final demand score is the sum of the three indicators.

Opportunities for climate regulation follow the standard approach: areas where there is overlap between demand scores in the top quartile and capacity scores in the bottom quartile are identified as opportunities. Because the capacity model identifies only woodland, scrub, and water as contributing to a local cooling effect, the capacity to provide climate regulation is 0 in the bottom two quartiles. Constraints are excluded.

<u>Inland flood mitigation</u>

Inland flood mitigation capacity is defined in this model as the ability of the landscape to slow the flow of runoff. It was adapted from the Ecoserv-GIS capacity model for water purification, which represented the capacity of land to intercept and slow water runoff through slope and ecosystem vegetation type (Winn et al., 2018). The EcoservR model added Standard Percentage Runoff (SPR) as an optional parameter to account for the impact of soil type on runoff. The NCT model takes in all three inputs: a digital terrain model (DTM) to calculate slope percent; Manning’s roughness coefficients assigned to habitat types to estimate vegetation roughness

(Liu & Smedt, 2004; Winn et al., 2018); and SPR values to estimate soil permeability (Gagkas & Lilly, 2024).

Slope percent is derived from OS Terrain 50, a DTM with 50 m resolution. The *terrain* function in the R package *raster* is used to calculate percent slope, and the raster is then reclassified to assign scores based on steepness (Table 4; Winn et al., 2018). Very steep slopes have a poor ability to slow the flow of runoff, while flat and gently sloping areas have a much higher ability.

Table 4: Slope reclassification values (from Winn et al., 2018)

Slope percent	Slope category	Value
0 – 5	Flat	1
5 – 8	Gentle	0.85
8 – 15	Sloping	0.7
15 – 25	Moderate	0.6
25 – 35	Steep	0.3
35 – 45	Very steep	0.2
45 – 90	Extreme	0.1

Each habitat type in the habitat lookup table is assigned a roughness score (in the field *Rough*; Winn et al., 2018). Structurally complex habitats such as woodlands and wetlands have higher roughness scores and are better able to slow the flow of water. Structurally simple habitats such as grasslands have a lower roughness score, while rocks and manmade surfaces have a roughness score of 0.

SPR values are based on two James Hutton Institute runoff risk maps: the map of runoff risk (partial cover) and a nationwide runoff risk map developed through spatial disaggregation (Gagkas & Lilly, 2024). Both maps allocate soils to a Hydrology of Soil Type (HOST) soil class to determine the SPR value (Boorman et al., 1995). The SPR values are then classified as low, moderate, or high runoff risk: < 20%, 20-40%, and > 40% runoff, respectively. To create the SPR map for the inland flood capacity model, gaps in the partial cover runoff risk map were filled with values from the disaggregated soil series map. A weighted SPR value was then applied to each of the three classes: 10.50%, 32.00%, and 54.52% (Z. Gagkas, personal communication, 20 January 2025). Urban areas without an assigned runoff risk class were classified as a runoff risk of 100%.

To model the capacity of an area to slow the flow of runoff, values of the three indicators are multiplied. This differs from the ecosystem service demand model indicators, which are rescaled to values of 0-1 and then summed. This allows areas with a roughness score of 0 or an SPR value of 100% to provide no capacity for slowing the flow of runoff. High values indicate areas with a high capacity to slow the flow of runoff: areas with a low slope, high roughness score, and low runoff risk will score the highest.

Roughness is the only parameter that is assumed to change following an intervention. The NCT interface cannot be used to model how changes to slope or SPR may impact the capacity of land to provide flood mitigation, as these parameters are not associated with a specific habitat type. To run the model with changes to SPR or elevation, or to input a custom SPR dataset, use the *natcaptool* R package.

Demand for inland flood mitigation is modelled as areas where flooding from rivers may negatively impact people and infrastructure. Three indicators contribute to the demand score: flood extent, vulnerability of assets, and population size. These are weighted 2:1:1, respectively. A weighted sum of the rescaled indicators is the final demand heatmap output.

Flood extent is scored from SEPA Flood Map Version 3.0 flood extent maps. Areas of high likelihood for river flooding are scored 3, medium likelihood areas are scored 2, and low likelihood areas are assigned a score of 1.

Vulnerability of assets is scored based on the SEPA *Flood Risk and Land Use Vulnerability Guidance* (SEPA, 2024). The guidance categorises land uses and developments into the categories most vulnerable, highly vulnerable, least vulnerable, essential infrastructure, and water compatible. Assets in the highly vulnerable, least vulnerable, and essential infrastructure categories are identified in the baseline (Table 5). Future work is planned using the asset categories in Open Street Map to identify buildings that fall into the most vulnerable category (e.g., hospitals and schools); this feature is available in the *natcaptool* R package.

Table 5: Assets identified in the habitat baseline map and their vulnerability score

Highly vulnerable (3)	Least vulnerable (2)	Essential infrastructure (1)
-Built-up areas (domestic) -School grounds -Camping/caravan parks -Institutional grounds -Landfills	-Improved grassland -Arable land -Built-up areas (commercial, farm buildings) -Orchards -Mineral workings	-Roads, tracks, and paths -Railways -Bridges -Communication infrastructure -Electricity infrastructure -Wind turbines

Inland flood mitigation opportunities are not limited to serving demand in a given study area. Instead, opportunities reflect the need for flood mitigation further downstream in a catchment. The model first identifies patches of land greater than 0.5 ha where demand for inland flood mitigation is high (in the third quartile of demand values, nationally). The upstream contributing area for each patch, where run-off will flow downstream over a patch, is modelled in R using the package *whitebox* (Wu & Brown, 2022; Lindsay, 2016). Areas that are unsuitable for significant changes in habitat type, such as built-up areas and sports fields, are then removed as opportunities. Areas that already provide some natural flood mitigation (i.e., a capacity score greater than the national median value or woodlands, bog, fen, and swamp habitats) are also removed as opportunities. Patches of demand located downstream will have much larger contributing areas than patches upstream; the number of overlapping upstream contributing areas is summed to create an opportunity score. The resulting output is indicative of areas where natural flood mitigation measures in the study area may improve inland flood mitigation in one or more areas further downstream.

Insect pollination

While most of the ecosystem service models in the NCT calculate capacity and demand scores using focal statistics, the insect pollination capacity and demand models apply a cost distance approach. This method takes in a list of target habitats from which to calculate 'paths' into the landscape that insect pollinators may reasonably travel (Briers, 2011). This is a change from the original version of EcoservR, which estimated pollination capacity using a visitation probability model (Schulp et al., 2014; Winn et al., 2018). A cost distance approach using the *costDist* function in the R package *terra* (Hijmans, 2025) was implemented to improve the speed of the model.

The insect pollination capacity model first identifies target or 'source' habitats in the study area. Source habitats are those that serve as nesting habitat for insect pollinators: unimproved grassland, montane heath, and most semi-improved grassland habitats. Woodland is also considered source habitat up to 20 m from the woodland edge when it is next to another source habitat, representing the area of transition into a dense stand. A size threshold of 0.5 ha is applied to exclude small patches of source habitat. Every habitat type is then assigned a cost between 0-50, representing the difficulty for a pollinator to travel 10 m (one pixel); source habitat has a cost of 0, while dense urban areas have a cost of 50 (Blake & Baarda, 2018).

The capacity model allows insect pollinators to travel a maximum distance of 2214 m (221 pixels) through non-source habitat. This value is equal to the distance from source pollinator habitat at which native pollinator visitation rate is 10% of its maximum (Ricketts et al., 2008). When a pollinator encounters a habitat type that has a movement cost greater than 0, its total movement is reduced by a factor of the movement cost. For example, broadleaved woodland has a pollinator movement cost of 20; for every 10 m travelled, the pollinator loses 200 m from its maximum distance. Movement is allowed in eight directions from source habitat into neighbouring pixels, and each pixel of non-source habitat is assigned the shortest cost distance from a source habitat pixel. Cost distance values above 2214 m are removed.

While the capacity model estimates how far pollinators can travel outward from their source habitat, the demand model highlights which habitats are within travel range of an area in need of pollination. Using the same travel costs, the cost distance model calculates how far pollinators may travel to reach areas with demand of pollination: arable land, horticulture, and large public gardens. Pollinators are again assigned a total movement cost of 2214 m, and a patch in need of pollination must be at least 0.5 ha.

The opportunities model combines these two aspects, finding areas where capacity and demand overlap, minus a pre-defined layer of constraints (for example, homes). The resulting layer shows areas where the creation of new source habitat would have connectivity both to existing source habitat and areas of demand.

It is important to note that pollinator populations are affected by many factors outwith land use, such as climate and disease. The NCT pollination model does not account for pollinator population dynamics, although these dynamics will undoubtedly impact the effectiveness of interventions to increase pollinator habitat.

Noise regulation

Noise regulation capacity reflects the ability of vegetation to reduce noise pollution. Each habitat type is assigned a noise regulation score from the habitat lookup table, which describes its ability to provide this service (Winn et al., 2018). The scores range from 0-100, with woodlands and other habitats with trees scoring the highest. The focal sum of the noise scores is calculated at the short (30 m) and local (300 m) range, and these values are summed to create the capacity score. Patches of habitat with capacity scores above 0 but that are less than 500 m^2 are considered not to provide the service, and they are assigned a score of 0. Very low capacity scores are also removed by applying a functional mask: a pixel is considered to have no capacity to provide the service if more than 10% of pixels in a 300 m radius have a capacity score of less than 10.

Noise regulation demand is scored based on three indicators: distance to noise sources, population and health. To create the first indicator, major roads, airports, and railways are defined as noise sources. These features are identified from OS VectorMap, with major roads including roads that are classified as 'Motorway', 'A Road' or 'Minor Road' in the dataset. Motorways are buffered by 15 m, airports are buffered by 500 m, and railways, minor roads, and A roads are buffered by 5 m. Within these buffered areas, each pixel is assigned its distance from the noise source. The scores are then converted to $\log_{10}$, and the inverse of the score is calculated to reflect that noise is greatest next to the source:

$$distance\ to\ noise\ source = 1 - \frac{log_{10}(distance\ to\ noise\ source + 1)}{log_{10}(buffer\ distance)}$$

A raster layer is produced for each of the five noise sources, and the five layers are summed to create the distances to noise sources indicator. The population and health indicators are created as described in Air Quality Improvement.

The three indicators are summed to create the score map for noise regulation demand. Distance to noise sources is given a weight of 1 to reflect that proximity to noise sources drives demand for noise regulation, and the population and health indicators are each weighted 0.5. To prevent very sparsely populated areas from scoring highly, demand for noise regulation is set to 0 in areas that do not meet a population threshold of 5 people per hectare.

Opportunities for noise regulation follow the standard approach: areas where there is overlap between demand scores in the top quartile and capacity scores in the bottom quartile are displayed as opportunities. Constraints are excluded.

River Cooling

Opportunities for river cooling are derived from the Scotland River Temperature Monitoring Network (SRTMN) – Riparian Woodland Prioritisation Scores (Jackson et al., 2018; Jackson et al., 2021). The data layer *Nationally scaled tree planting prioritisation score where trees are planted on both banks* assigns a rank to rivers based on where the creation of riparian woodland will have the greatest benefit for river temperature. We used this layer to identify and highlight the riverbank along stretches of rivers with tree planting prioritisation scores in the top quartile. Rivers were buffered by 30 m and then masked to leave only the riverbank as opportunities, and all opportunities were assigned a score of 1 (Feld at al., 2018; Ogilvy et al., 2022). This layer is not displayed in the Natural Capital Tool, but it is included as a benefit from broadleaved woodland in the Multiple Benefits from Broadleaved Woodland layer.

Like other opportunities layers, constraints were excluded as opportunities for riparian planting. Other factors that may make an area unsuitable for riparian planting, such as the presence of wetlands, species-rich grasslands, and reedbed and tall herb communities important for wildlife, have not been considered (Farm Advisory Service, n.d.). Riparian planting opportunities are only applicable to native trees and shrubs or other ecologically appropriate broadleaved trees (Forest Research, 2023).

Habitat network layers

In addition to ecosystem service uplift, the tool allows users to investigate how interventions could provide space for biodiversity through the enhancement of habitat networks. Sufficient access to food and nesting resources in a landscape is necessary to sustain biodiversity. In a fragmented landscape, such as the agricultural landscape in Scotland, species are less able to access these resources due to the distances they are required to travel between patches of habitat. The more connected a landscape, the more likely it is to provide viable habitat for biodiversity. Increasing habitat connectivity is a current priority of the Scottish Government, with local authorities encouraged to develop Nature Networks in line with the goals of the Scottish Biodiversity Strategy (SBS; Scottish Government, 2025). Users will be able to present tool outputs to both public and private financers to highlight these efforts and show plans for network contribution.

Existing habitat networks

The NCT includes six habitat network layers: woodland, grassland, heath, bog and fen, wetland, and ponds. Habitat networks are comprised of continuous areas of habitat and patches of habitat that can accessed by mobile species. Each layer displays the network at three dispersal distances, representing the ability of different species to travel greater distances.

Table 4. Habitats included in the habitat networks model in the Natural Capital Tool.

Habitat network	Included habitats (HabBroad)	Dispersal distances (m)
Native woodland	• Woodland, broadleaved • Woodland, mixed	• Short: 150 • Medium: 1000 • Long: 1500
Semi-improved grassland	• Grassland, semi-natural • Maritime cliff and slope	• Short: 150 • Medium: 1000 • Long: 1500
Heathland	• Heathland	• Short: 250 • Medium: 1000 • Long: 1500
Marsh/wetland	• Grassland, marshy	• Short: 150 • Medium: 1000 • Long: 1500
Bog and fen	• Grassland, marshy • Mire • Swamp • Saltmarsh	• Short: 150 • Medium: 2000 • Long: 3000
Ponds	• Water, fresh (< 1 ha, shape index ≤ 5)	• Short: 50 • Medium: 1000 • Long: 1500

Habitats belonging to each network type are identified by the HabBroad field in the habitat baseline (Table 4). For example, the native woodland habitat network is made up of habitats in the 'Woodland, broadleaved' and 'Woodland, mixed' HabBroad category. For a given habitat network type, the model identifies continuous patches of these habitat types that meet a minimum size (0.1 ha by default) as 'source' habitat.

Habitat networks are then generated from a cost distance analysis for a generic focal species (Figure 6). A generic focal species represents the dispersal behaviours of species associated with a particular habitat. This analysis is performed using the habitat baseline map and three additional inputs: 1) the minimum patch size that is considered viable habitat (0.1 ha); 2) maximum dispersal distances at three scales (Table 4); and 3) landscape permeability scores (i.e., how easily the generic focal species can move through different habitats; see the About section of the NCT). The cost distance analysis then calculates how far a generic focal species can move outside an area of source habitat and through the habitats that surround it (e.g., how far a generic woodland species can move out of an area of woodland habitat through surrounding habitat). Habitats with a higher landscape permeability cost for the focal species will shorten the distance it can travel from core habitat. The result is a habitat network comprised of short dispersal distance habitat (representing species with low dispersal ability) and useable space for species of medium and high dispersal ability around the core habitat. To help users, these are displayed as most, some, and few. Most, some and few refers to the number of species that are associated with each species dispersal level; 'most' represents species with short dispersal distances, and 'few' represents species with high dispersal distances.

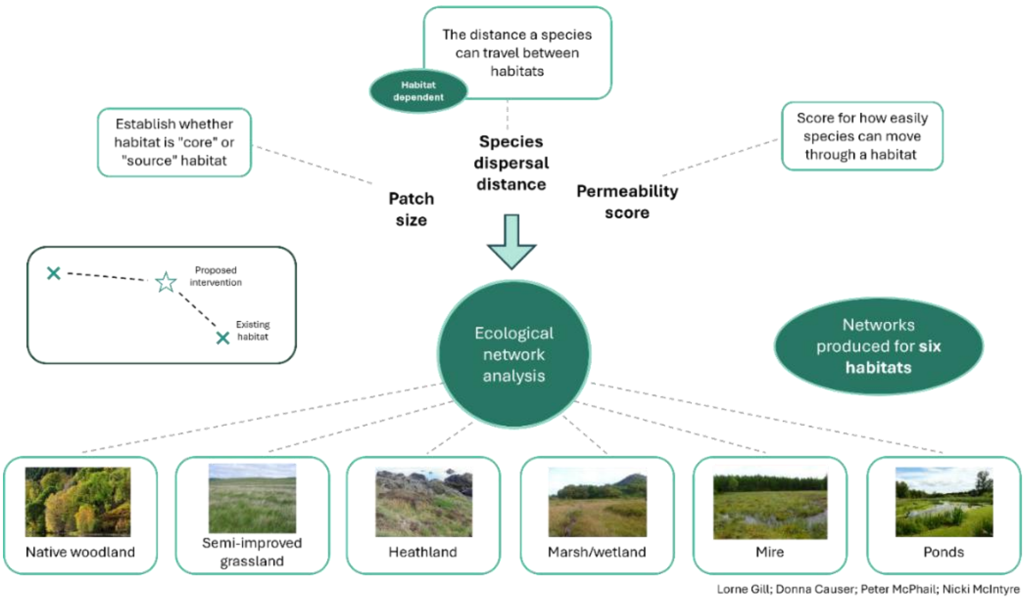

Figure 6. An overview of the Natural Capital Tool habitat network model.

Permeability scores represent how easily a generic focal species can move through a habitat. Scores are given in relation to the six habitats that form the basis of the habitat networks. Upon reviewing the EcoservR habitat network model, there were discrepancies between scores used in EcoServ-GIS and those present in Scottish Natural Heritage (SNH) Research Report No. 887 *Developing a habitat connectivity indicator for Scotland* (Blake & Baarda, 2018). This prompted a wider literature review to ensure the costs presented are as robust as possible. As a result, the team created a spreadsheet that a) highlighted the differences between EcoServ-GIS and SNH Research Report No. 887, and b) recorded the team's decision regarding whether to replace these values (and record the source of these new values in the habitat lookup table).

Throughout the development of the habitat networks model, the team spent time discussing which habitat networks should exist in the NCT and whether they believed the networks present in EcoServ-GIS deserved reviewing. One of these discussions centred around whether the NCT needed separate habitat networks for 'broadleaved woodland' and 'native pine woodland', as opposed to a single 'native woodland' network. Scotland's ancient Caledonian pine forests are a defining feature of the landscape and culturally significant. The team want to ensure that, where appropriate, native pine forest is prioritised as an opportunity over broadleaved woodland. Therefore, there is a strong argument to create a separate network to help promote the expansion of native pine forests. However, as the underlying data will be near identical, and the two networks ecologically similar, there is concern that there is no substantive reason to differentiate the two. Considering the data that will inform the networks, the team decided to move forward with one single woodland network.

<u>Habitat network opportunities</u>

This layer shows users two types of opportunities to improve a given habitat network:

- Buffer opportunities: areas within 10 m of existing source habitat (considered adjacent, with a small allowance for minor fragmentation due to paths etc.)
- Stepping stone opportunities: areas between 10 m and 1000 m from existing source habitat (upper limit from the Nature Networks Evidence Handbook, NERR081).

Source habitat is calculated using habitat codes specific to each of our six broad habitat classes. Note that source habitat is not the same as the core network (the latter describes where a species can disperse). Land use, heritage, ancient woodland, and power infrastructure constraints are also removed from the opportunity layer. These steps are in line with the habitat network methodology.

If newly created habitat overlaps with a buffer opportunity, then the assumption is that the source habitat has been expanded. If newly created habitat is only contained within the stepping stone opportunity, then we cannot assume that this new habitat is linked to another source habitat (although this may be the case). Thus, users can use this layer to identify how to connect existing source habitat both to each other and to newly created habitat.

Multiple benefits layers

Multiple benefits are the third opportunity type in the NCT. These layers are a summary of the total number of opportunities that are associated with the creation of a specific habitat. Multiple benefits can be displayed for each of the same six habitat types as the habitat networks: woodland, grassland, heath, wetland, bog and fen, and ponds.

In the tool, users are prompted to select a habitat type from the multiple benefits drop-down list. The tool will then display a layer showing the amalgamation of the opportunities associated with that habitat.

To create the multiple benefits layers, each pixel of the opportunity layers are assigned a score of 1 and then summed to give the total number of benefits per pixel that the habitat could contribute to providing. Only certain ecosystem services are included in the multiple benefits layers for each habitat type (Table 6).

There must be at least two opportunities present in a pixel for an intervention to provide multiple benefits. The maximum number of benefits varies depending on the habitat type and the number of opportunities present in the study area; the minimum number of benefits associated with an intervention is 3, but this will increase as new ecosystem service models are added to the NCT.

Table 6. Habitats that contribute to ecosystem service uplift in the Natural Capital Tool.

Habitat	**Ecosystem services**									**Maximum number of benefits**
	Access to nature	Air quality improvement	Climate regulation	Carbon sequestration	Inland flood mitigation	Insect pollination	Noise regulation	River cooling	Habitat network	
Grassland	✓					✓			✓	3
Heath	✓				✓	✓			✓	4
Bog and fen	✓		✓		✓	✓			✓	5
Pond	✓		✓		✓				✓	4
Wetland	✓		✓		✓	✓			✓	5
Woodland	✓	✓	✓	✓	✓		✓	✓	✓	8

The multiple benefits layers provide users with locations for interventions that could produce the most benefits for people and nature. This gives users a simplified view of the potential for interventions of different types to enhance multiple ecosystem services. This also allows for a more strategic approach to incorporating nature-based interventions on an area of land, contributing to one of the key goals of the NCT.

Economic and biophysical valuations of ecosystem services

Providing uplift in economic terms was flagged as a priority by many users during the NCT co-design process. The NCT team engaged with the NatureScot Nature Finance team and the University of Exeter Land, Environment, Economics and Policy (LEEP) Institute to integrate best practice economic valuation models into the tool. Many suggested the inclusion of such valuations in order to link the tool and its outputs with green/nature finance opportunities.

While economic valuations provide guidance in terms of assessing the tangible benefits of nature-based interventions, the NCT does not provide a valuation of direct financial benefits gained following the implementation of particular interventions on a target area of land. Instead, the NCT provides economic valuations in relation to the societal benefit those interventions would bring, which could support funding applications or give an indication as to potential nature finance opportunities. It is also important to note that the economic valuations of two separate ecosystem services should not be directly compared, as the units on which these valuations are based vary depending on the service.

Ecosystem services were valued using methodology from NCRAT (Lenane et al., 2023), adjusted to Scotland data where appropriate. To reflect social time preference for present over future benefits, a discount rate is applied when calculating the net present value (NPV) outputs. The model for air quality regulation – a service that contributes to positive outcomes for human health – uses the Green Book health discount rates. All other models use the Green Book standard discount rates (Table 7).

Table 7. Standard and health discount rates as published in the Green Book (HM Treasury, 2022)

Period of years	**0-30**	**31-75**	**76-125**
Standard discount rate	3.50 %	3.00 %	2.50 %
Health discount rate	1.50 %	1.29 %	1.07 %

Where the accounting year for ecosystem service values does not equal the current year, the economic value is inflated to the current year using the HM Treasury GDP deflator (December 2025 update) (HM Treasury, 2025).

<u>Access to nature</u>

Economic and biophysical values are estimated through a revised ORVal (Outdoor Recreation Valuation) model, which was developed and adapted for use in Scotland by the University of Exeter. See the ORVal User Guidance and Advanced Technical Report for a full explanation of the methodology (Day & Smith, 2017; Day & Smith, 2018).

Biophysical values represent the estimated annual number of adult Scottish residents that are likely to visit greenspaces within a given site boundary. A statistical model assesses the likelihood of individuals attending a specific greenspace each day, based on assumed socioeconomic characteristics and home location of greenspace visitors, day of the week and week/month of the year. The model then aggregates the probabilities of individuals visiting that specific greenspace and produces an estimated yearly visitor count.

Economic values represent the welfare benefit provided by the recreational spaces present within a site boundary. The adjusted ORVal model estimates this welfare benefit through a travel cost method, which assumes the welfare benefit to each visitor is equal to the cost of travelling to the recreational site. In other words, an individual would only travel to a greenspace if they thought the greenspace was worth the trip. Estimated travel costs are calculated from the average cost of car travel (25p per km) and costs of travel time (based on Department for Transport estimates).

Several attributes of a greenspace impact the estimated biophysical and economic values, including the following:

- Greenspace size
- Landcovers
- Water margins
- Designations and points of interest
- Availability and qualities of alternative greenspaces

The biophysical and economic values are derived through the English Monitor of Engagement with the Natural Environment (MENE) survey. MENE was used to derive access to nature values due to data accessibility restrictions for equivalent Scottish data. The use of an English survey, rather than Scottish, will likely result in conservative estimates, as Scottish recreational visitors tend to travel further for recreational greenspace visits: 64% of Scottish greenspace visitors travel over 2 miles (Scotland's People and Nature Survey (SPANS); Stewart & Eccleston, 2025), while only 32% of English greenspace visitors travel over 2 miles (People and Nature Surveys (PANS); Natural England, 2024).

Air pollutant removal

Air pollutant removal is valued using the 2024 data (latest available) from the 2025 UK Natural Capital Accounts (NCA; Office for National Statistics (ONS), 2025). The UK NCA includes data on annual physical flows and monetary benefits for the removal of pollutants (NH_3, NO_2, O_3, PM2.5, PM10, and SO_2) across various habitat types for each of the Scottish local authorities. This is presented as a total benefit across the entire habitat area for each local authority (for example, all broadleaf woodland within Aberdeenshire collectively provides an annual benefit of £901k for the whole local authority). The total benefit across all habitats is also provided.

To quantify the biophysical value of pollutant removal, the air quality benefit per hectare of habitat is calculated for each pollutant, habitat type, and local authority. These rates are then applied across an area of interest to calculate total pollutant removal. The UK NCA includes biophysical and economic values for nine habitat types:

- broadleaf woodland
- coniferous woodland
- coastal margins
- enclosed farmland

- freshwater, wetlands, and floodplains
- mountains, moorland, and heath
- semi-natural grassland
- urban grassland
- urban trees

The NCT habitats are first assigned to the UK NCA classifications. All NCT habitats outwith the nine UK NCA habitats are designated as 'unclassified'. Urban trees, urban woodland, and urban grassland are classified by intersecting the OS Open Built Up Areas dataset with the NCT baseline for the area of interest; woodland and grassland habitats that intersect with built-up areas are considered to be urban, and patches of urban woodland less than 0.5 ha in size are classified as urban trees. The NCT baseline is then intersected with a map of Scottish local authorities. Polygons that intersect the boundary of a built-up area or local authority are divided. The total hectarage of each habitat type across each local authority in the area of interest is summed, and the UK NCA rates are joined to resulting dataset. The biophysical removal of each pollutant can then be calculated by multiplying the habitat area with its corresponding pollutant removal rate. Removal of each pollutant across the area of interest is the sum of pollutant removal by each habitat type. The results are displayed in the NCT as tonnes of the six individual pollutants removed (NH_3, NO_2, O_3, PM2.5, PM10, and SO_2) or the sum of all pollutant removal (excluding PM2.5, which is encompassed by PM10).

Following the quantification of the biophysical removal of air pollutants, the economic value and NPV per tonne of pollutant removed can be applied to calculate the total value of pollutant removal. Unlike the biophysical rates, the economic value and NPV of pollutant removal are aggregated by habitat type at the local authority level. While existing habitats can be attributed to a particular economic value of pollutant removal, it is not reasonable to apply a habitat-specific economic value to an intervention: the value of pollutant removal is determined by the amount of the pollutant that is removed. The total economic value and total NPV for the area of interest is calculated by multiplying the biophysical amount of pollutant removal by the corresponding economic value and NPV for each pollutant. NH_3 and PM10 are not valued economically by the UK NCA, so there are no economic values for these pollutants in the results table of the tool. The monetary air quality benefit is in 2024 prices which have been inflated to prices for the current year.

The total pollutant removal benefit for each habitat type in each local authority was divided by the area of that habitat type in that local authority. This assumes that air pollutant removal rates for each habitat type are consistent across the local authority. This assumption may overestimate or underestimate pollutant removal depending on the surrounding polluting activities. For example, the strategic placement of urban trees in an optimal location to mitigate pollutants could have a significant and positive air quality regulation potential and could therefore be underestimated using the regional average urban tree pollutant rate. Conversely, there could also be a negative effect in some locations due to the effect of dispersion – particularly in dense, urban areas – and in some cases this effect could be overlooked by the tool. Therefore, it is important to consider the local air quality demand and wider context when utilising these values.

Carbon sequestration

Carbon sequestration rates have been assigned to each habitat type according to Natural England Research Report NERR094 (Gregg et al., 2021). These carbon sequestration rates have been multiplied by the greenhouse gas emission values (carbon values) as produced by the UK Department for Energy Security and Net Zero (DESNZ; n.d.). This is inherently a social benefit calculation and does not reflect the 'carbon price', or the financial price of one tonne of carbon in the carbon market. In this case, carbon values represent the monetary value that society places on one tonne of CO_2 emitted or sequestered. These values have been developed using a marginal abatement cost curve, which models the cost of carbon emission reductions at various abatement effort levels (carbon-emission-reduction actions). The DESNZ carbon value is set at the effort level necessary to meet UK targets. DESNZ has produced a high, central and low series of carbon values. Central values are used for carbon sequestration social benefits in this tool. The monetary carbon benefit is in 2020 prices, which have been inflated to current year prices within the tool.

Timber

Timber economic valuation assesses the provisioning potential of the selected area of woodland. Assigning this land a timber value does not mean that the woodland is actively used for timber production. Rather, it is an indication of the value placed on the existence of that woodland for its potential ability to supply timber.

A timber economic benefit per hectare of woodland is calculated using the following inputs:

- Total Scotland timber yield – This was calculated as the sum of the latest available total timber and total woodfuel yield in Scotland as recorded in the 2025 UK NCA. The latest available data for timber and woodfuel yields were from 2024 and 2023 respectively (ONS, 2024).
- Total woodland area in Scotland – As reported by Forest Research (2024 values were used for consistency with timber yield) (Forest Research, 2024).
- Timber price – As reported by Forest Research (2025). Average coniferous standing sales price was used for this calculation, as recorded on 30th September 2024. This follows the NCRAT methodology (Lenane et al., 2023).

Average yield per hectare of woodland was calculated by dividing the total yield by the total area of woodland in Scotland. Average economic benefit of timber production per hectare was calculated by multiplying the average yield per hectare of woodland by the timber price. The monetary timber benefit is in 2024 prices which has been inflated to prices for the current year.

Woodland water storage

Woodland habitats, forests, and trees outside woodlands (TOW) enhance floodplain water storage by increasing soil infiltration and hydraulic roughness (Nisbet, 2022). The NCT woodland water storage model returns biophysical and economic values representing the volume of floodwater that woodlands in a study area may capture and store. NCRAT version 1.2 assigns all UK woodland habitats a biophysical value of 165 m^3 of water stored per hectare per year, based on a 2018 study by Forest Research (Broadmeadow et al., 2018; Lenane et al., 2023). To better represent the water storage capacity of broadleaved and coniferous woodlands in Scotland, the NCT biophysical model uses values derived from an updated version of the Forest Research study (Broadmeadow et al., 2023). This updated study also refined estimates for the economic value of floodplain water storage by woodlands, allowing an economic model to be developed for the NCT.

Broadmeadow et al. (2023) present annual woodland water storage values for Scotland, England, Wales, and Great Britain as a whole. For each area, a storage value is presented for three storage mechanisms (storage through interception, below ground storage, and storage generated by floodplain hydraulic roughness) across three habitat types (broadleaved woodland, coniferous woodland, and trees outside woodland). The values are presented for two counterfactual land covers: bare soil and grass. The area of broadleaved and coniferous woodland canopy in Scotland, England, Wales, and Great Britain is also presented in the study.

To calculate per-hectare annual water storage rates for Scotland across each habitat, the annual storage values were divided by the extent of each canopy type (Table 8). Grass was chosen as the counterfactual habitat, as planting in Scotland may be more likely to occur on non-arable agricultural land or other semi-natural habitats. Rates were then calculated for mixed woodland as the average of broadleaved and coniferous rates, and for parkland as 10% of the TOW rate.

Table 8. Annual floodwater storage rates for woodland and TOW habitats in Scotland, compared to a grass baseline. All rates are calculated from values extracted directly from Broadmeadow et al., 2023: Tables 2 (area of woodland), 5b (storage from interception), 7b (below ground storage), 9 (floodplain storage from hydraulic roughness), and 10b (storage for TOW). Rates for mixed woodland are the average of broadleaved and coniferous, and rates for parkland are 10% of TOW. *Note: the summer and winter figures are averaged rather than summed, as has been done in the report's final summary table 15.*

Habitat Type	Interception (m^3 ha^{-1} $year^{-1}$)	Below ground (m^3 ha^{-1} $year^{-1}$)	Floodplain Roughness (m^3 ha^{-1} $year^{-1}$)
Broadleaved woodland	21.69	72.52	518.36
Coniferous woodland	64.86	173.99	518.36
Trees outside woodland (TOW)	21.55	71.83	0
Mixed woodland	43.27	123.25	518.36
Parkland	2.15	7.18	0

The model first identifies and extracts broadleaved woodland, coniferous woodland, mixed woodland and parkland features from the habitat baseline for the study area. A map of TOW is not currently available for Scotland, and TOW are therefore not included in the NCT baseline. The area of each woodland type is calculated in hectares and multiplied by the interception rate and below ground rate to produce total interception and below ground storage.

Storage by hydraulic roughness only applies to woodland in floodplains. Broadmeadow et al. (2023) define floodplain woodland as woodland intersecting flood zones in the Flood Map for Planning (Rivers and Seas) Zone 2 layer produced by the Environment Agency. As this map only applies to England, the NCT model uses the Medium likelihood extent layer of the SEPA River Flood Maps (version 3.0) to define floodplains. Woodlands and parkland intersecting a floodplain are subsetted from the previously identified study area woodlands, and the area of each type of floodplain woodland is calculated. The total area of floodplain woodland is multiplied by the hydraulic roughness storage rate to return the value of floodplain storage. The sum of interception, below ground storage, and floodplain storage is the final biophysical woodland water storage value for the study area.

Broadmeadow et al. (2023) define the 'replacement' cost of providing flood storage with a reservoir as £14/m^3 (2021 prices). This is equivalent to an annual monetary value of £0.47/m^3 over 100 years, starting in 2021. The NCT economic model adjusts these values for inflation. The economic value for woodland water storage is calculated by multiplying the adjusted annual monetary value by the total biophysical woodland water storage value of the study area. The 100-year NPV is then calculated by the sum of the annual discount factors (29.8) at Treasury Green Book rates.

Valuation of contribution to habitat networks

As of April 2026, users can see how their interventions affect existing habitat networks alongside predicted uplift in ecosystem services. This will be presented spatially, showing physical contributions to habitat networks on their mapped area of interest, and presented in hectarage in a table beside the map.

Once users have simulated their chosen interventions, the NCT will rerun the habitat network models to quantify how interventions have impacted existing habitat networks. The models are explained in detail on page 37. Depending on the type of intervention, this could result in either a gain *or* a loss in one of more of the habitat networks or a gain in one habitat network and a loss in another. The hectarage will be shown across three levels: most, some and few. This refers to the number of species associated with each level, with 'most' referring to species with short dispersal distances, and 'few' referring to species with high dispersal distances. This wording has been chosen to assist users in learning how different interventions would affect different species. In this way, users will be able to report how they've impacted habitat networks not just as a whole, but for each species dispersal level measured in the tool. This could be useful in a variety of applications, such as in a Local Development Plan or bolstering a funding application.

Reporting

Throughout the co-design process, participants regularly highlighted the importance of having a report as an output of the NCT. Upon completing a project, users will have the ability to save and export results produced in the NCT, alongside maps and visual aids portraying the impact of chosen interventions. The aim of the automatic report is to provide users with a tangible means of: a) evidencing planned interventions for potential funders; b) presenting opportunities to local stakeholders in the hope of creating landscape-scale partnerships; or c) documenting project progress.

The automatic report comprises a selection of the outputs generated in the NCT and it is presented as a printable HTML report. The report includes a summary of the land use change observed as part of the scenario planning (i.e., habitat change in hectares), habitat network coverage, and all related ecosystem service uplift figures (relative, biophysical, and economic). The tool also provides users with an indication of the UN Sustainable Development Goals (SDGs) they will have contributed to upon successful implementation of the interventions planned in the NCT and signposts towards relevant funding opportunities.

The automatic report is generated by running an R Markdown script, which calls upon NCT outputs that are automatically pulled into a Python server connected to the NCT interface. The R Markdown script, and its associated .css file, is available in the GitHub repository. Once users choose to export their results, the NCT interface triggers the R Markdown script, and the user is presented with a printable, downloadable HTML file. The report as of now does not include any interactive maps, due to file size limitations, and is not customisable (i.e. the user cannot select which maps they want to see in the report). It is hoped that in future iterations users will have the ability to choose what they want to prioritise in the automatic report so it is customisable to their specific goals. Additionally, the tool would give users the option to include interactive elements if preferred, which could include features of the NCT such as the before and after slider (showing their target area pre- and post-intervention).

<u>Funding opportunities</u>

One of the aims of the NCT is to provide users with a means of accessing public funding opportunities and emerging nature finance markets. Please see Table 7 for further clarification as to the services the NCT provides in relation to connecting land managers with nature finance opportunities. Whilst the NCT does not provide a direct link between users and finance, (insofar as the NCT is not a prerequisite step in applying for NatureScot funds, for example) throughout the co-design process, it became clear that having an automatic report to document and evidence planned changes was a priority of users, particularly with regards to applying for funding. Compiling planned interventions and being able to show predicted impacts on existing natural capital and ecosystem services will assist users in justifying projects and bolstering funding applications.

Furthermore, the automatic report provides an overview of the public capital funds available to users – these comprise the funds that are available through NatureScot and Scottish Government, such as the Nature Restoration Fund and Peatland ACTION. These are separated by habitat, making it simple for users to navigate what funds they could apply for depending on their desired intervention. There is also a summary of the funding available to users who want to develop a project or prepare it for further investment once established, such as the Facility for Investment Ready Nature in Scotland (FIRNS) or the Neighbourhood Ecosystem Fund. Consequently, the NCT gives a comprehensive overview of the public funds available to users and directs them to relevant online guidance.

Table 7. Functionality of the Natural Capital Tool in connecting users with funding opportunities and nature finance markets.

Natural Capital Tool – funding opportunities	
What the NCT provides:	What the NCT does not provide:
Supports decision-making and evidences interventions – clear plans and evidencing of these plans will assist in finding and securing appropriate funding	The NCT does not directly connect users to any sources of funding.
A printable report to present as evidencing of planned interventions	The automatic report cannot be used in place of an application form for funding.
Signposting towards open-source guidance on specific interventions	The NCT does not supply guidance with regards to writing grant applications
An overview of available sources of public capital funding (with the caveat that deadlines and objectives for each will change year on year)	The NCT does not provide an overview of private sources of funding.
An economic valuation of the societal benefit ecosystem service uplift would bring as a result of proposed interventions	The NCT does not provide an economic valuation that is a direct measure of funds available to land managers following proposed interventions.

<u>Contribution to UN Sustainable Development Goals</u>

The UN 2030 Agenda for Sustainable Development, agreed upon and signed up to by all UN member states, comprised 17 Sustainable Development Goals (SDGs) with the primary aim of ending poverty and addressing inequalities whilst also preserving biodiversity and increasing climate resilience. Due to its global application, it is beneficial for those wanting to make nature-based interventions and seek funding to align their project with the SDGs and evidence how they might be achieved. In the automatic report, the user will see a summary of the SDGs that may be achieved dependent on the interventions they made within the NCT. Each intervention triggers different SDGs, so these vary depending on the habitat. A table summarising the SDGs triggered by each habitat intervention can be found in Appendix 11.

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Lenane, R., Moore, K., Jones, R., Kinsey, G. (2023). The Natural Capital Register and Account Tool Technical Report v1.2. Environment Agency, Bristol.

Appendix 2: Context layers included in the Natural Capital Tool

Core Paths

- Scottish Government – Available under the Open Government License v3.0.

Cycling Network

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- Scottish Government – Available under the Open Government License v3.0.

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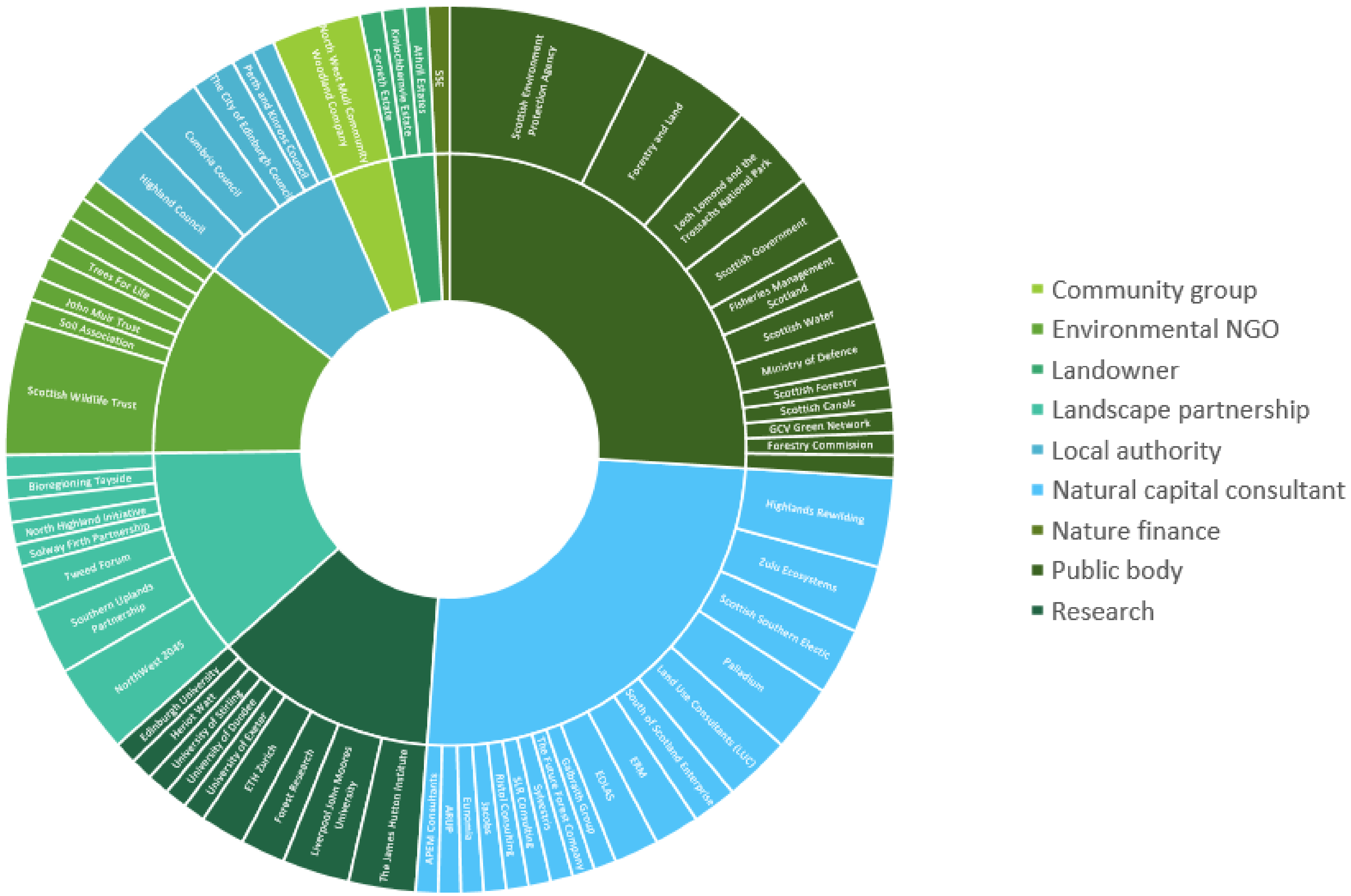
Appendix 3: Natural Capital Tool (Beta) - Version updates

Version 1.1 – 1st December 2025

- Fixed spacing and layout issues on small screens
- Name changes to Step 1 and Step 2
- Rescaled inland flood mitigation model
- Added Dynamic Coast context layers
- Allowing touching intervention areas
- Updated watershed context layer display
- Other minor bug fixes and improvements

Appendix 4: Organisations in co-design group

APEM Consultants
Argyll and the Isles Coast and Countryside Trust
ARUP
Atholl Estates
Butterfly Conservation Scotland
Dumfries and Galloway Council
Edinburgh University
EOLAS Insight
ERM
ETH Zurich
Eunomia
Fife Coast and Countryside Trust
Fisheries Management Scotland
Food, Farming and Countryside Commission Scotland
Forest Research
Forestry and Land
Forestry Commission
Galbraith Group
Galloway and Southern Ayrshire Biosphere
Game and Wildlife Conservation Trust
GCV Green Network
Heriot Watt
Highland Council
Highlands Rewilding
Jacobs
John Muir Trust
Kinlochbervie Estate
Land Use Consultants
Liverpool John Moores University
Loch Lomond and the Trossachs National Park
NatureScot
North Highland Initiative
Northwest 2045
North West Mull Community Woodland
Palladium
Ministry of Defence
Perth and Kinross Countryside Trust
Ristol Consulting
Scottish Canals
Scottish Environment Protection Agency
Scottish Forestry
Scottish Government
Scottish Southern Electric
Scottish Water
Scottish Wildlife Trust
SLR Consulting
Solway Firth Partnership
Soil Association
South of Scotland Enterprise
SSE
Southern Uplands Partnership
Sylvestris
The City of Edinburgh Council
The Future Forest Company
The James Hutton Institute
Trees for Life
Tweed Forum
University of Dundee
University of Exeter
University of Stirling
Zulu Ecosystems


Scottish Environment Protection Agency
Forestry and Land
Loch Lomond and the Trossachs National Park
Scottish Government
Fisheries Management Scotland
Scottish Water
Ministry of Defence
Scottish Forestry
Scottish Canals
GCV Green Network
Forestry Commission
Highlands Rewilding
Zulu Ecosystems
Scottish Southern Electic
Palladium
Land Use Consultants (LUC)
South of Scotland Enterprise
ERM
EOLAS
Galbraith Group
The Future Forest Company
Sylvestris
SLR Consulting
Rintal Consulting
Jacobs
Eunomia
ARUP
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The James Hutton Institute
Liverpool John Moores University
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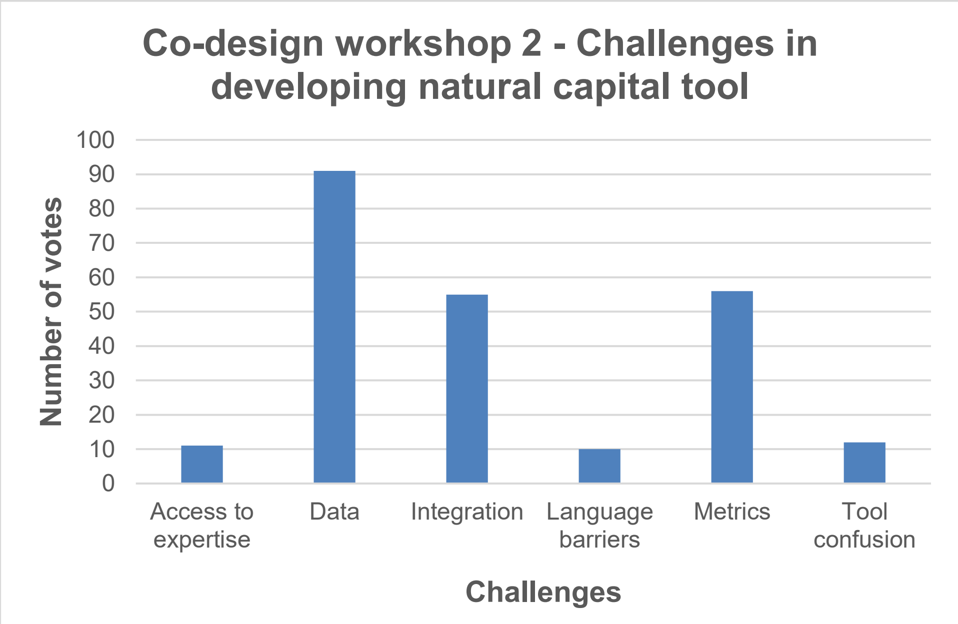
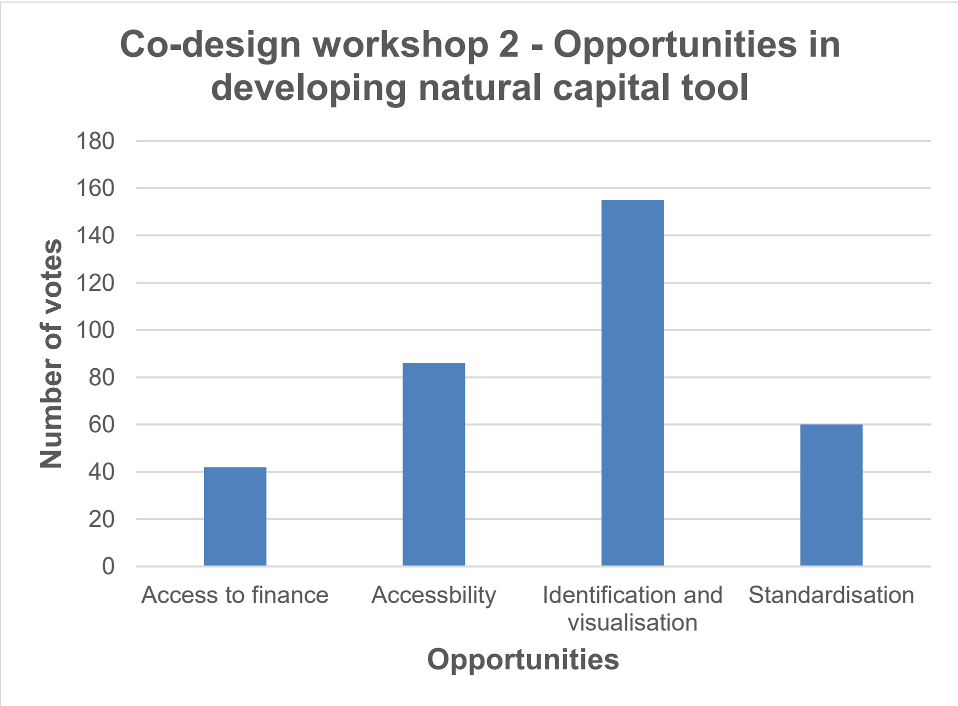
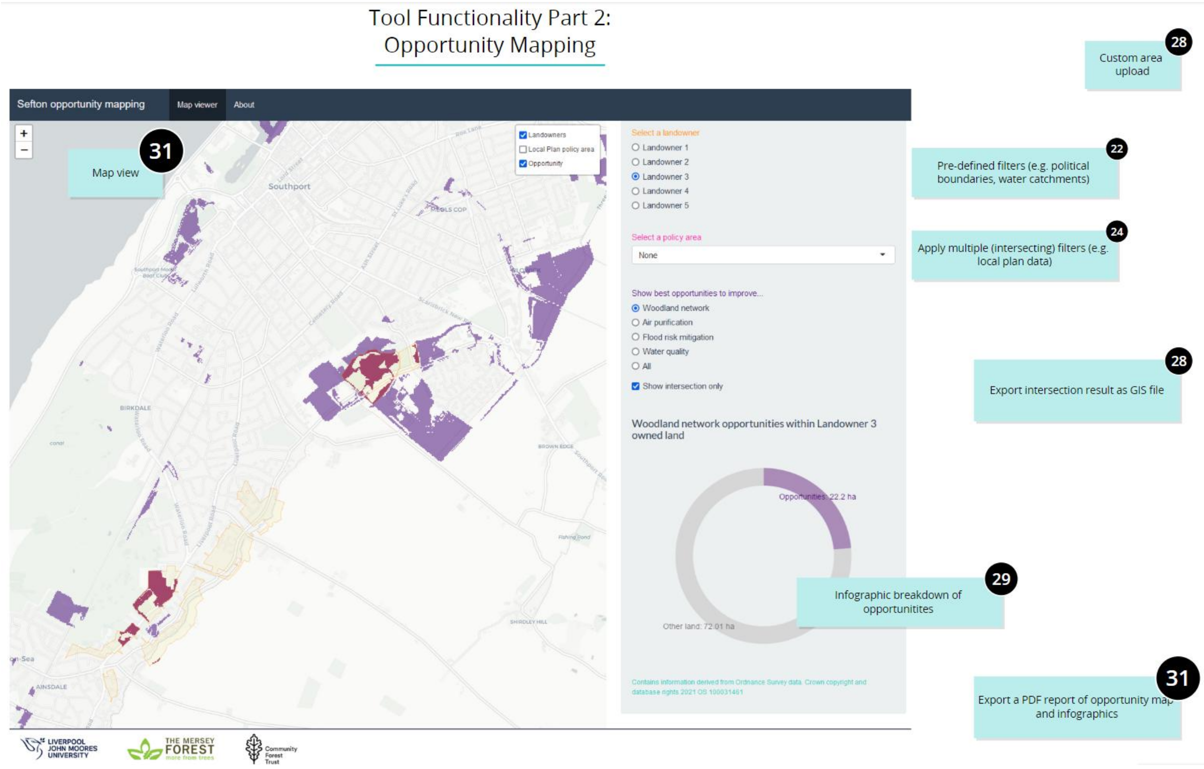
ETH Zurich
University of Exeter
University of Dundee
University of Stirling
Heriot Watt
Edinburgh University
NorthWest 2045
Southern Uplands Partnership
Tweed Forum
Solway Firth Partnership
North Highland Initiative
Bioregioning Tayside
Scottish Wildlife Trust
Soil Association
John Muir Trust
Trees For Life
Highland Council
Cumbria Council
The City of Edinburgh Council
Perth and Kinross Council
North West Mull Community Woodland Company
Forneth Estate
Kinlochbervie Estate
Atholl Estates
SSE
Community group
Environmental NGO
Landowner
Landscape partnership
Local authority
Natural capital consultant
Nature finance
Public body
Research

Appendix 5: Challenges and opportunities in developing a natural capital tool identified by participants in Co-design Workshop 2

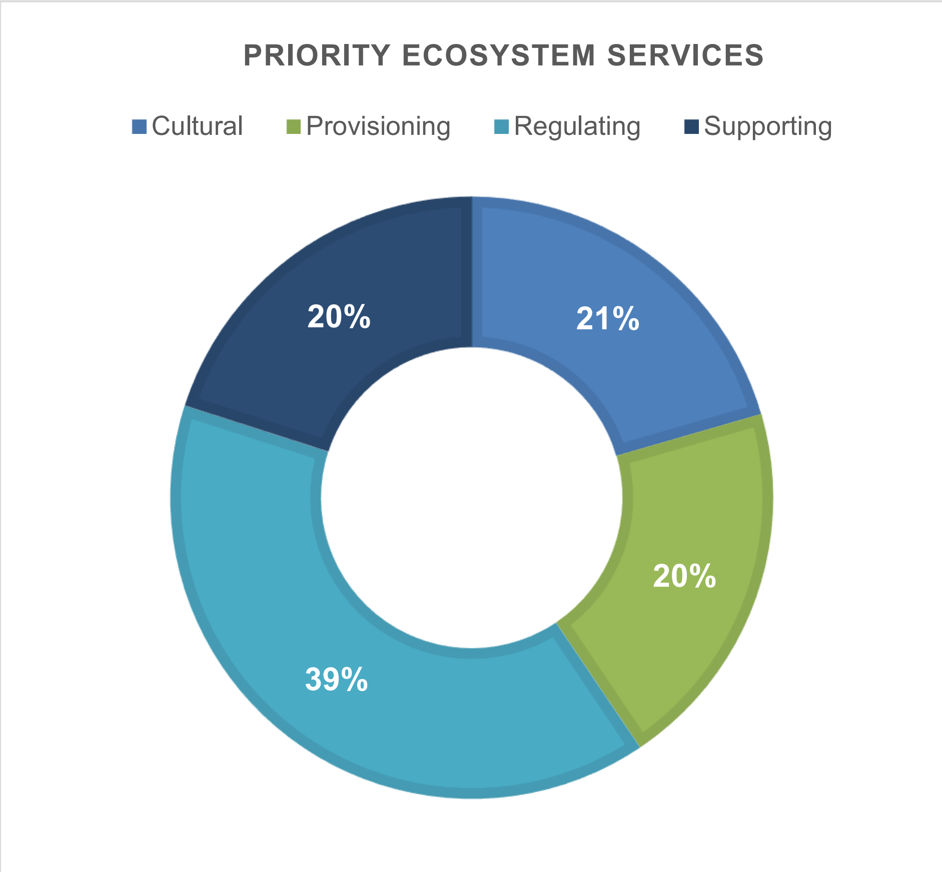




Appendix 6: Example of feedback gathered during Co-design Workshops



Appendix 7: Priority ecosystem services identified during Co-design Workshop 2



Appendix 8: Pilot Phase 1 Executive Summary

Pilot Phase 1 strategy

A Pilot Strategy was developed to undertake an evidence-based approach to stakeholder engagement. The aims of the Pilot Strategy were to identify pilot partnerships willing to trial the Tool prototype, collect feedback on user experience, and gather insights from participants' backgrounds and interests in natural capital approaches to inform the Tool's development. These included insights into how pilot partnerships used the Tool prototype, whether it met their expectations, how intuitive the Tool prototype was to use, and what further suggestions pilots had for what should be included in the Tool's functionality.

Pilot Phase 1 took place between November 2023 and April 2024. A prototype version of the NCT was created by the Tool Development Team for each of the seven pilot partnerships. Given the timing of Pilot Phase 1, not all features of the NCT were developed yet. The prototype used for piloting included the Access to Nature, Air Purification, Noise Regulation, Local Cooling and Pollination ecosystem service models, and the Woodland Ecological Network and Multiple Benefits from Woodland opportunity models.

Seven pilot partnerships were selected through the project's Co-design Group and external engagement. Pilot partnership selection aimed to create a pilot pool representing a sample of different types of land use and interests typically found across Scotland.

A Pilot Engagement Strategy was developed to guide the project's engagement with the pilot partnerships. This included a three-phase approach with each pilot partnership:

- Engagement Session 1: Introducing the aims and concepts behind the Tool to ensure all pilots began on an equal footing and gathering background information about the pilots' interests and experiences regarding natural capital approaches to decision-making and land management.
- Engagement Session 2: Demonstrating the NCT prototype, a Q&A session, and requesting pilots to explore the tool during an allocated piloting period.
- Engagement Session 3: Gathering feedback of the pilots' experience of using the Tool, what features they liked or disliked, and what future features they would like to see in the final version of the Tool.

Pilot backgrounds

The seven pilot partnerships selected for Pilot Phase 1 came from a variety of backgrounds selected to represent a diverse range of land uses and possible future audiences and end users of the Natural Capital Tool. These included:

- A peri-urban partnership (Cumbernauld Living Landscape);
- Two Regional Land Use Partnerships (RLUP) (South of Scotland Enterprise and NorthWest 2045);
- A community landowner (North West Mull Community Woodland Company – Isle of Ulva);

- A National Park authority (Loch Lomond and the Trossachs National Park);
- An agricultural cluster (Game and Wildlife Conservation Trust – Farmer Cluster); and
- A public body (Forestry and Land Scotland).

For the purposes of data collection, these pilots were then categorised into four sectors (Agriculture, Conservation, Forestry and Game), and eight subcategories of land ownership or management. This was to allow for a later analysis of how the engagement and piloting process performed across these categories, and how relevant and accessible the NCT prototype was across these sectors for future development and piloting.

Information about pilot background was gathered during Engagement Session 1 – Introducing the Tool and a subsequent questionnaire circulated for those unable to attend. The eight subcategories generated from initial data collection included:

- Landowner – agriculture,
- Landowner – mixed agriculture, conservation and game,
- Landowner – mixed game, forestry and conservation
- Landowner – urban and peri-urban conservation,
- Landowner – mixed agriculture, forestry and conservation,
- Land manager – mixed agriculture, conservation and game,
- Land manager – agriculture, and
- Land manager – mixed forestry and conservation.

Feedback summary

Familiarity with natural capital

Respondents from the conservation sector emerged with the highest average familiarity (14% 'Very Familiar', 43% 'Familiar' and 43% 'Somewhat Familiar'), followed by forestry (75% 'Familiar', 25% 'Somewhat Familiar'), game (33% 'Familiar', 67% 'Somewhat Familiar') and agriculture (20% 'Very Familiar', 80% 'Somewhat Familiar'). Piloting had greatest impact on those newer to natural capital approaches and decision-making, fulfilling the NCT's aim of increasing capacity to adopt natural capital approaches to land management and decision-making.

Reasons for piloting

'Management' (40%), 'Knowledge' (13%) and 'Decision-Making' (13%) emerged as the most popular reasons for joining the project and engaging with the NCT across both landowner and land manager groups. Landowners selected 'Management' (34%), 'Knowledge' (22%) and 'Decision-making' (22%) as the most popular choices. Land managers selected 'Management' (40%), 'Monitoring' (20%), 'Assessing' (20%) and 'Planning' (20%) as the most popular choices. There was no discernible trend for reasons for piloting across sectors.

Ranking of ecosystem service outputs

'Carbon Sequestration' (13.2%), 'Biodiversity Enhancement' (12.2%), 'Flood Mitigation' (11.3%) and 'Water Purification' (10.9%) emerged as the most popular ecosystem services across land user types and sectors, followed by 'Sustainable Agriculture' (9.6%), 'Access to Nature' (9.6%), 'Tourism' (9.3%), 'Air Purification' (8.7%), 'Restoration of Historical Sites' (8%) and 'Noise Management' (7.1%). These varied significantly across sectors, though 'Carbon Sequestration', 'Biodiversity Enhancement', 'Flood Mitigation' and 'Water Quality' were among the most popular.

Usability

Overall feedback across the pilot groups indicated that 8.3% of the respondents felt the NCT prototype was 'User friendly', 75% described the Tool Prototype as 'Relatively easy to use' and 8.3% responded with 'Challenging but usable'.

Respondents from the forestry sector voted 'User friendly' (16.7%), 'Relatively easy to use' (66.7%) and 'Challenging but usable' (16.7%). Respondents from the conservation sector voted 'User friendly' (10%), 'Relatively easy to use' (80%) and 'Challenging but usable' (10%). All respondents from the agricultural and game sectors voted 'Relatively easy to use' (100%).

Pilot use of the prototype

'Exploring the tool in general' (21.4%) was the most common use of the NCT across all categories. 'Calculating ecosystem service change' (14.2%) was the second most popular use and 'Opportunities – woodland ecological networks' (10.7%) and 'Opportunities – native woodlands' (10.7%) as joint third. These uses were followed by 'Opportunities – multiple benefits' (7.1%), 'Opportunities – natural flood management' (7.1%), 'Uplift' (7.1%), 'Exploring layers' (7.1%), 'Checking data – woodland creation' (7.1%) and 'Checking peat depth' (7.1%).

The average prevalence of 'Exploring in general' as the primary use of the NCT across user categories was expected given the context of pilot testing, as was the general preference towards testing. The average popularity of 'Calculating ecosystem service change' as the second most common use of the NCT suggested an interest in exploring the concept of trade-offs between different ecosystem services as part of a natural capital approach to decision-making.

Accuracy of habitat baseline

Overall feedback across the pilot groups indicated that 50% of the respondents felt the habitat baseline was 'Accurate', 33% described the habitat baseline as 'Somewhat Accurate' and 17% responded with 'Not very accurate'. 'Somewhat accurate' and 'Not very accurate' responses were overall attributed to inaccurate upland polygons (23.8%), peat data (21.4%), a lack of grassland types (14.3%), crop types (11.9%), inaccurate habitat condition (7.1%) and habitat locations (7.1%) and mislabelled land use types (2.4%). Customisable polygons were included in subsequent tool development, though constrains of nationally available peat data, grassland and crop types was a limiting factor. We are however working with the James Hutton Institute across 2025-2026 to include nationally available datasets on peatland, grassland and crops. Habitat condition is not within the remit of the NCT.

The varied perceptions of accuracy on elements of the habitat baseline indicated that there is subjectivity with regards to what is considered to be accurate, and this is largely based on the users' specific interests and intended use of the NCT. This subjectivity was influenced by the demand and interests of their sector in relation to natural capital approaches to decision-making and offered insight into future uses of the Tool.

Usefulness of land use change breakdown

Overall feedback across the pilot groups indicated respondents felt the land use change breakdown menu was 'Useful' (75%), 'Somewhat useful' (16.7%) and 'Not useful' (8.3%). There was no discernible trend across landowner and land manager categories, nor across sectors. Of those who responded 'Somewhat useful', reasons cited included that the polygons could not be customised (50%) and the choices were too broad and lacked peatlands (50%). Those who responded 'Not useful' cited the lack of ground truthing (100%). The polygon issue was still under development at the time of the first pilot phase and subsequently addressed. The lack of peatlands was also addressed by the inclusion of SLAM and EUNIS maps. The lack of ground truthing, while outside the remit of the tool, is currently being addressed, with external parties (i.e., EOLAS Insight) looking to ground truth the datasets used to form the habitat baseline.

Usefulness of ecosystem service uplift %

Overall feedback across the pilot groups indicated respondents felt the ecosystem service uplift was 'Very useful' (25%), 'Useful' (25%), 'Somewhat useful' (33%) and 'Not useful' (17%). Those who responded 'Somewhat useful' cited uncertainty around what the units signified (50%), lack of timescales (25%) and the inclusion of areas outwith target polygons (25%). Those who responded 'Not useful' cited the lack of ground truthing (66%) and uncertainty around what the units signified (33%). There was no discernible difference from the overall ratings across landowner and land manager categories, though there was considerable variation across sector categories.

Interestingly, ground truthing did not emerge as an article of critical feedback for non-traditional natural capital sectors such as agriculture and game, potentially because the features of the NCT were sufficient for entry level users in this regard, thereby potentially fulfilling a key aim of the Tool.

Usefulness of the before and after feature

Overall feedback across the pilot groups indicated respondents felt the before and after feature was 'Very useful' (8.3%), 'Useful' (41.7%) and 'Somewhat useful' (50%). Those who responded 'Somewhat useful' cited lack of timescales (33%), the slow speed of the feature (16.7%), the inclusion of areas outwith the target polygons (16.7%), uncertainty about the accuracy of the feature (16.7%), and the difference between the before and after results being too subtle to easily discern (16.7%). There was no discernible difference from the overall ratings across landowner and land manager categories, though there was considerable variation across sector categories. The speed of this feature has been significantly improved through hosting the tool on a different server and improving coding. Timescales is not currently within the remit of the tool.

The prevalence of feedback regarding the lack of timescales in the feature across different sectors indicated an awareness and investment in the long-term implications of ecosystem service change. Insight into this subject could arguably enhance arguments in favour of taking natural capital approaches to decision-making.

Requests for additional features and functions

The inclusion of the following features and functions emerged from the feedback (from most popular to least popular): Biodiversity enhancement (15.4%), food provision (14.1%), soil erosion (12.8%), water quality (12.8%), insect pollination (9%), diffuse pollution (5.1%), peatland restoration opportunities (3.8%), carbon sequestration (3.8%), designated sites (2.7%), native/riparian woodland creation (2.7%), Scheduled and Historical Monuments (2.7%), enhanced grasslands (2.7%), LIDAR (2.7%), SCIMAP (2.7%), floodplain connectivity (2.7%), agricultural buffers (1.3%), Land Classification for Forestry and Agriculture (1.3%), contoured water features (1.3%), and a glossary of terms (1.3%)

A significant proportion of the requested features and functions were already in the tool development pipeline at the time of Pilot Phase 1, including food provision, carbon sequestration, and native/riparian woodland creation – carbon sequestration and native woodland creation are now integrated, with the development of a food provision model commencing 2025.

The features and functions requested by participants largely reflected the broader interests of their sectors. This will be considered when defining target audiences for the NCT during the phased release of the Beta-MVP in Spring/Summer 2025.

Next steps

The Tool Development team will assess feedback to explore what elements will and can be incorporated into the project pipeline leading up to the phased release of the Beta-MVP in Spring/Summer 2025. The feasibility and importance of different elements of feedback will be assessed on the basis of available budget and capacity within the NCT team and according to the remit of the tool's purpose and functionality.

As part of the phased release, a workshop will be held with pilot partners and members of the Co-design Group, where we will take the time to outline which aspects of the feedback gathered in Pilot Phase 1 were integrated into the Beta-MVP, which were not, and why.

Pilot Phase 1 informed the planning for Pilot Phase 2, which will be aimed at farmers, crofters and landscape scale partnerships. Pilot Phase 2 will aim to engage with 50 farmers and crofters and any organisations they are in partnership with.

Appendix 9: Pilot Phase 1 – Questionnaire 1

Engagement Session 1 Questions

1. How familiar are you with natural capital?

- ◯ Unfamiliar / I do not know of natural capital
- ◯ Somewhat familiar / I think I understand what natural capital is
- ◯ Familiar / I have used natural capital approaches
- ◯ Very familiar / I actively use natural capital approaches

2. Why have you chosen to be part of the piloting?

3. How would you describe your familiarity with the project so far?

- ◯ Unfamiliar
- ◯ Somewhat unfamiliar
- ◯ Familiar
- ◯ Very Familiar

4. Please pick one of the following to best describe your relationship to land management.

- ◯ Land Owner
- ◯ Tenant
- ◯ Manager
- ◯ Worker
- ◯ Other

5. How would you describe your holding?
Select all that apply....

- ☐ Farm
- ☐ Croft
- ☐ Nature Reserve
- ☐ Forestry
- ☐ Sporting Estate
- ☐ Other

6. What type of projects/land uses/work do you currently have?

Examples include: forestry, agriculture, peatland restoration, rewilding, carbon sequestration, conservation, biodiversity. Please put n/a if you currently do not have any.

7. How many projects involving Natural Capital are you currently undertaking?

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5+

8. What expectations or hopes do you have of the Tool?

9. How would you rate the following from 1 - least important to 5 – most important to you?

	1	2	3	4	5
Carbon Sequestration	◯	◯	◯	◯	◯
Water Purification	◯	◯	◯	◯	◯
Noise Management	◯	◯	◯	◯	◯
Sustainable Agriculture	◯	◯	◯	◯	◯
Biodiversity Enhancement	◯	◯	◯	◯	◯
Air Purification	◯	◯	◯	◯	◯
Restoration of Historical Sites	◯	◯	◯	◯	◯
Access to Nature	◯	◯	◯	◯	◯
Tourism	◯	◯	◯	◯	◯
Flood Mitigation	◯	◯	◯	◯	◯

Appendix 10: Pilot Phase 1 – Questionnaire 2

Piloting the Prototype: Questionnaire 2 - Your Experience

The **Landscape Scale Natural Capital Tool** is currently in its **prototype testing phase**. This Questionnaire is an opportunity to offer your insight and opinions on the prototype and what we have developed so far.

This Questionnaire will accompany your piloting of the prototype between Engagement Sessions 2 and 3, and will allow you to **share your initial thoughts and experiences** whilst they are fresh. We will draw on this feedback and discuss how you found the prototype during Engagement Session 3.

Many thanks for taking the time to trial the prototype and fill out the Questionnaire. Your **participation and feedback is greatly appreciated**, and will shape the development of this Tool going forward.

* Required

1

Pilot Partnership name (this will be kept anonymous) *

2

How would you describe your familiarity with the prototype after the Engagement Sessions and Piloting? *

- ◯ Very unfamiliar
- ◯ Unfamiliar
- ◯ Somewhat familiar
- ◯ Familiar
- ◯ Very familiar

3

In what ways did you use the prototype whilst piloting it? *

4

Did the prototype fulfil what you used it for? Please elaborate. *

5

Did the prototype meet your expectations? *

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neither agree of disagree
- ◯ Agree
- ◯ Strongly agree

6

Please elaborate *

7

Did you feel the prototype provided you with the information you need to carry out natural capital related work? *

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neither agree nor disagree
- ◯ Agree
- ◯ Strongly agree

8

How user friendly was the prototype to operate? *

- ◯ Not user friendly at all
- ◯ Difficult to use
- ◯ Challenging but usable
- ◯ Relatively easy to use
- ◯ User friendly

9

In relation to the habitat baseline (habitat map), how accurately did it reflect your land? *

- ◯ Completely innacurate
- ◯ Not very accurate
- ◯ Somewhat accurate
- ◯ Accurate
- ◯ Very accurate

10

Please elaborate *

11

Which opportunities were you most interested in? Please drag choices up or down, or use arrows that appear on each option when your mouse hovers over them, to rank your choices from top (most important) to bottom (least important). *

- Air purification
- Noise regulation
- Cooling
- Flood mitigation
- Ecological network – woodland habitat connectivity
- Opportunity areas that can provide multiple benefits

12

How useful did you find the land use change breakdown as you were exploring different scenarios? *

13

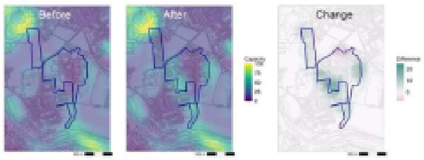
How useful did you find the ecosystem services % change table? *

	Baseline	Projected	Change (%)
Carbon storage	1420499	1423059	0.18
Air purification	12960.11	12980.95	0.16
Water purification	30.39	30.4	0.01
Climate regulation	507.83	508.88	0.21

14

How useful did you find the before/after ecosystem service provision maps?

*



15

The Tool is currently in its prototype phase. We are working to include additional ecosystem services (e.g. insect pollination, access to nature etc.) and ecological connectivity mapping (e.g. grasslands, wetlands etc.).

What additional ecosystem services, habitats for ecological connectivity mapping, or other opportunities would you like to see included in the final Tool? (These can include the ones given as examples in this question, if they are of interest). *

16

Did using the prototype help you identify more benefits to existing projects and/or potential for new projects altogether? *

17

Did the prototype support your decision making and allow you to prioritise actions / projects at the landscape scale (the area of your pilot study)? *

18

How did you find the speed of the prototype? *

- ◯ Very slow
- ◯ Slow
- ◯ Average
- ◯ Fast
- ◯ Very fast

19

What features and functions of the prototype did you not find useful and/or intuitive to use? *

20

We are looking to do another round of piloting for the final Tool. We would like to give first priority to our existing pilot groups for the prototype testing (yourselves).

Would you be interested in being part of a pilot for testing for the final Tool? *

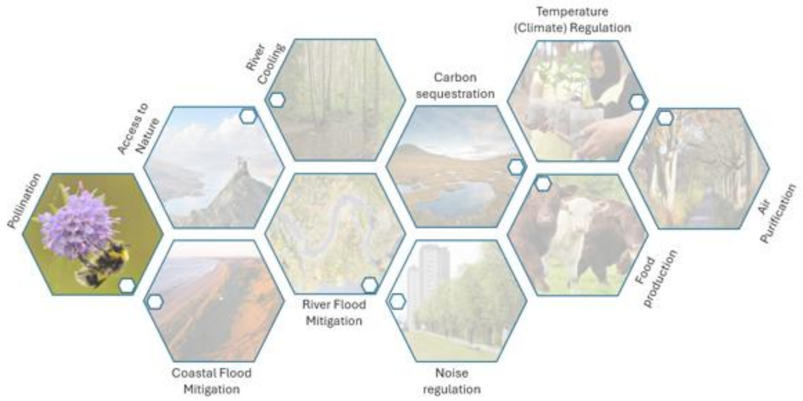
- ◯ Yes
- ◯ No
- ◯ Maybe

21

How would you prefer to receive instructions for using the Tool? Please select as many as are relevant. *

- ☐ Written guidance (e.g. PDF)
- ☐ Video tutorial
- ☐ An interactive tour once the Tool is launched

Appendix 11: Pollination workshop report



REPORT

POLLINATOR WORKSHOP

ABOUT THE REPORT

Thank you for your participation in our Ecosystem Services Workshops. This report summarises the outputs of the workshop and highlights lines of inquiry that we will explore going forwards and leading up to the public release of our Tool by the end of March 2025. The report and its outputs reflect the three-part structure of the workshops.

If you have any further insights or questions, please get in touch at cameron.singh-johnstone@nature.scot.

STEP 1 – PARAMETERS

Participants were asked to list parameters that they considered to impact the **capacity and demand** of habitats in relation to pollination. This allowed for the establishment of a baseline of parameters which informed the course of the workshop and discussion.

These parameters were then voted on by participants to establish popularity. The most popular choices were clustered thematically to inform the discussion in Steps 2 and 3. The less popular choices were not actively discussed in Steps 2 and 3, but were nonetheless included in the final research outputs of the workshops.

PARAMETER	VOTES
Larva habitat suitability	6
Average climate / weather	5
Habitat patch size	4
Linear feature hedgerows	4
Pollinator movement / habitat connectivity	4
Habitat fragmentation	3
Species diversity within patch	3
Shelter availability	3
Flowering crops	2
Habitat type	2
Location / number of managed pollinators	2
Light pollution	2
Drought resilience	2
Pesticide use	2
Species competition	1

STEP 2 – DATA, EVIDENCE AND COMMENTS

Having identified and voted on different parameters, participants were then asked to list data, evidence and comments that they felt were most relevant. These were synthesised below and will be drawn upon by the Natural Capital Team in the next development phase of the Tool.

PARAMETER	DATA AND EVIDENCE	COMMENTS
Habitat patch size and fragmentation	Habitat Map of Scotland	Can be quite high-level in terms of habitat types.
	'Light pollution can be a pollinator barrier', Knop, E., Zoller, L., Ryser, R., Gerpe, C., Hörler, M. and Fontaine, C., 2017. Artificial light at night as a new threat to pollination. *Nature*, *548*(7666), pp.206-209.	Many pollinators will not cross waterbodies or large roads.
	Neighbourhood planting - case study from Arnhem https://www.arnhemzoemt.nl/	This can be highly variable and very localised, some fragmented habitats such as households proving greater or lesser support for pollinators.

PARAMETER	DATA AND EVIDENCE	COMMENTS
Hedgerows and other linear features	*'The effects of land use and climate change on British bumblebees'*, Journal of Applied Ecology 59: 1837	Research highlights that hedges and lanes were particularly associated with number of bumblebee species.
	Satellite data	Can be used to identify location and types of linear features.

PARAMETER	DATA AND EVIDENCE	COMMENTS
Average climate and regional weather	Drought modelling impacts on vascular plants, Megan Stamp	Predicts flowering and impacts on pollinators
	Flood risk mapping	Flooding can destroy shelter for overwintering and summer, many pollinators are ground nesting.
	Had-UK dataset, 1km climate observational data from Met Office	Freely available data including annual rainfall, temperatures etc.
	'*Landscape impacts on pollinator communities in temperate systems: evidence and knowledge gaps'*, Senpathi, D	Interplay between landscape and pollinators

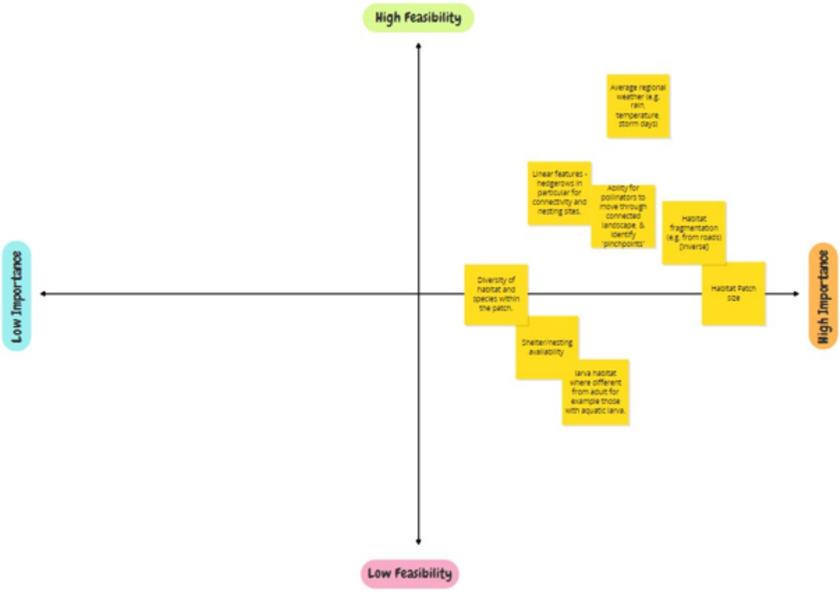
PARAMETER	DATA AND EVIDENCE	COMMENTS
Ability for pollinators to move through connected habitats and identify 'pinch points'	'Evaluation of landscape connectivity between protected areas using pinch points', September 2021 Turkish Journal of Forestry	n/a
	'Addressing issues of conservation concern based on Principles of Landscape Ecology'	n/a
	Least cost modelling, Clyde Grasslands Brochure - GCV Green Network	n/a

PARAMETER	DATA AND EVIDENCE	COMMENTS
Shelter and nesting availability, and larva habitat where different from adult, e.g. aquatic larva	Ops Officer Lorna Blackmore's PhD work looking at shelter and larval needs of hoverflies	Work yet to be published. Consideration given to pollinator larva needs such as habitat and food sources often disproportionately low

PARAMETER	DATA AND EVIDENCE	COMMENTS
Diversity of habitat and species within a patch	Research on commercial pollinators foraging with less biodiversity showing poorer health, so could apply to wild pollinators?	Agricultural mono crops vs beetle banks and hedgerows
	'*Bumblebee family lineage survival is enhanced by high quality landscapes'*, Carvell et al, Nature	Good info on what constitutes a 'high quality landscape'.
	Positive correlation between biodiversity and carbon sequestered by grasslands, Grasslands-as-a-Carbon-Store.pdf (plantlife.org.uk)	n/a

STEP 3 – FEASABILITY AND IMPORTANCE

Participants were lastly asked to discuss and rate the feasibility and importance of the most voted for parameters in Step 1 as they were clustered in Step 2 on an axis chart. Parameters with the highest average feasibility and importance were **Average Regional Weather**, **Hedgerows and other Linear Features**, **Pollinator Movement through Connected Landscapes** and **Habitat Fragmentation**. Comments and discussion points were linked to different parameter ratings to highlight points of further consideration for tool development.



Habitat patch size and fragmentation

- Many of these parameters are interconnected. A resilient landscape with connectivity and diversity will be able to support pollinators in changing weather condition.
- Patch size must be linked to biodiversity as a large patch with low biodiversity would likely have less capacity than a small patch with high biodiversity
- Proximity of other patches relevant here, i.e. a small patch's capacity could be higher if other small patches are nearby
- Clyde Grasslands study identified patches with an area of 0.5ha as core habitats of species rich grassland

Average Climate and Regional Weather

- Depends on the broad taxonomic groups, e.g. different relationships among butterflies and climate and bees and climate.
- Weather impacts on forage plants and shelter, some species adapt better than others

Hedgerows and other Linear Features

- Hedgerows are important for nesting and foraging, as are small lanes
- Is there an inverse relationship with habitat size and quality and a need for linear features?

Diversity of Habitat and Species within Patch

- Arguably even more important than habitat size, both within and across different habitats

Shelter and nesting availability and larva habitat

- These are often small scale habitat features that are hard to capture in landscape scale data, but would be good if possible

NEXT STEPS

The next few months will involve following lines of inquiry drawn from our workshops. We will explore these model by model, considering which of these we can incorporate into our ecosystem service models between now and our release date by the end of March 2025.

We will release a report outlining which aspects of feedback were incorporated into the model in March 2025. This will be distributed to all participants of the workshops as well as our co-design group. For any further inquiries about our Ecosystem Services Workshops, please email cameron.singh-johnstone@nature.scot.

Thank you for your participation in these workshops, we really appreciate your input.

Kind regards,

The Natural Capital Team at NatureScot

Appendix 12: Attribution of UN Sustainable Development Goals (SDG) to habitat creation interventions made in the Natural Capital Tool

Intervention	SDG
Cultivated / disturbed land	0
Gardens / Parks / Brownfield	3, 11
Green urban surfaces	3, 11
Water	0
Woodland, broadleaved	3, 6, 11, 13, 15
Woodland, coniferous	6, 8, 12, 13, 15
Woodland, mixed	3, 6, 8, 11, 12, 13, 15
Scrub	3, 6, 13, 15
Trees/Parkland	3, 11, 13, 15
Felled woodland	0
Grassland, semi-natural	2, 3, 6, 8, 12, 13, 15
Grassland, improved	0
Grassland, marshy	3, 6, 13, 15
Heathland	3, 6, 13, 15
Bog and fen	3, 6, 13, 15
Swamp	3, 6, 13, 15
Saltmarsh	3, 6, 13, 15
Sand dune	0
Built up areas	0
Roads	0
Pavement	0
Railway	0
Path	0
Garden	0