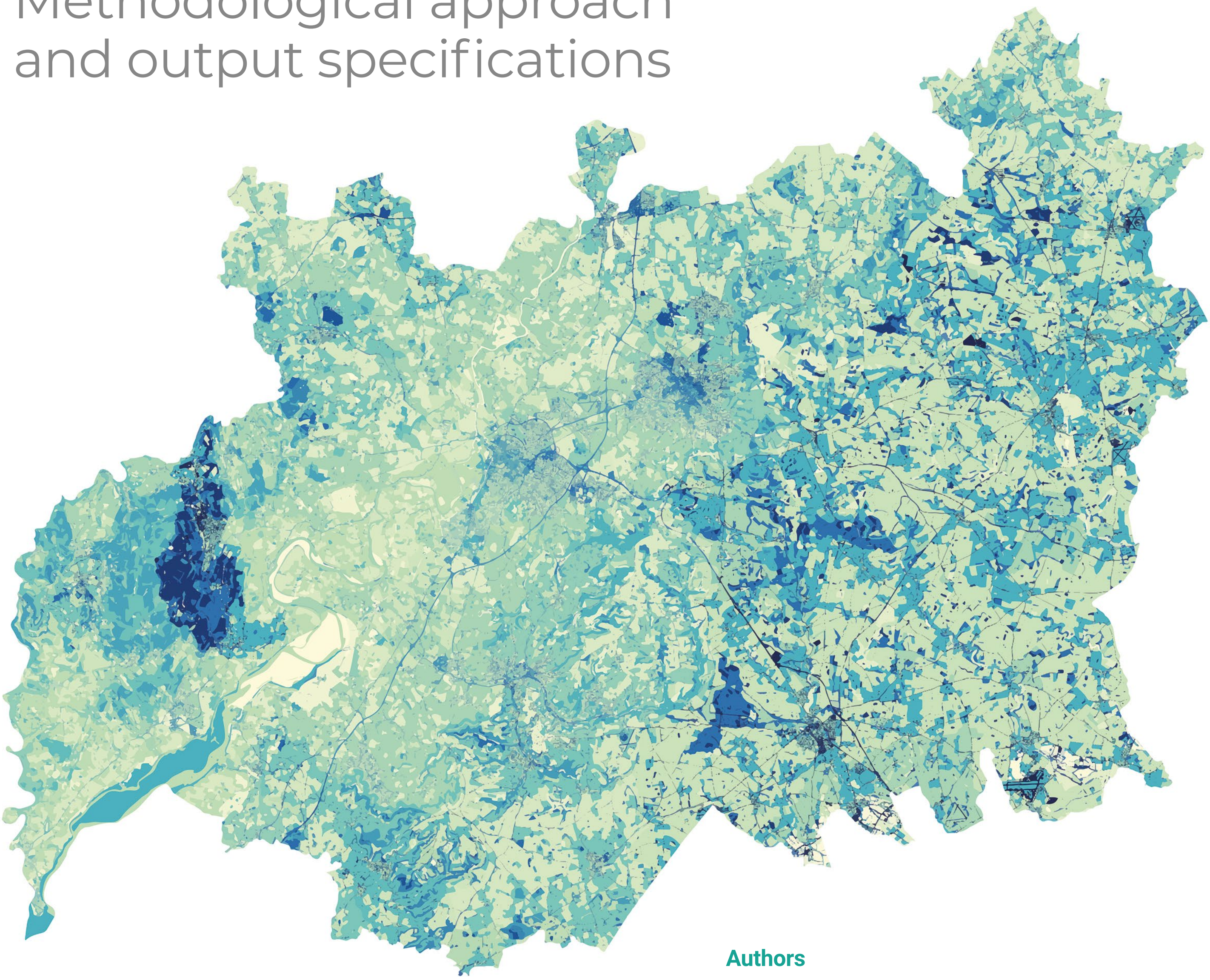
Natural capital and Ecosytem service mapping for Gloucestershire

Methodological approach and output specifications



Authors
Paul Jepson, Nature Recovery Lead, Ecosulis Ltd
Joseph Millington, Spatial Ecologist, Ecosulis Ltd

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GLOUCESTERSHIRE LOCAL NATURE PARTNERSHIP

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Authorship

This report was researched and written by Paul Jepson, Nature Recovery Lead, Joseph Millington, Spatial Ecologist, Ecosulis Ltd. with contributions from Sara King, former Senior Ecologist, Ecosulis Ltd.

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Disclaimer

Contact

Ecosulis Ltd
Harwell Innovation Centre
Building 173
Curie Avenue
Harwell Campus
Oxford, OX11 0QG

T: 01235 612216
E: info@ecosulis.co.uk
W: ecosulis.co.uk

Company Regisration Number: 372 4176
Vat Number: 601216305

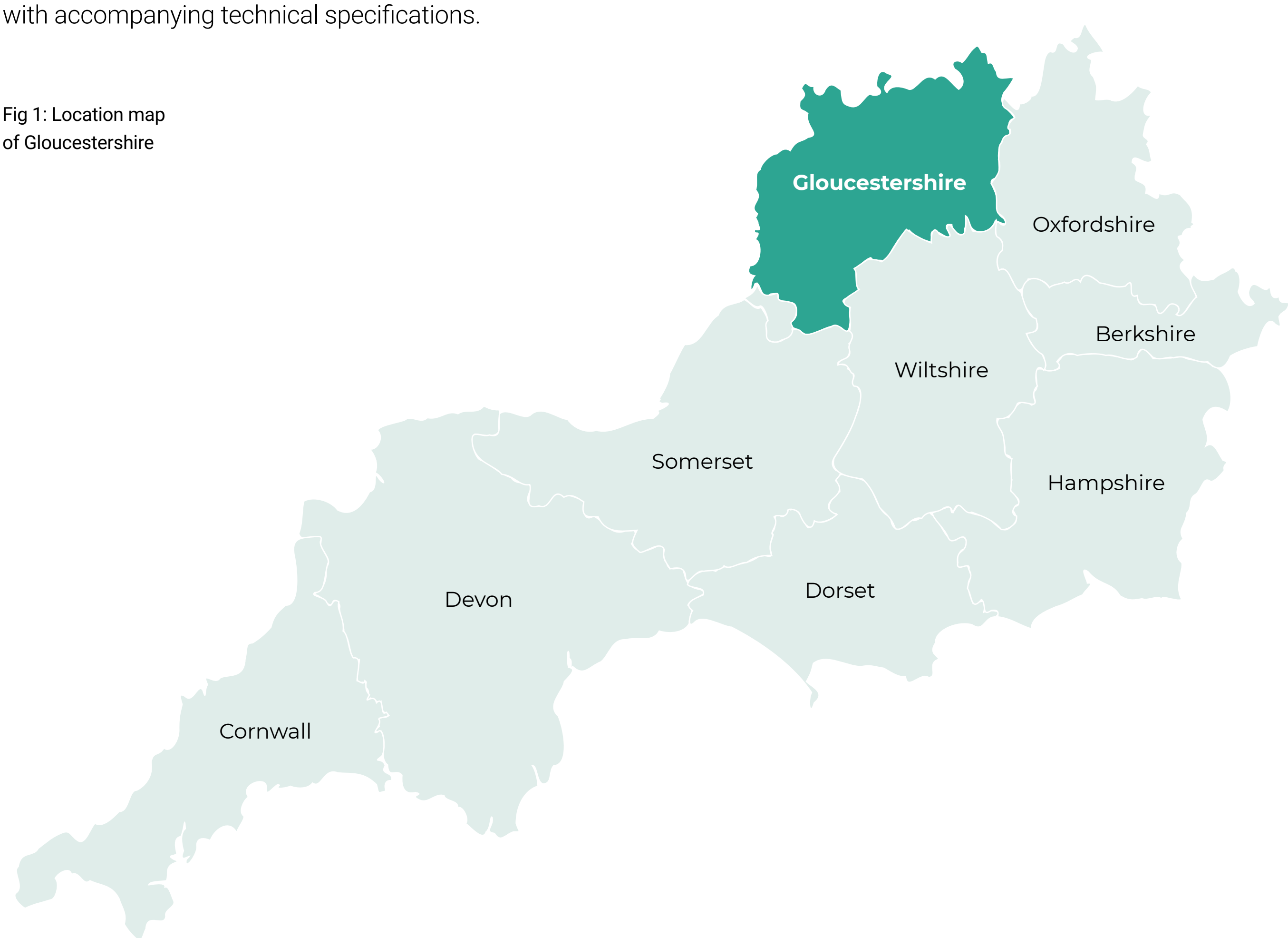
Contents

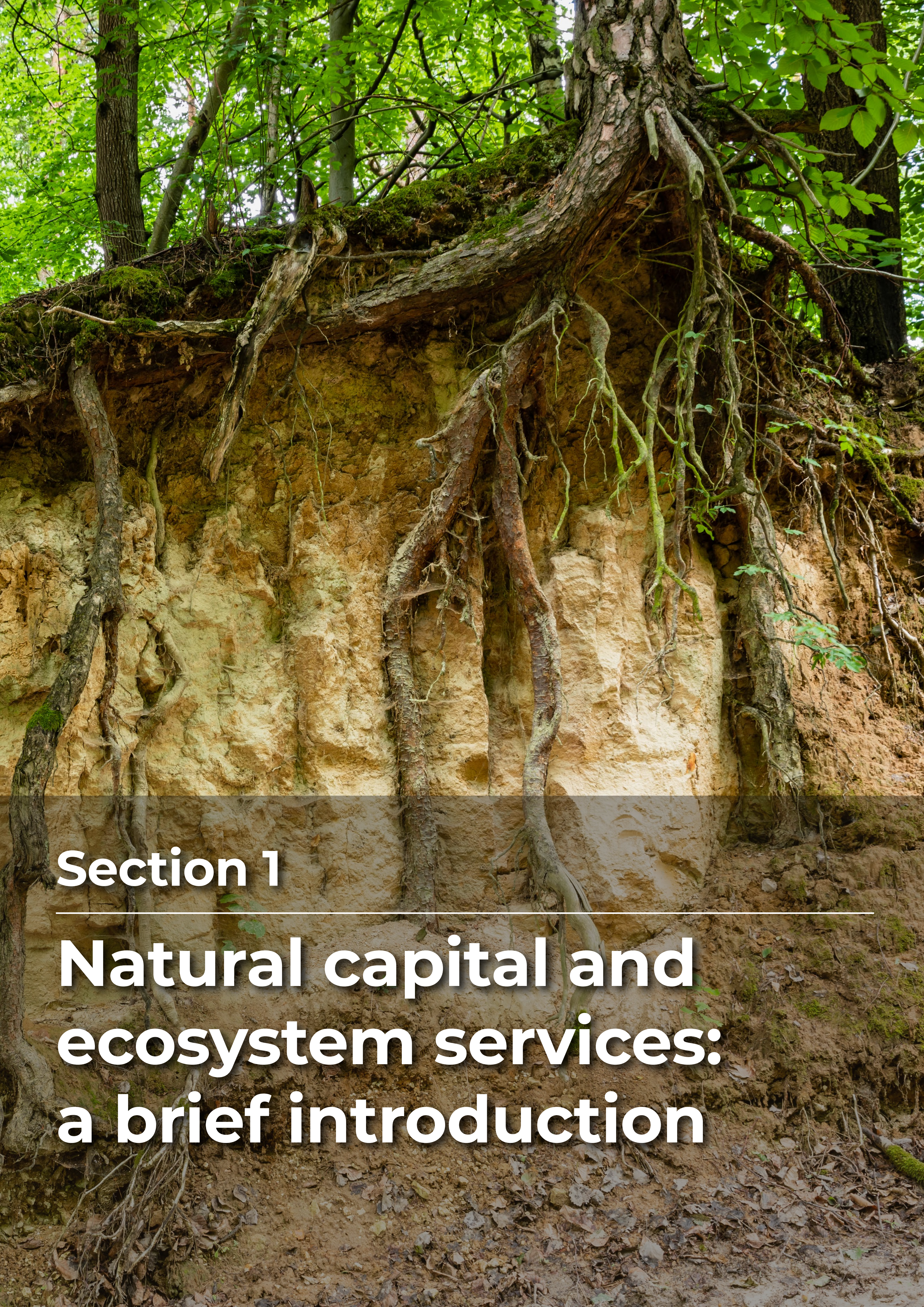
Introduction

In March 2020, Ecosulis was commissioned to develop a natural capital baseline map for Gloucestershire. The aim of this spatial mapping exercise is to create natural capital and ecosystem service maps to inform future decisions in the county, including biodiversity off-setting (linked to net gain), spatial planning, climate change policies, and natural capital investment. As part of this commission, Ecosulis was tasked with identifying and applying the best method for spatially mapping natural capital and ecosystem services, in accordance with a set of guiding principles and objectives generated in consultation with the steering group.

In the UK, natural capital mapping is still relatively new, and methods are still in development. They are emerging at the intersection of academic research seeking to apply the linked concepts of natural capital and ecosystem services, and DEFRA guidelines that seek to operationalise these concepts in policy delivery. This technical report is structured into three parts: the first section introduces the concepts of natural capital and ecosystem services and briefly reviews current approaches to natural capital mapping in the UK. The second part justifies and specifies the methodological approach and steps used to generate a series of natural capital and ecosystem services need maps for Gloucestershire. The third part presents the mapped output with accompanying technical specifications.

Fig 1: Location map of Gloucestershire




Section 1
Natural capital and ecosystem services: a brief introduction

1. Conceptual origins

1.1. The concept of natural capital arose during the early 1990s[1] to address shortcomings of conventional economics in relational to the environment. It extends economic logics by recognising that non-human life generates goods and services that contribute to economic activity and collective and individual well-being. The core idea is that ecosystems can be degraded or improved and such changes affect the 'production' of ecosystem goods and services.

1.2. An important milestone in the development of the natural capital concept was the Millennium Ecosystem Assessment (2005)[2], which popularised the concept in policy and established four broad categories of ecosystem services, namely:

- Supporting services
  (e.g. nutrient cycling, primary production, soil formation, pollination)
- Provisioning services
  (e.g. food, raw and medicinal materials, water purity, biomass fuels)
- Regulating services
  (e.g. climate regulation, predation, decomposition, flood control, disease control)
- Cultural services
  (e.g. cultural representations, spiritual, recreational and therapeutic experience, science and education)

1.3. The categorisation of ecosystem services initiated the development of techniques to a) value ecosystem functions, goods and services and incorporate these in economic cost–benefit analysis and b) spatialise natural capital and the production of ecosystem services. However, the development of both proved to be enormously challenging due to the complexity of interactions between ecosystems, society and economy and our limited knowledge on how many ecosystem services are produced. Operationalising the natural capital approach has required a mix of conceptual simplification, alignment of existing frameworks for classifying natural systems, and use of indicators that can be derived from available data sets.

1.4. Research on ecosystem services has focused on spatially explicit economic and ecological models. This is because, in economics, value is associated with a trade-off (the cost of one course of action compared to another) and this often manifests in spatial planning decisions. Further, this is because the production and use of services from ecosystems varies spatially and this affects their value. The purpose of natural capital mapping is to quantify existing ecosystems (the underlying natural capital assets) and the ecosystems services they produce for use in different forms of spatial planning. There are generally two components to this: a)

1 See Costanza, R. and Daly, H.E., 1992. Natural capital and sustainable development.Conservation biology,6(1), pp.37-46.

2 See https://www.millenniumassessment.org/en/index.html which was informed by The Economics of Ecosystems and Biodiversity (TEEB) initiative (2008-2011) http://www.teebweb.org/

mapping the existing state of both and b) identifying investment opportunities that will arise from the production of beneficial ecosystem services in strategic locations.

2. Operationalising natural capital and ecosystem services in the UK

2.1. The UK Government was an early adopter of the natural capital discourse. In 2009, DEFRA commissioned a National Ecosystem Assessment (UK NEA) and put natural capital logic at the centre of its 2011 Natural Environment White Paper, entitled The Natural Choice: Securing the Value of Nature [3]. In 2012, the Government established the Natural Capital Committee (NCC) to provide expert, independent advice to the Government on the state of England's natural capital.

2.2. The NCC (2013) defined natural capital as: 'The elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions. Natural Capital is a broad term that includes many different components of the living and non-living natural environment, as well as the processes and functions that link these components and sustain life.'

2.3. The UK NEA defined ecosystems in terms of broad habitat types. It viewed ecosystem processes as the product of interactions between different groups of organisms and argued that the diversity of species underpins the functioning of ecosystems and thereby the delivery of ecosystem services. Furthermore, the UK NEA argued that in a UK ecosystem, the great majority of primary producers are higher plants [4]. This interpretation enabled alignment between the policy discourses of natural capital and biodiversity and retention of habitat as the primary spatial unit of nature for conservation planning, protection and accounting.

2.4. Natural capital approaches are based on the logic that if stocks of natural capital are maintained in good condition (in terms of quality and quantity), they will deliver a sustainable flow of the ecosystems services that underpin human health and well-being. In the UK, the concept of a natural capital stock has been aligned with our habitat-based approach to conservation planning and management. Different types of habitat are equated to different categories of natural capital 'stocks'. The UK NEA specifies eight broad habitat types: i) Urban, ii) Enclosed Farmland, iii) Mountains, Moors and Heathland, iv) Freshwater, v) Woodland, vi) Coastal Margins, vii) Marine, and viii) Semi-natural Grassland.

2.5. The latest DEFRA guidance on 'Enabling a Natural Capital Approach' (March 2020) adopts a more nuanced and conceptually rigorous definition of natural capital. It gives more focus to ecosystems, noting that natural capital includes 'both the living and non-living aspects of ecosystems' and notes that whilst 'stocks' of natural capital provide flows of services, the benefits these produce emerge in combination with other forms of capital (human, produced and social).

3 https://www.gov.uk/government/publications/the-natural-choice-securing-the-value-of-nature
4 http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

2.6. The guidance also clearly restates the reality that ecosystem services generate 'use' values with both monetary (e.g. timber, fish), non-monetary (e.g. landscape beauty) and 'non-use' values (e.g. the value people may place on the knowledge that nature is recovering). As a result of this more relational concept of natural capital, the term natural capital asset is coming to replace the term 'stocks of natural capital' [5]. The UK NEA opted not to specifically consider supporting ecosystem services, on the basis that they do not produce outputs for final consumption or production but underpin the other categories, thereby introducing a risk of double counting. The latest DEFRA guidance continues this approach and adopts a category of 'bundled ecosystem' services, in recognition of the fact that benefits produced from natural capital are not easy to disaggregate into specific types of ecosystem services, and many supporting services are included in 'reduceable bundled services'.

2.7. The five DEFRA ecosystem service categories (Table 1) introduce a sub-category of provisioning services entitled 'abiotic flows of nature capital'. These include minerals and wind, and capture the interaction between ecosystems and Earth systems over geological time. These components of natural capital are mapped by the minerals and energy sector and are already integrated into spatial planning. However, they merit consideration in natural capital mapping because both sectors offer partnership opportunities linked to restoring or creating new natural capital. On the basis that abiotic flows are likely to have already been mapped, this category was excluded from the natural capital mapping project for Gloucestershire.

2.8. The 2020 DEFRA guidance has further sub-divided these categories into 18 ecosystem types with tangible examples of each service that can be mapped, measured and assigned a value. This is based upon the Natural Ecosystems Assessment Methods of Natural Capital (2016).

Databook Category	Description	Examples
Provisioning	Tangible outputs that can be obtained from ecosystems that meet human needs	Food, timber, supply, crops
Abiotic flows of natural capital	Flows which are not dependent upon functioning ecosystems	Minerals, oil & gas, solar, wind and tidal power
Regulating services	Ecological processes that regulate and reduce pollution and other adverse effects	
Cultural Services	Environmental settings that enable cultural interaction and activity	Settings for recreation, education, tourism
Aggregated/bundled services	In practice the benefits provided by nature are not easily reducible to specific ecosystem services, or can reflect a bundle of cultural or regulating services. There can be overlap with these categories.	Amenity, biodiversity, landscape, water quality, non-use values

Table 1: Services provided by Natural Capital, source: Enabling a Natural Capital Approach Guidelines (source. Defra, March 2020)

5 The words 'house' and 'home' illustrate this distinction between stock and asset. In the language of economics, we can speak of the housing stock and attribute a capital (monetary) value to this, and account for revenues in terms of rents or council taxes that these capital assets generate. On the other hand, the value for people and society is as a home: an asset that produces life-quality value and cannot be easily quantified. However, we know that a nice garden, access to green space or a beautiful view will increase the capital value (cost) of a home.

2.9. The effort to apply economic frameworks to the management of complex socio-ecological systems has been at the cost of some conceptual rigour and over-simplification. This is particularly the case in the mapping and valuation of cultural ecosystem services. Indeed, the authors of a Natural England research report on mapping ecosystem services questions concluded that it was questionable weather habitat-based maps could capture the CES described in the NEA.

3. Natural capital mapping initiatives in England

3.1. Despite these conceptual and methodological challenges, a number of approaches for natural capital mapping have been developed in the UK that offer a workable framework for integrating the value of natural capital into cross-sectoral, spatial decision making.

3.2. Spatial planning of nature gained momentum 15–20 years ago in response to requirements for local authorities to produce local biodiversity action plans and the launch of the 'Living Landscapes' programme by the Wildlife Trusts. The primary approach has been the production of polygon-based, priority habitat and ecological networks plans (which are the basis of Nature Recovery Network plans). These present boundaries (e.g. cores and corridors), which are required in the local planning system.

3.3. Natural capital mapping is newer and involves the production of raster (grid cell) maps that assign a nature-related value. An advantage of the natural capital mapping approach is that all land is assigned a natural capital or ecosystem service value, whereas the established polygon-based approach leaves large areas of the map blank. Because of this, natural capital maps are better suited to master planning (which often involves modelling), attracting investment and possibly for promoting nature recovery in agricultural settings through integration with the new ELMs.

3.4. Three methodological approaches have been applied in regional natural capital mapping in England. All use habitats as proxies for the potential of a particular area to deliver a particular ecosystem service. These are based on existing habitat typologies and do not make any reference to the quality of a habitat.

3.5. The SENCE (Spatial Evidence for Natural Capital Evaluation) toolkit has been developed by Environment Systems Ltd. This adds an ecosystem service value to existing ecological (habitat) network maps by overlaying them with, for example, flood risk maps.

3.6. The Greater Manchester initiative led by Eftec and Environmental Finance and Countryscape Ltd. was designed to inspire the design of financial models for natural capital maintenance and creation. It focused on mapping ecosystem services that could attract investments, specifically:

- Physical and mental health and wellbeing derived from exposure and access (i.e. recreation and aesthetics),
- Sustainable travel (e.g. cycle paths where natural capital is enhanced),
- Water quality and flood management (surface water and fluvial),
- Climate regulation - carbon storage and sequestration, urban cooling and building sheltering;
- Air quality improvements
- Habitat and wildlife conservation and enhancement (including through potential biodiversity net gain from developments and major infrastructure projects)

3.7. The Greater Manchester analysis combined data from assets (e.g. priority green infrastructure areas), quality indicators (e.g. water body classifications), social indicators (Index of Multiple Deprivation [IMD]), ecosystem services (e.g. Accessible Natural Greenspace Standards) and development areas (e.g. Strategic Housing and Employment Land Availability Assessment). Each opportunity layer was assigned a score of between 0 and 1 to express the natural capital investment opportunity across a 1km square grid. The scoring for each layer was then combined to create a heatmap across Greater Manchester to provide a broad visual overview of natural capital investment opportunities.

3.8. A habitat service scoring matrix (HSSM) approach was first applied by Natural England in 2014 at a national scale and has been further developed by a consortium led by Oxford University's Environmental Change Institute (ECI), for natural capital mapping in Oxfordshire and subsequently as an input to the OxCam master planning.[6]

3.9. The HSSM approach is based on a scoring matrix that assigns a score (0–10) to the potential of a habitat type to generate the list of 18 ecosystem services specified in the DEFRA guidance[7]. The scores enable the production of ecosystem service (natural capital) maps based on existing habitat maps. The HSSM was initially generated by expert assessment, but the ECI refined the scores based on the findings of a major systematic review of 780 scientific papers that provided evidence on links between natural capital and 13 regulating, provisioning and cultural ecosystem services[8]. A second methodological innovation was the application of 'multipliers' to some ecosystem services scores in locations where other factors may influence the supply of services, such as habitat quality and spatial location.

6 Smith, A. 2020 Natural Capital in Oxfordshire. A short Report. Environmental Change Institute, Oxford. https://www.eci.ox.ac.uk/research/ecosystems/bio-clim-adaptation/downloads/bicester-Natural-capital-mapping-in-Oxfordshire-Short-report-V2.pdf

7 ITRC (2020). A Sustainable Oxford-Cambridge Corridor? Spatial analysis of options and futures for the Arc. Infrastructure Transitions Research Consortium.

8 Smith, A.C., Harrison, P.A., Soba, M.P., Archaux, F., Blicharska, M., Egoh, B.N., Erős, T., Domenech, N.F., György, Á.I., Haines-Young, R. and Li, S., 2017. How natural capital delivers ecosystem services: A typology derived from a systematic review. Ecosystem Services, 26, pp.111-126.

3.10. The HSSM is a key component of a forthcoming Eco-metric tool that is being co-developed with DEFRA and Natural England to work alongside the DEFRA biodiversity metric to support the delivery of natural capital net gain (that links biodiversity net gain with environmental net gain). The HSSM approach is very similar to that adopted in Scotland's Natural Capital Accounting Index (NCAI)[9] (see Fig. 2 below). This index is designed to provide a high-level indicator (cf. GDP) of the state of well-being benefits generated from the ecosystem services produced by natural capital stocks. It does not involve a spatial component. However, the basic methodology components are the same, and it offers ideas for how county-level natural capital mapping could be adapted to an index and/or investment return.

3.11. Alongside the above developments, the Environment Agency (EA) is incorporating the natural capital approach in its spatial modelling and decision making. This is linked to its expanded remit from being a largely regulatory agency towards having a more active role in place-making and environmental 'betterment'. The EA views natural capital as assets that support a supply-chain of goods required for the production of economic as well as social goods and is researching the business dependency of different ecosystem services. Methodologically, they have adopted an 'absolute measurement' approach to natural capital mapping. As with other approaches, this adopts habitat type as the unit of natural capital but attaches a quantitative measure of specific ecosystem services (e.g. m3 of water, tonne of pollutants removed) based on evidence from the scientific literature. These are attributed a value using the DEFRA Ecosystem value look up table, which enables natural capital to be used in accordance with HM Treasury Green Book guidelines concerning the appraisal of polices, programmes and proposals. A limitation of this approach is that the current evidence base is limited to very few ecosystem services. Whilst the ES matrix approach adds monetary value, it has the benefit of being comprehensive and consistent and provides relative measures of impact and opportunities.

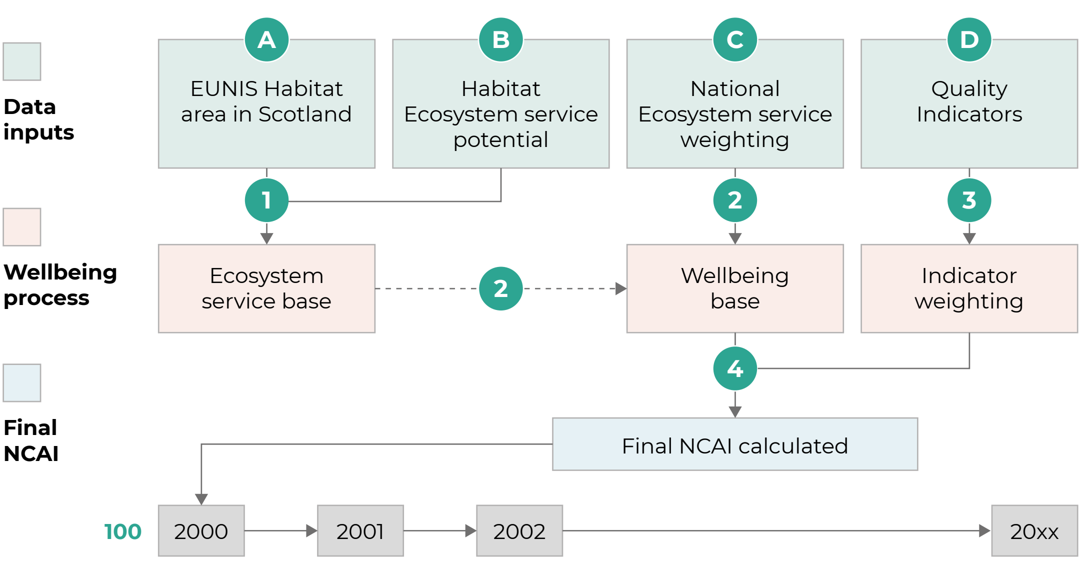


Fig. 2: Flow diagram of Scottish Natural Capital Asset Index redrawn from McKenna et al. Ecological Indicators, 107, 2019. Boxes A-D are the four data inputs and numbers 1 to 5 the processing workflow.

9 McKenna, T., Blaney, R., Brooker, R.W., Ewing, D.A., Pakeman, R.J., Watkinson, P. and O'Brien, D., 2019. Scotland's natural capital asset index: Tracking nature's contribution to national wellbeing. Ecological Indicators, 107, p.105645.

Section 2

Methodological approach used to map ecosystem services in Gloucestershire

Photo: JJobes

4. Mapping objectives

4.1. The mapping project was overseen by the GLNP Partnership co-ordinator and the Data Steering Group, which was established to approve the methodological approach and advise on data and other technical issues. In May 2020, the group agreed the following principles to guide the project:

i. The mapped outputs must be accessible and usable by all stakeholders involved in decisions relating to land in both urban, semi-urban and rural areas.

ii. The underlying data must be accessible and be supported by clear metadata and records of data ownership that show how it was processed and updated.

iii. The resolution of maps should be appropriate to the data and the application of the maps.

iv. Mapped outputs should be produced and communicated in a manner that generates trust and buy-in from landowners and managers.

v. The methodological approach should support regular updating of the evidence base, be improvable and form a baseline for monitoring the impact and performance of natural capital.

vi. It should assess land according to its ecosystem services potential, in addition to its present use.

vii. It should have a commercial opportunity for hosting and distributing the map.

viii. Mapped outputs should be compatible with other national approaches, e.g. Buglife B-lines, and support a future biodiversity net-gain strategy.

ix. Mapped outputs should be produced and communicated in a manner that generates trust and buy-in from landowners and managers.

5. Methods and approach

5.1. It was agreed that the HSSM approach was best suited to deliver the mapping objectives because it is closely aligned with DEFRA/NE logic and guidelines. In addition, the scoring matrix supports the principles relating to accessibility and updatability of the underlying data.

5.2. To ensure the data sets are accessible to a wide range of users, they have been made available on a new interactive website developed by the Gloucestershire Centre for Environmental Records (GCER) on behalf of GLNP. Key metadata on each map, along with methodological notes, are presented in Section 3 of this report and relevant information is included in the website.

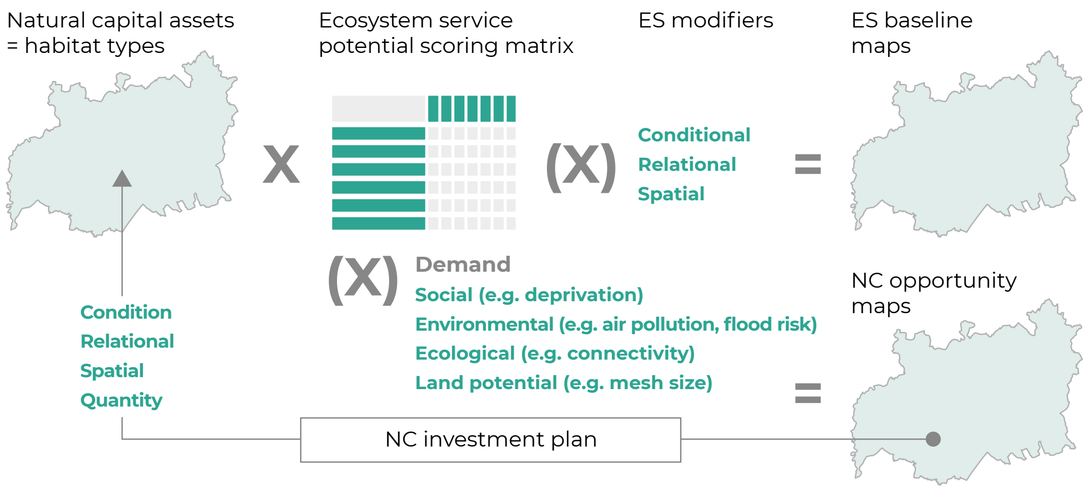


Fig. 3: Methodological flow used to map ecosystem services in Gloucestershire adapted from Smith et al. 2020.

5.3. The methodological steps adopted are shown in Fig 3. As mentioned previously, the natural capital mapping uses habitats (reframed as natural capital assets) as a proxy for a potential area to produce ecosystem services. We used the Gloucestershire Complete Coverage Habitat Map, V1 April 2020 (GCHM). In brief, this 'base layer' was created by attributing OS Mastermap polygon shapefiles with habitat data from the Centre for Ecology and Hydrology (CEH) land cover map 2015. Habitat boundaries based on the 2018 UK Habitats Classification System were generated through spatial analysis of the following layers. OS Mastermap data on water, roads and built environment, the National Forest Inventory, Habitat Inventory England, Phase 1 habitat surveys (from GCER, National Trust, Wye Valley AONB) and Butterfly Conservation Society. The base Key Sites. The GCHM supports mapping down to 2m by 2m grid squares resolution.

5.4. The GLNP requested that we apply the Habitat Service Scoring Matrix to 69 habitat classes (7 Level 1, 20 Level 2, 23 Level 3, 1 Level 4, and 18 secondary codes) in order to enhance the value of the mapping for net-gain planning and influencing a future ELMS. This creates smaller spatial units that in turn create more complex and harder-to-interpret maps and may stretch the assumption that habitats and specific ecosystem services can be linked. It also required assigning ES scores to some L2 and L3 habitat classes not covered in the Oxfordshire application. This was conducted through expert review (the GLNP data partnership informed by the Oxfordshire scores) (see Annex 1). The process takes each ES and assigns each habitat a potential score for each ES on a 0 to 10 scale, where 0 means that the habitat definitely does not produce the ES specified, 1–3 = low level of provision, 4–6 = moderate level and 7–10 = high level.

5.5. In addition, it was decided to focus on 13 ecosystem services based on ES priorities for Gloucestershire, available data and time constraints (Table 1). Following the HSSM approach, we applied multipliers in cases where the potential for a natural capital asset to generate an ecosystem service is enhanced by either its condition, location and/or relation to other types of assets. This was a conceptually challenging aspect of the methodology because it required us to distinguish between potential of habitat to deliver and ES (the baseline map) and demand/need for an ecosystem service (the opportunity/need map). In reality, ES opportunity and need overlap and the distinction depends on the ES concerned. We used the term *need* when we were able to apply modifiers to identify particular areas (for example the ES of air pollutant removal where there is a strong spatial correlation between where air pollution is generated and where natural capital assets are required) and the term *opportunity* where benefits are less localised such as the ecosystem service of biodiversity or recreation where there are multiple locations.

5.6. The baseline maps that have a modifier applied and the ES for which both baseline and opportunities maps have been prepared are identified in Table 2. The reasoning and methods for each ES are provided in Section 3. In addition, composite ES baseline and opportunity maps were produced by comparing scores for each habitat type for all ecosystem services and producing a sum of the amount of ecosystem services for which the habitat scored greater than or equal to 7 (or 70% of the maximum value).

6. Mapping and scoring cultural ecosystem services

6.1. The Covid summer of 2020 has brought to the fore the value of natural assets for our health and well-being and has increased demand for access to cultural ecosystem services. Dales et al. (2014) concluded that habitats were not a valid proxy for mapping CES provision and instead used data sets that indicate where people experience CES (e.g. AONB designations). This approach has problems of its own, so for methodological consistency the Oxford team populated the HSSM with CES scores based on expert review expert review, photo analysis and literature review. However these scores as adapted by the GLNP review groups appeared to exhibit levels of subjectivity and 'conservation desirability' bias that would render the outputs unreliable.

7. A new CES habitat service scoring methodology

7.1. To overcome this subjectivity issue and develop the HSSM approach, we devised an alternative scoring methodology based on the natural asset approach, which was developed to address some of the limitations of the natural capital approach. This considers value as a relational outcome and is consistent with developments in ecosystem service theory, which increasingly recognises CES as an outcome of engagements between human culture and nature over time[10]. Specifically it postulates that: i) the human, social and cultural benefits provided by nature are an outcome of practices of engagement with natural assets (outdoor activities), ii) the different benefits (physical and mental health, sense of places etc.) gained from participating in different activities can be scored on a 0–10 scale, and iii) the suitability of a particular habitat for a particular outdoor activity can similarly be scored.

10 See e.g. Chan, K.M., Guerry, A.D., Balvanera, P., Klain, S., Satterfield, T., Basurto, X., Bostrom, A., Chuenpagdee, R., Gould, R., Halpern, B.S. and Hannahs, N., 2012. Where are cultural and social in ecosystem services? A framework for constructive engagement. BioScience,62(8), pp.744–756.

Table 2: Summary of ecosystem service definitions and applied modifiers

<table>
<tr><th colspan="2">Ecosystem Service</th><th>Definition</th><th>Baseline Modifier</th><th>Opportunity Modifier</th></tr>
<tr><td rowspan="2">Provisioning</td><td>Food Provision</td><td>Agricultural and horticultural production of food products via arable crops, livestock, vegetables, and fruits. Production of food products (i.e. berries, fungi, and game) through gathering and hunting practices.</td><td>Agricultural Land Classification (ALC).<table><tr><th>ALC Grade</th><th>Modifier Value</th></tr><tr><td>1</td><td>3.03</td></tr><tr><td>2</td><td>2.40</td></tr><tr><td>3a</td><td>1.83</td></tr><tr><td>3</td><td>1.33</td></tr><tr><td>3b</td><td>1.00</td></tr><tr><td>4</td><td>0.67</td></tr><tr><td>5</td><td>0.50</td></tr></table></td><td>No modifier applied.</td></tr>
<tr><td>Water Supply</td><td>The extent to which surface flow and groundwater recharge are impacted by soils and vegetation through processes of run-off and filtration.</td><td>No modifier applied.</td><td>Water Resource Availability as a Percentage of Time.<table><tr><th>Percentage</th><th>Modifier Value</th></tr><tr><td>95</td><td>1.2</td></tr><tr><td>70-94</td><td>1.4</td></tr><tr><td>50-69</td><td>1.6</td></tr><tr><td>30-49</td><td>1.8</td></tr><tr><td><30</td><td>2.0</td></tr></table></td></tr>
<tr><td rowspan="4">Cultural</td><td>Recreation</td><td>Provision of green and blue spaces that can be used for any leisure activity, e.g. walking, cycling, running, picnicking, camping, boating, playing or just relaxing.</td><td colspan="2" rowspan="4"></td></tr>
<tr><td>Education</td><td>Provision of green and blue spaces that can be provide educational benefit.</td></tr>
<tr><td>Interaction with Nature</td><td>Provision of opportunities for formal or informal nature-related activities, e.g. birdwatching, random encounters with wildlife, or feeling ‘connected with nature’. There is some overlap with biodiversity, but access by people can have negative impacts on some wildlife habitats. Excludes recreational fishing, hunting, shooting, intrinsic value of nature and existence value.</td></tr>
<tr><td>Sense of Place</td><td>The aspects of a place that make it special and distinctive – this could include locally characteristic species, habitats, landscapes or features; places related to historic and cultural events, or places important to people for spiritual or emotional reasons.</td></tr>
</table>

Table 2: Summary of ecosystem service definitions and applied modifiers

<table>
<tr><th colspan="2">Ecosystem Service</th><th>Definition</th><th>Baseline Modifier</th><th>Opportunity Modifier</th></tr>
<tr><td rowspan="4">Regulating</td><td>Carbon Storage</td><td>Quantities of carbon stored in soil and vegetation, rather than the ability of habitat to actively sequester carbon over time.</td><td>No modifier applied.</td><td>No modifier applied.</td></tr>
<tr><td>Water Flow Regulation</td><td>Impact of soil and vegetation on reducing surface run-off, peak flow, and flood extent and depth. Mechanisms include interception, evapotranspiration, infiltration, and physical water flow slowing.</td><td>Flow pathways (generated from DEM) intersected with habitat parcels.<table><tr><th>Intersect</th><th>Modifier Value</th></tr><tr><td>Yes</td><td>1.4</td></tr><tr><td>No</td><td>0.0</td></tr></table></td><td>Flow pathways (generated from DEM), Environment Agency flood risk data.</td></tr>
<tr><td>Local Climate Regulation</td><td>Cooling effects of vegetation and water, in particular in urban areas where these can reduce heating and cooling costs and provide areas of shade.</td><td>No modifier applied.</td><td>Distance from urban areas.<table><tr><th>Distance (km)</th><th>Modifier Value</th></tr><tr><td>> 0.25</td><td>1.0</td></tr><tr><td><= 0.25</td><td>0.0</td></tr></table></td></tr>
<tr><td>Air Pollutant Removal</td><td>Effect of vegetation on concentrations of air pollutants through mechanisms including deposition, absorption, and chemical breakdown.</td><td>No modifier applied.</td><td>Distance from national and regional roads, and urban areas.<table><tr><th>Distance (km)</th><th>Modifier Value</th></tr><tr><td>> 0.30</td><td>1.0</td></tr><tr><td><= 0.30</td><td>0.0</td></tr></table></td></tr>
<tr><td rowspan="3">Bundled Benefits</td><td>Biodiversity</td><td>The ability of a habitat to support a diverse range of species, providing a variety of environmental, social, and economic benefits.</td><td>GWT Nature Recovery Network, existing connectivity.<table><tr><th>Connectivity</th><th>Modifier Value</th></tr><tr><td>Core</td><td>2.0</td></tr><tr><td>500m</td><td>1.4</td></tr><tr><td>>500m</td><td>1.0</td></tr></table></td><td>GWT Nature Recovery Network, potential connectivity.<table><tr><th>Distance (km)</th><th>Modifier Value</th></tr><tr><td>High</td><td>1.6</td></tr><tr><td>Medium</td><td>1.4</td></tr><tr><td>Low</td><td>1.2</td></tr><tr><td>Existing Priority</td><td>0.0</td></tr></table></td></tr>
<tr><td>Water Quality</td><td>Uptake of pollutants dissolved or suspended in water by vegetation, and the ability of vegetation to prevent pollutants reaching waterbodies through interception and filtration.</td><td>No modifier applied.</td><td></td></tr>
<tr><td>Soil Health</td><td>Soil health is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans.</td><td></td><td>No modifier applied.</td></tr>
</table>

7.2. Our variant of the HSSM approach considers CES values (scores) to be a function of the interactions between a) the cultural and well-being values people experience from different types of outdoor recreation, b) the suitability of a particular habitat type for different outdoor recreation activities, and c) the diversity of outdoor recreation activities a habitat can support.[11]

7.3. To generate the HSSM scores, we first adapted a three-tier typology of value-generating practices (VGPs = outdoor activities) that was developed in Brazil to the UK context. We then generated scores based on our expert judgement for 30 L2 VGP categories assigned to four of five L1 categories, namely: i) outdoor games, ii) outdoor leisure activities, iv) outdoor hobbies and v) organised activities. The ECI team categorised CES into recreation, sense of place, education, and interaction with nature. The VGP approach scores the value that practices of engaging with nature generate for people, economy and society. The approach is easily adapted to generate scores for education, interaction with nature and sense-of-place ecosystem services but not for recreation (which is an activity as well as a benefit).[12] To overcome this, we generated scores for the physical and mental health, belongingness (sociality) and 'sense-of-purpose' benefits of each VGP. We then generated a new 'Well-being' ES by averaging the scores for these four benefits. A nature recreation ES score was then generated by averaging the scores for 'well-being', 'education', 'sense of place' and 'interaction with nature'.

7.4. Second, we scored such a habitat category and sub-category in the Gloucestershire HSSM matrix on a scale of 0–10 for its suitability for each VGP based on our expert judgement. We then multiplied the VGP scores by the Habitat Suitability Scores to create L1 and L2 habitat benefit scores (HBS).

7.5. However, the CES value of habitat is related to the diversity of different activities (VGPs) it can support. Furthermore, some habitats are extremely good for a few VGPs, whereas others are good for a range of VGPs. The novelty of our method means that typologies of leisure VGP (unlike habitats) are still under development and the number of L2 VGPs in each L1 category is based on 'visibility' rather than systematic research. To address this limitation and introduce standardised generation of L1 VGP scores, we aggregated the mean of the top three scoring L2 VGPs in each L1 VGP category. We then generated a Simpson Diversity Index (which measures evenness) value based on scores for L1 VGP categories. To conclude this third step, we then normalised the Simpson index values to 0–10 and multiplied the HBS value scores by this value to generate the habitat service score for each CES type.

11 In her informal review of this report A.Smith noted that the ECI team had incorporated factors b) and c) in their scoring.

12 Referred to as cultural identity and pride in the Natural Asset Framework.

7.6. A trial mapping of the resulting CES HSSM scores produced maps that were complex and difficult to interpret due to the large number of L3 habitats mapped at 2m x 2m grid square resolution. Furthermore, we question whether a CES can be assigned directly to VGP associated with L3 habitats. We therefore developed and applied a statistical procedure to aggregate and cluster L3 habitats at L2 habitat classifications and, as follows:

7.7. The mapped CES value appeared to be difficult to interpret due to the large number of L3 habitat classifications in the Gloucestershire HSSM at a 2m x 2m grid squares resolution. To overcome this problem and make the map more understandable, we merged habitats into clusters, using the following protocol:

Step 1: Convert smaller L3 habitat areas into single points corresponding to the centres of said areas (centroids).

Step 2. For each of the centroids, perform the K-Nearest Neighbour Classification on the points to capture the dominant habitat of the centroid with respect to its k-nearest neighbour.

7.8. This involved the following four sub-steps:

Select an arbitrary k value (k = 100).

For each x centroid, calculate the distance between x and the different other centroids. We used the Euclidean distance using the latitude and longitude values.

Sort the distances and determine the k-nearest neighbours based on minimum distance value to x.

Assign the new habitat category/cluster to x based on majority vote.

7.9. Our method provides a logical and systematic means for generating habitat-based scores for CES and has the advantage that the underlying data (VGPs) scores could be evidenced with quantitative data from, for example, citizen surveys.

8. Mapping centres of cultural ecosystem service delivery

8.1. The validity of using habitats as a proxy for CES delivery was questioned by Day et. al. (2014), who chose instead to map areas where people are expected to 'capture' CES using available data sets, such as national park boundaries. Our HSSM approach offers a more robust means to generate scores for habitats yet does account for the interaction of VGPs and multiple habitat types. Our view is that more than one form of spatial analysis is required in order to assess the CES value currently generated by natural assets and to identify areas for future investment.

8.2. A number of recent studies have analysed images uploaded to the photo-sharing platform Flickr as a proxy for where CES are being captured[12]. This method is underpinned by the logic that many people now carry a camera or smartphone when outdoors and take photographs when they experience something, and a proportion of camera-carrying people then upload and share their photographs on platforms. Flickr was one of the earlier photo-sharing platforms and all publicly shared photographs are available for analysis for the years 2004 to 2020. It is a form of 'big data' representing empirical evidence of where citizens have captured 'cultural value' from nature and landscape.

8.3. We downloaded all photographs and the associated information (n = 68,499) for Gloucestershire using the Flickr API and assigned them to a 1km x 1km grid (2,816 squares). They were then analysed with the label detection tool forming part of the Google Cloud Vision's algorithm, which attributes up to five keywords to each input image. Photographs for which the algorithm returned less than five keywords (n = 3,193) were excluded from further analysis. Next, we grouped photos based on their similarity using the Gibbs' Latent Dirichlet Allocation (LDA) topic modelling algorithm. Five simulations were obtained with different numbers of groups (3, 4, 5, 6, 7 and 8 groups) and we manually analysed the word composition of groups in each simulation, then selected the one which had the least variation of words and topics in its groups. This process identified two major groupings related to CES, which we termed 'landscape' (words relating to scenery and views) and 'nature' (words relating to nature objects). Photographs in these groups were then mapped using GIS procedures in QGIS software.

8.4. We then generated a landscape and nature score for each cell representing the total number of photographs. The two values were combined, and an inverse distance weighted interpolation was conducted using the total scores to calculate the value of cells with no data. This procedure generated a contour-like 'heat map' of CES (add reference to section 3).

12 See e.g. Retka, J., Jepson, P., Ladle, R.J., Malhado, A.C., Vieira, F.A., Normande, I.C., Souza, C.N., Bragagnolo, C. and Correia, R.A., 2019. Assessing cultural ecosystem services of a large marine protected area through social media photographs. Ocean & Coastal Management, 176, pp.40-48.

8.5. The above analysis identifies where CES value is captured, as measured by photographs uploaded to Flickr. To enhance the quality of the spatial model, we applied a visitor infrastructure multiplier based on the reasoning that areas with visitor infrastructure would generate CES for a wider cross-section of society and would have larger numbers of more frequent users who would not repeatedly upload photos to Flickr. To generate the visitor infrastructure multiplier layer, we classified visitor infrastructure on a four-point scale of 1 = no specific visitor infrastructure, 2 = car park, 3 = car park and toilets, and 4 = car park, toilets and visitor centre. GLNP member organisations that owned nature reserves and other natural assets were asked to supply information on sites with these categories of infrastructure and their responses were mapped. We then created an arbitrary 2km buffer around each infrastructure (as an estimate of common walking distance). The buffered area was assessed to represent its recreational effect on the surrounding landscapes and the buffer truncated where there was a clear obstacle, such as a main road or river. To combine the two data layers, all scores were converted to decimals.

8.6. We believe that these two spatial representations of CES service provision and capture represent the current state of the art in this aspect of natural capital mapping. However, they should be considered a 'first cut', which can be improved upon as techniques and data improve. As with other ecosystem services maps, they should be used in conjunction with the Gloucestershire Nature Recovery Network maps and as one input to natural capital investment planning.

Section 3

Specification of individual ecosystem services layers

Photo: JJobes

9. P1: Food Provision

9.1. Ecosystem service definition

Agricultural and horticultural production of food products via arable crops, livestock, vegetables, and fruits. Production of food products (i.e. berries, fungi, and game) through gathering and hunting practices.

9.2. Baseline methods and rationale

A relational (i.e. spatially modified) baseline dataset was produced to map food provision as an ecosystem service within Gloucestershire. Use of a spatial modifier was considered appropriate as the location of a given habitat was judged to be important in influencing its productivity, and therefore the provision of the service.

The modifying dataset and values were derived from the Oxfordshire natural capital study (Smith, 2020), which applied Agricultural Land Classification (ALC) data produced by Natural England (2020) as a modifier to the food provision ecosystem service baseline. These weighting values are provided in Table P1.1 below. These values were identified on the basis of estimated differences in productivity between each land class.

ALC Grade	Multiplier
1	3.03
2	2.40
3a	1.83
3	1.33
3b	1.00
4	0.67
5	0.50

Table P1.1: Multiplier values applied for each ALC grade

9.3. Opportunity Methods & Rationale

An opportunity dataset was not produced for the carbon storage ecosystem service due to the absence of a meaningful data that can be used to assess where the ecosystem service of carbon sequestration currently being delivered by natural capital assets is not meeting demand for delivery of the ecosystem service.

9.4. Limitations and Further Development

ALC data is not accurate enough to be used as anything other than general guidance, more accurate data should be used to indicate productivity of land, as a result, this dataset should not be used for assessment of individual land parcels, but rather for higher-level analysis.

The current habitat classification does not fully account for land management regimes, which may have a substantial impact on food production output.

Future work could include an assessment of different approaches to agriculture and food production (e.g. intensive, small-scale, crops, livestock) to provide a greater understanding of the spatial distribution of food provision in the county.

Data indicating productivity (the food production output) of land used for food production would also provide insights into the productivity of natural capital assets in delivering the food provision ecosystem service. Approaches to food production should be considered in the context of productivity data, to ensure impacts on other ecosystem services of these approaches are fully recognised; intensive agriculture can significantly impact water quality, for example.

An opportunity layer has not been produced for production, due to the current deficit of information regarding the location of natural capital assets managed for food production and the management regimes these assets are subject to. This data could allow production of an opportunity dataset through identification of how current food production is distributed in relation to the suitability of land to support food production.

9.4. References

Natural England, 2020. Provisional Agricultural Land Classification (ALC). Available at: https://data.gov.uk/dataset/952421ec-da63-4569-817d-4d6399df40a1/provisional-agricultural-land-classification-alc

Smith, A., 2020. Natural capital in Oxfordshire: Short report. Environmental Change Institute, University of Oxford.

P1: Food Provision (modified)

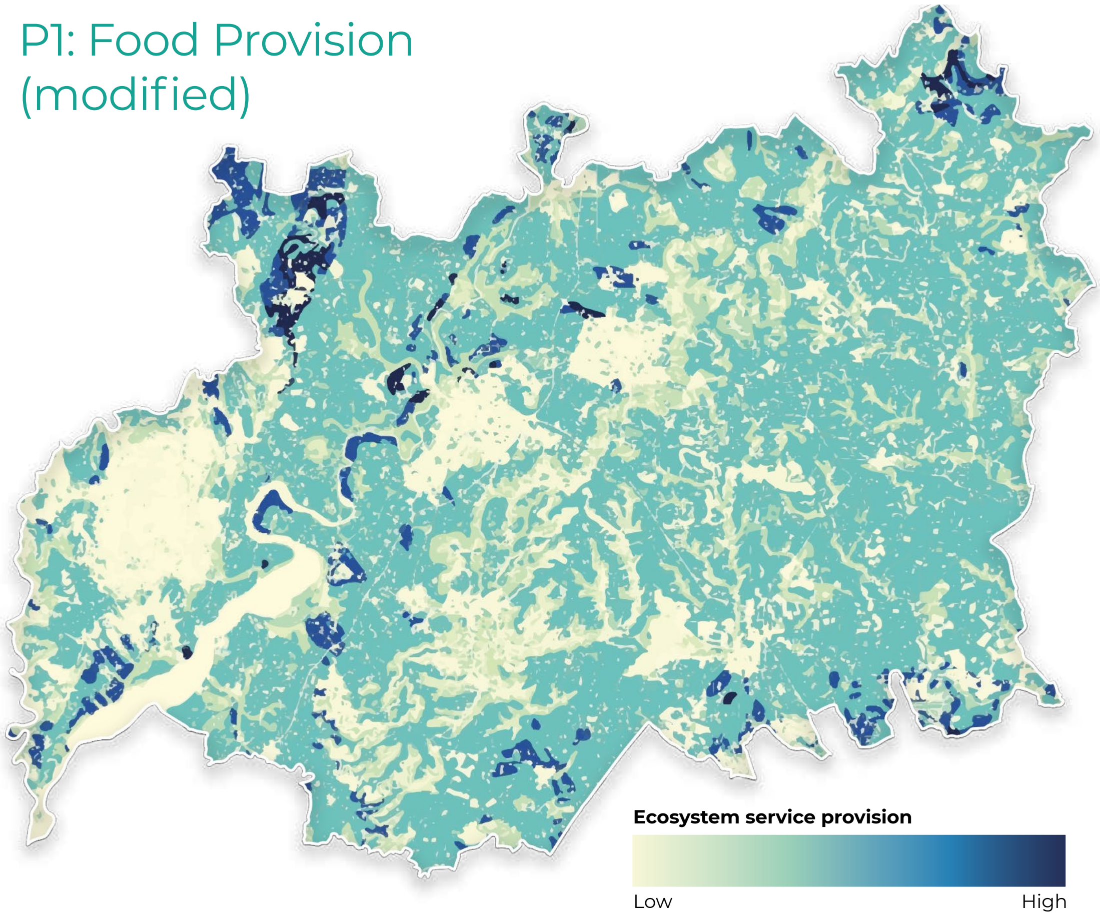


Figure P1.1: Food Provision Baseline (relational)

10. P2: Water Supply

10.1. Ecosystem Service Definition

The extent to which surface flow and groundwater recharge are impacted by soils and vegetation through processes of run-off and filtration.

10.2. Baseline Methods & Rationale

A non-relational baseline dataset was produced to map the Water Supply ecosystem service baseline within Gloucestershire. The rationale for not selecting a modification layer for the Water Supply baseline was the absence of an available dataset that could be used as a spatial modifier for the ecosystem service.

10.3. Opportunity Methods & Rationale

A relational opportunity dataset was produced to map Water Supply ecosystem service opportunity within Gloucestershire. The Environment Agency's (2020) Water Resource Availability and Abstraction Reliability Cycle 2 dataset was used as a spatial modification layer. This layer was selected as a proxy for water supply.

Water Resource Availability (% of time)	Multiplier
>= 95	1.2
94-70	1.4
69-50	1.6
49-30	1.8
<30	2.0
No available data	1.0

Table P2.1: Multiplier values applied for each classification of water resource availability

10.4. Limitations and Further Development

It is recognised that the ability for habitats to supply water is impacted by other spatial factors. However, a meaningful dataset that represented these factors could not be identified at the time of this study. Future work should further explore the availability of suitable modification layers to the baseline analysis to account for spatial variation of water supply provision. These datasets may include climate datasets (i.e. temperature, sun exposure, precipitation) and geological datasets (i.e. porosity, and aquifer location).

The opportunity methods modification dataset is not factual or measured, but rather modelled and estimated by the Environment Agency (2020) using best available data. Replacing this dataset with one which contains measured variables relevant to the potential capacity of a given area of habitat to supply water. In addition, the dataset is not fully contiguous and does not provide full coverage for Gloucestershire; where this is the case, a modifier value of 1.0 has been used.

The use of the water resource availability data as a modifying dataset also assumes that water resource availability is only impacted by habitat type and does not account for extraction activities in these regions.

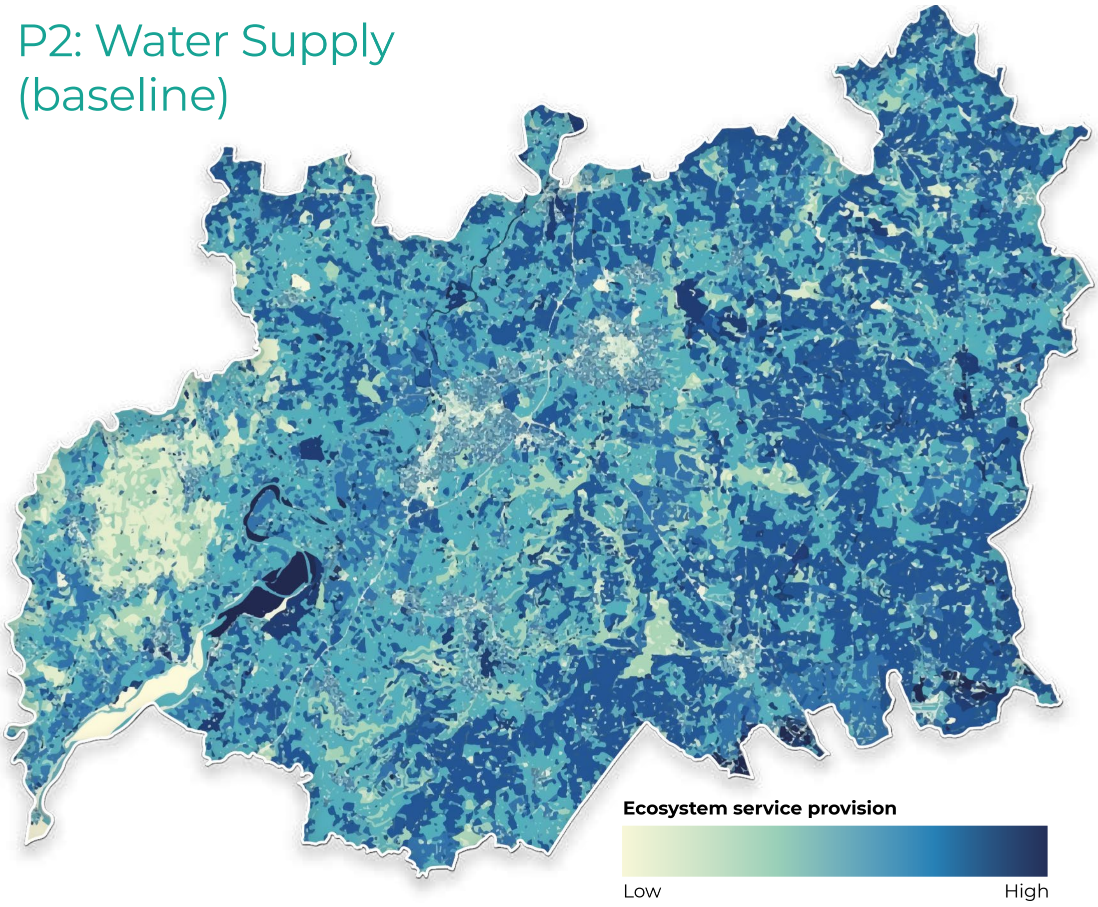
Future work should therefore also consider the degree to which water extraction activities are undertaken. This will provide greater insights into how the benefits of water supply are captured for use by people, allowing further refinement of the baseline layer.

10.5. References

Environment Agency, 2020. Water Resource Availability and Abstraction Reliability Cycle 2. Available at: https://data.gov.uk/dataset/b1f5c467-ed41-4e8f-89d7-f79a76645fd6/water-resource-availability-and-abstraction-reliability-cycle-2

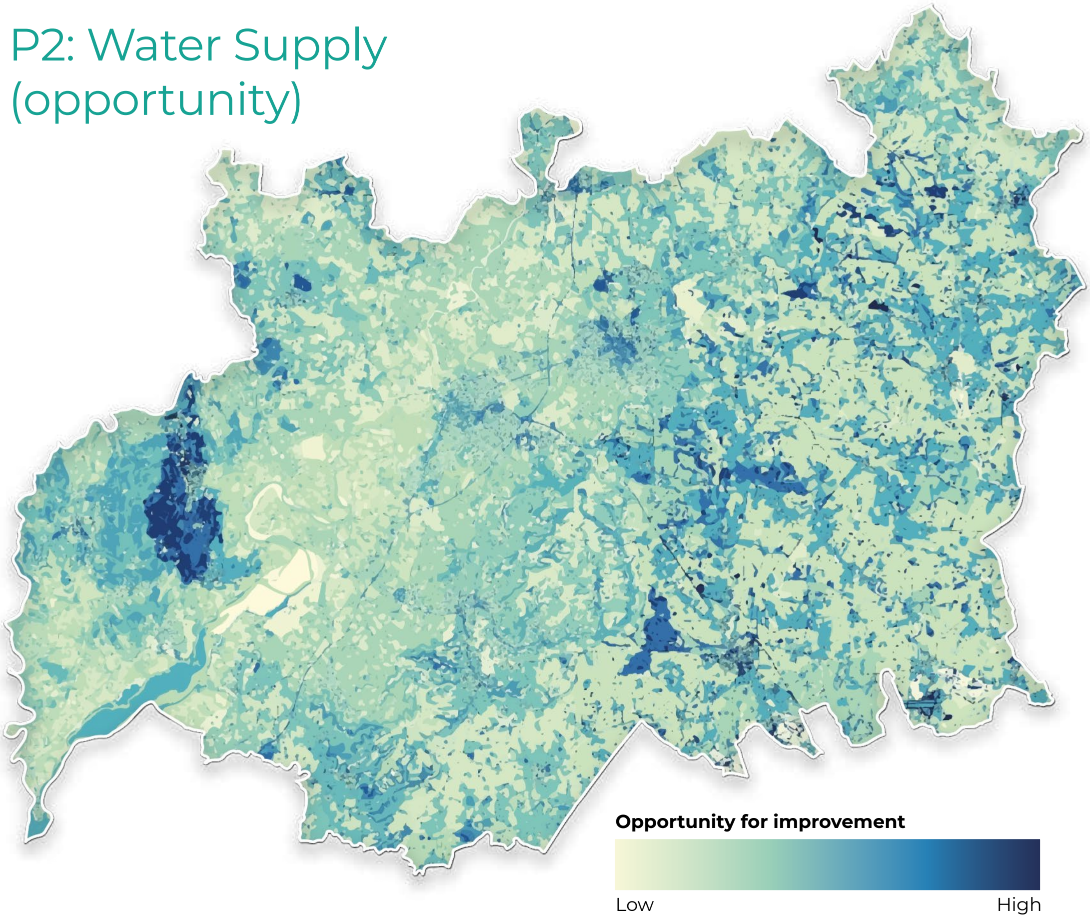
P2: Water Supply (baseline)

Figure P2.1: Water Supply Baseline (non-relational)



P2: Water Supply (opportunity)

Figure P2.2: Water Supply Opportunity (relational)



11. R1: Carbon Storage

11.1. Ecosystem Service Definition

Quantities of carbon stored in soil and vegetation, rather than the ability of habitat to actively sequester carbon over time.

11.2. Baseline Methods & Rationale

A non-relational dataset was produced to map the Carbon Storage ecosystem service baseline within Gloucestershire. The rationale for not selecting a modification layer for the Carbon Storage baseline was (i) the absence of an available dataset that could be used as a spatial modifier for the ecosystem service and (ii) the complexity of interaction between a habitat's spatial configuration and its ability to sequester carbon.

11.3. Opportunity Methods & Rationale

An opportunity dataset was not produced for the carbon storage ecosystem service due to the absence of a meaningful data that can be used to assess where the ecosystem service of carbon storage currently being delivered by natural capital assets is not meeting demand for delivery of the ecosystem service.

11.4. Limitations and Further Development

Knowledge of wetland and soil carbon storage is currently less developed than is the case with woodlands and as a result, these habitat classes may be underscored in the HSSM.

Literature indicating the extent to which habitats near to sources of carbon emissions store carbon in relation to those further from these sources could allow a meaningful modifier for the carbon storage baseline to be developed.

Soil depth – and the impact this may have on carbon storage – can vary across similar habitats and is not accounted for in the eco-metric scoring (Smith, 2020). The National Soil Resource Inventory provides estimates of soil carbon storage and may be a useful modifying layer for the carbon storage ecosystem service.

11.5. References

Smith, A., 2020. Natural capital in Oxfordshire: Short report. Environmental Change Institute, University of Oxford.

R1: Carbon Sequestration (baseline)

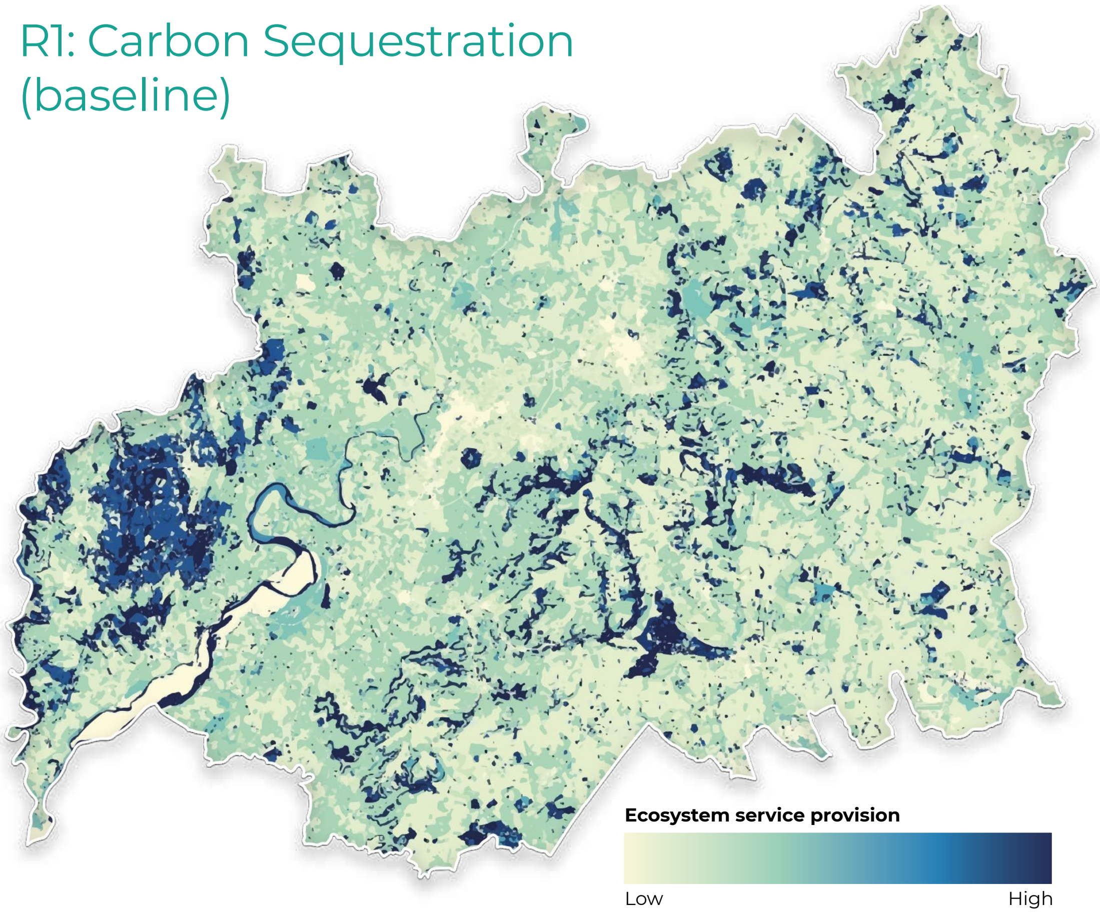


Figure R1.1: Carbon Storage Baseline (non-relational)

12. R2: Water Flow Regulation

12.1. Ecosystem Service Definition

Impact of soil and vegetation on reducing surface run-off, peak flow, and flood extent and depth. Mechanisms include interception, evapotranspiration, infiltration, and physical water flow slowing.

12.2. Baseline Methods & Rationale

A relational dataset was produced to map the Carbon Storage ecosystem service baseline within Gloucestershire. The modifier layer from this dataset consists of the intersection of habitats from the Gloucestershire Habitat Inventory with flow pathways generated from a 25m-resolution Digital Elevation Model (European Environment Agency, 2016) of the county. Multiplier values for intersecting and non-intersecting habitats are shown in Table R2.1.

Habitat Intersects Flow Pathway	Multiplier
Yes	1.4
No	1.0

Table R3.1: Multiplier values applied for intersecting and non-intersecting habitats

12.3. Opportunity Methods & Rationale

A relational dataset was also produced to map Carbon Storage ecosystem service opportunity.

Flow pathways, flow pathway nodes, and the Water Flow Regulation Baseline layer, were inputted into the model. The baseline input was 'inverted' by subtracting each value from the maximum in the dataset. Cost analysis was used to calculate cumulative flood risk of cells intersecting flow pathways from outlet to source. The cumulative flood risk values were split into deciles to produce a 10-point score used to modify baseline values (Table R2.2).

Cumulative Flood Risk Decile	Multiplier
1	1.0
2	1.1
3	1.2
4	1.3
5	1.4
6	1.6
7	1.8
8	2.0
9	2.2
10	2.4

Table R2.2: Multiplier values applied for each cumulative flood risk decile

The line vector data was converted to distinct polygons for each decile using Voronoi polygons, defined from the vertices of the flow pathways. These polygons were then dissolved to produce one polygon per decile, and the polygons rasterised as per the multiplier values in Table R2.2.

12.4. Limitations and Further Development

Flow pathways generated with a relatively low-resolution digital elevation model (DEM) of 25m (EU Copernicus). Higher resolution datasets are available; however, these are not yet available with full coverage of Gloucestershire and require a much greater amount of computer processing capacity. Further work should make use of updated DEMs as and when they become available with full coverage and computer processing capacity improves.

The flow pathway intersection completed for the baseline layer does not account for position of an intersecting habitat within the catchment. This may be completed through a cost analysis of the flow pathways from outlet to source; this would act as a proxy for measuring the position of each cell within a pathway from the pathway's outlet.

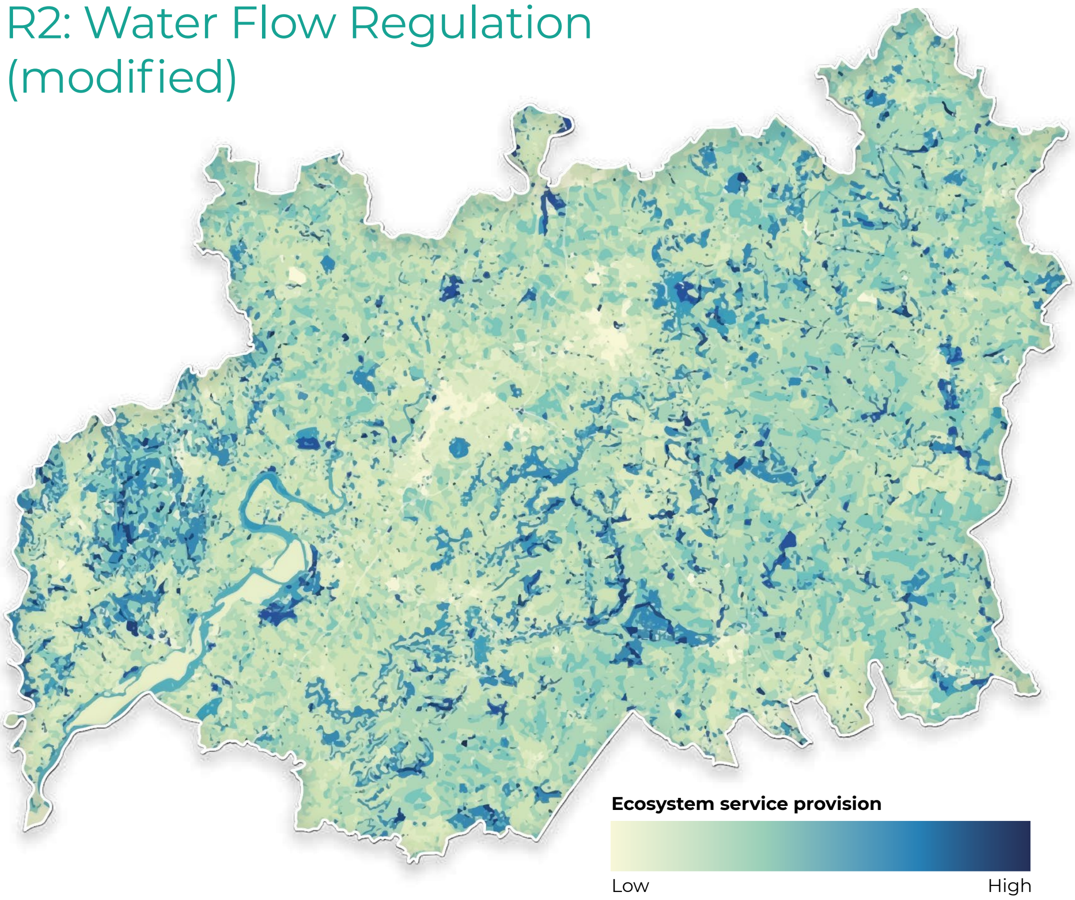
Climate change is also not factored into the flood risk data used here but should be considered when flood risk data is updated to include modelled climate change impacts.

12.5. References

European Environment Agency, 2016. European Digital Elevation Model (EU-DEM), version 1.1. Available at: https://land.copernicus.eu/imagery-in-situu/eu-dem/eu-dem-v1.1?tab=metadata

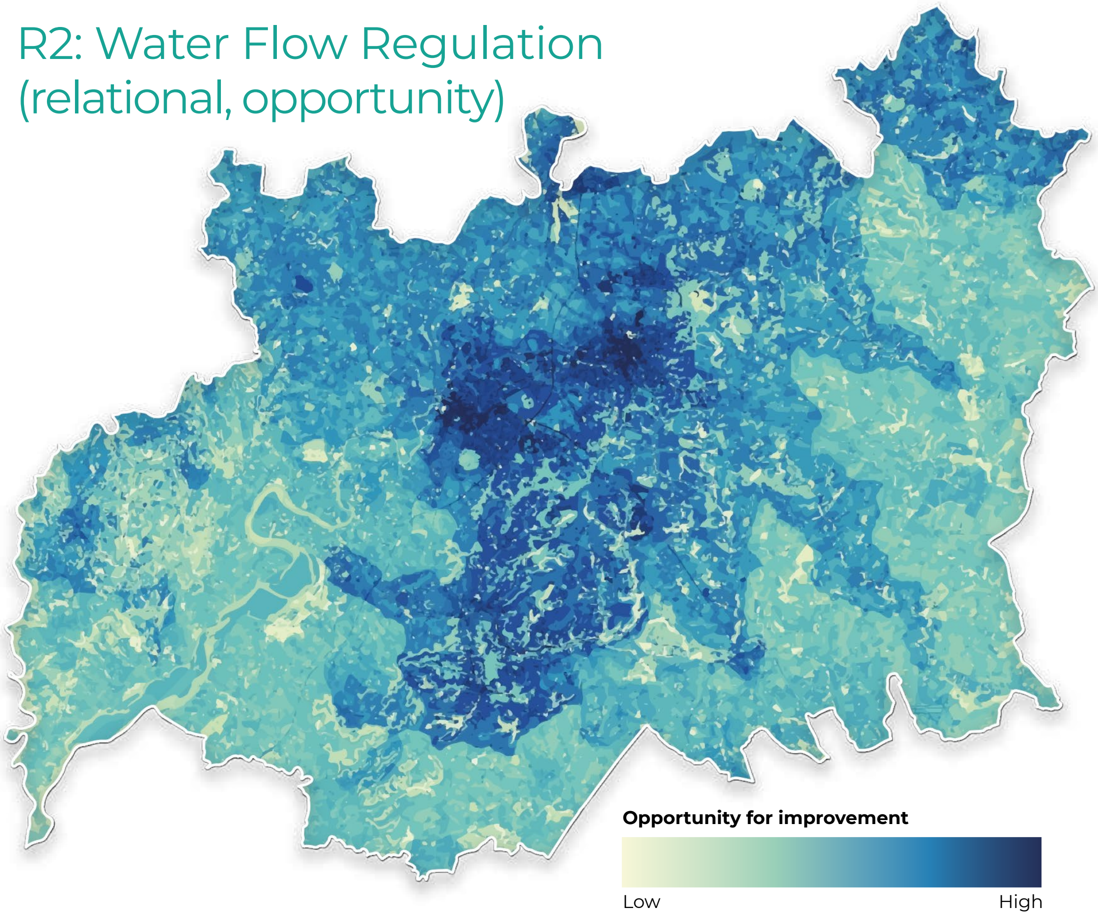
R2: Water Flow Regulation (modified)

Figure R2.1: Water Flow Regulation Baseline (relational)



R2: Water Flow Regulation (relational, opportunity)

Figure R2.2: Water Flow Regulation Opportunity (relational)



13. R3: Local Climate Regulation

13.1. Ecosystem Service Definition

Cooling effects of vegetation and water, in particular in urban areas where these can reduce heating and cooling costs and provide areas of shade.

13.2. Baseline Methods & Rationale

A non-relational dataset was produced to map the Local Climate Regulation ecosystem service baseline within Gloucestershire. The rationale for not selecting a modification layer for the Local Climate Regulation baseline was (i) the absence of an available dataset that could be used as a spatial modifier for the ecosystem service and (ii) the complexity of interaction between a habitat's spatial configuration and its ability to regulate climate on a local scale.

13.4. Opportunity Methods & Rationale

A relational dataset was also produced to map the Local Climate Regulation ecosystem service opportunity. The opportunity output was produced by subtracting each value from the maximum value in the dataset, so the lowest scoring baseline cells are the highest scoring for opportunity. Cells which fell outside of 250 m of an urban area were multiplied by zero (Table R2.1). Urban and non-urban areas were identified using Ordnance Survey (2020) Open Zoomstack data.

Class	Multiplier
Urban or within 0.25 km of urban areas	1
Non-Urban	0

Table R3.1: Multiplier values applied for intersecting and non-intersecting habitats

13.5. Limitations and Further Development

Urban trees (and green roofs and green walls) are not well-represented in the natural capital maps and their current impact on local climate regulation may be underrepresented in the outputs. Datasets mapping these features could be a valuable inclusion into future work. Traffic data could also be used in conjunction with urban tree locations to further account for variations of localised heating within the urban environment.

In addition, the baseline ability of a habitat to deliver the local climate regulation ecosystem service is likely to be enhanced where the habitat is in proximity to surfaces that radiate heat (i.e. urban sealed surface). Consequently, proximity of a habitat to urban areas may form the basis of a meaningful baseline modifier dataset. Demand for air pollutant removal is greatest in residential areas (Smith, 2020). In recognition of this, future work should consider classifying urban areas to general categories (e.g. commercial, industrial, residential) to recognise different levels of demand for the ecosystem service within urban areas. Population density may also be used as a proxy for approaching ecosystem service demand in urban areas.

13.6. References

Ordnance Survey, 2020. OS Open Zoomstack. Available at: https://www.ordnancesurvey.co.uk/business-government/products/open-zoomstack

R3: Local Climate Regulation (baseline, unmodified)

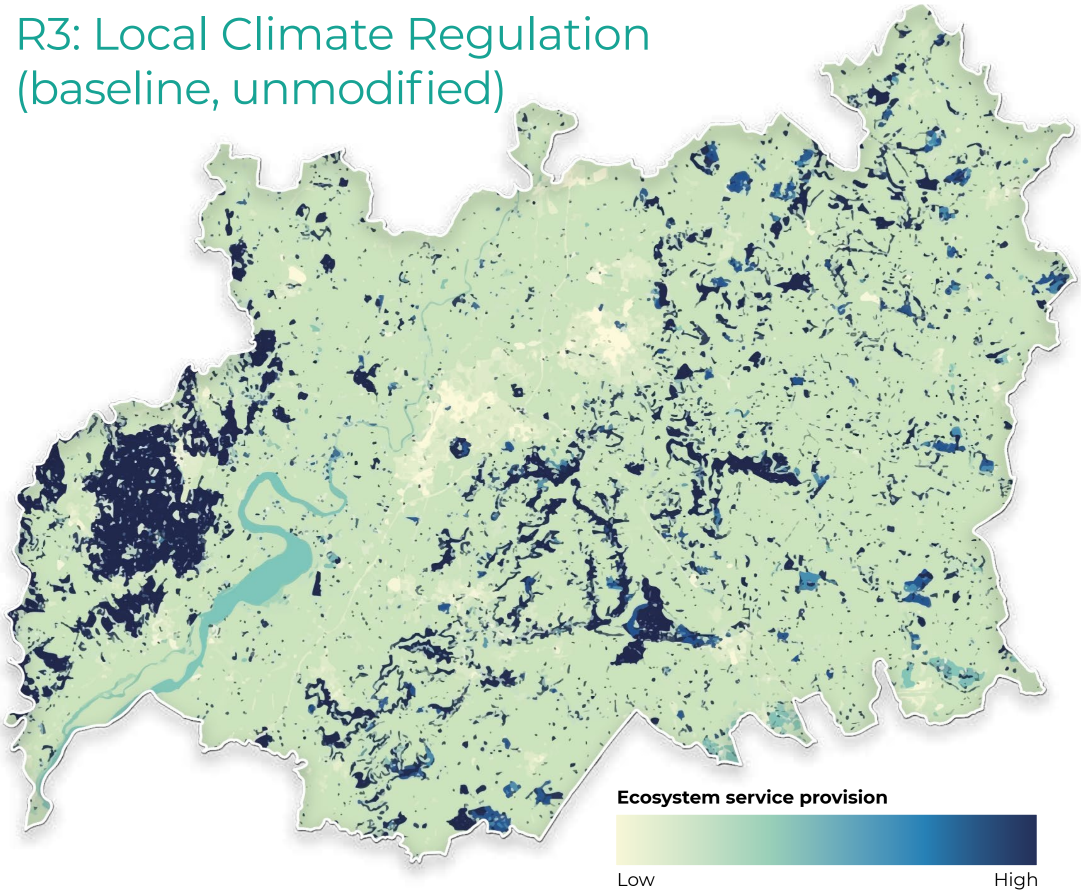


Figure R3.1: Local Climate Regulation Baseline (non-relational)

R3: Local Climate Regulation (opportunity)

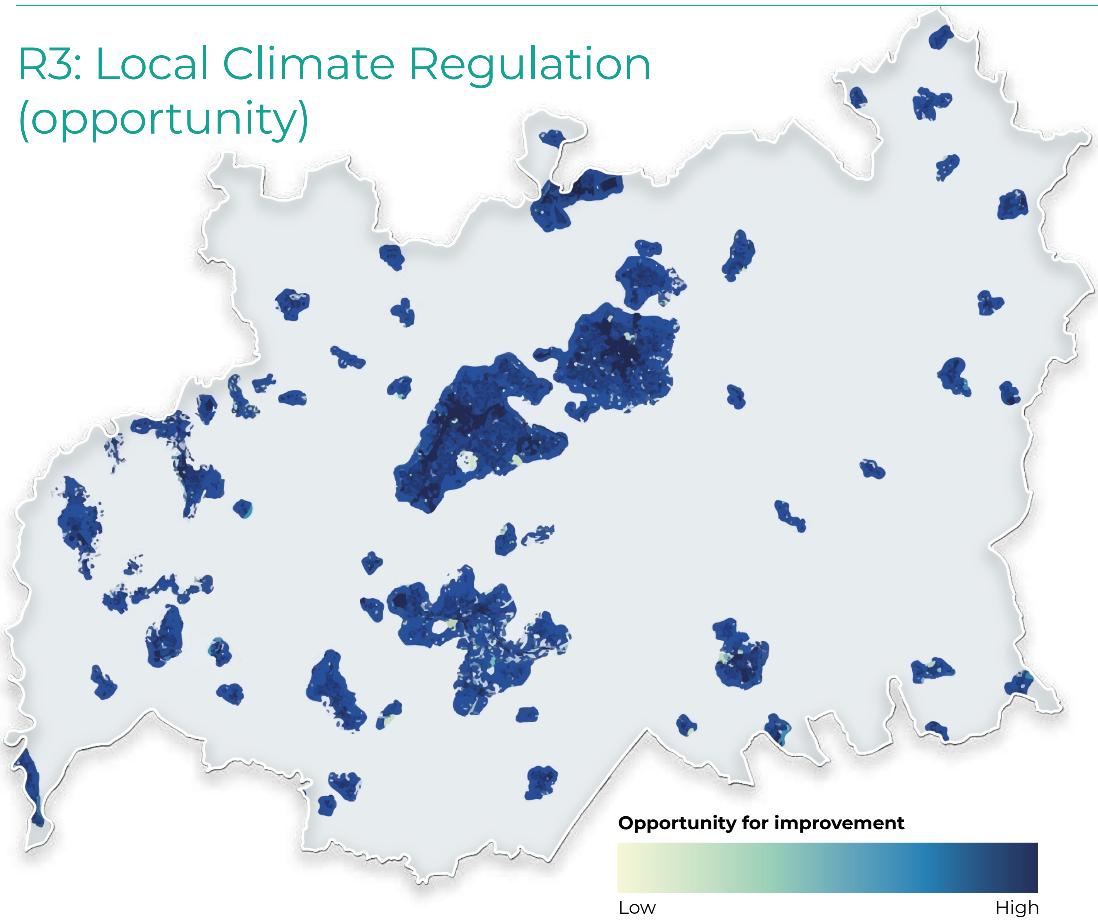


Figure R3.2: Local Climate Regulation Opportunity (relational)

14. R4: Air Pollutant Removal

14.1. Ecosystem Service Definition

Effect of vegetation on concentrations of air pollutants through mechanisms including deposition, absorption, and chemical breakdown.

14.2. Baseline Methods & Rationale

A non-relational dataset was produced to map the Air Pollutant ecosystem service baseline within Gloucestershire. During the habitat service scoring process, each habitat classification was scored on its ability to remove general air pollutants, rather than focusing on individual pollutants. The rationale for not selecting a modification layer for the Air Pollutant baseline was the absence of an available dataset that could be used as a spatial modifier for the ecosystem service, although it is recognised that the ability of a natural capital asset to provide the service is influenced by spatial factors.

14.3. Opportunity Methods & Rationale

A relational dataset was also produced to map the local climate regulation ecosystem service opportunity. The opportunity output was produced by subtracting each value from the maximum value in the dataset, so the lowest scoring baseline cells are the highest scoring for opportunity. Cells which fell outside of 300m (Natural England, 2016) of an urban or regional or national road were multiplied by zero (Table R4.1). Urban areas and roads were identified using Ordnance Survey (2020) Open Zoomstack data.

Class	Multiplier
Urban or within 0.3km of regional and national roads and urban areas	1
Non-Urban	0

Table R4.1: Multiplier values applied for intersecting and non-intersecting habitats

14.4. Limitations and Further Development

It has been assumed that national and regional roads and urban areas are the major sources of air pollution within Gloucestershire. However, there are likely to other sources – both point and diffuse – that have not been accounted for in this analysis. These may include nitrogen emissions from arable land and point source emissions from industrial sources. These could be included in future analysis, should suitable data be available.

The value used to determine the buffer distance from roads and urban areas is based on values from nitrogen oxide (NOx) emissions, the behaviours of other atmospheric pollutants (e.g. carbon dioxide) is likely to vary. Future work could account for this by allocating pollutants to each source and producing a buffer value from these sources based on the specific pollutants. As discussed under 'R3: Local Climate Regulation', demand for air pollutant removal is greatest in residential areas (Smith, 2020) with opportunities for future work consider classifying urban areas to broad classes (e.g. commercial, industrial, residential) to recognise variations in demand for the air pollutant removal within urban areas. Population density may also be used as a proxy for this.

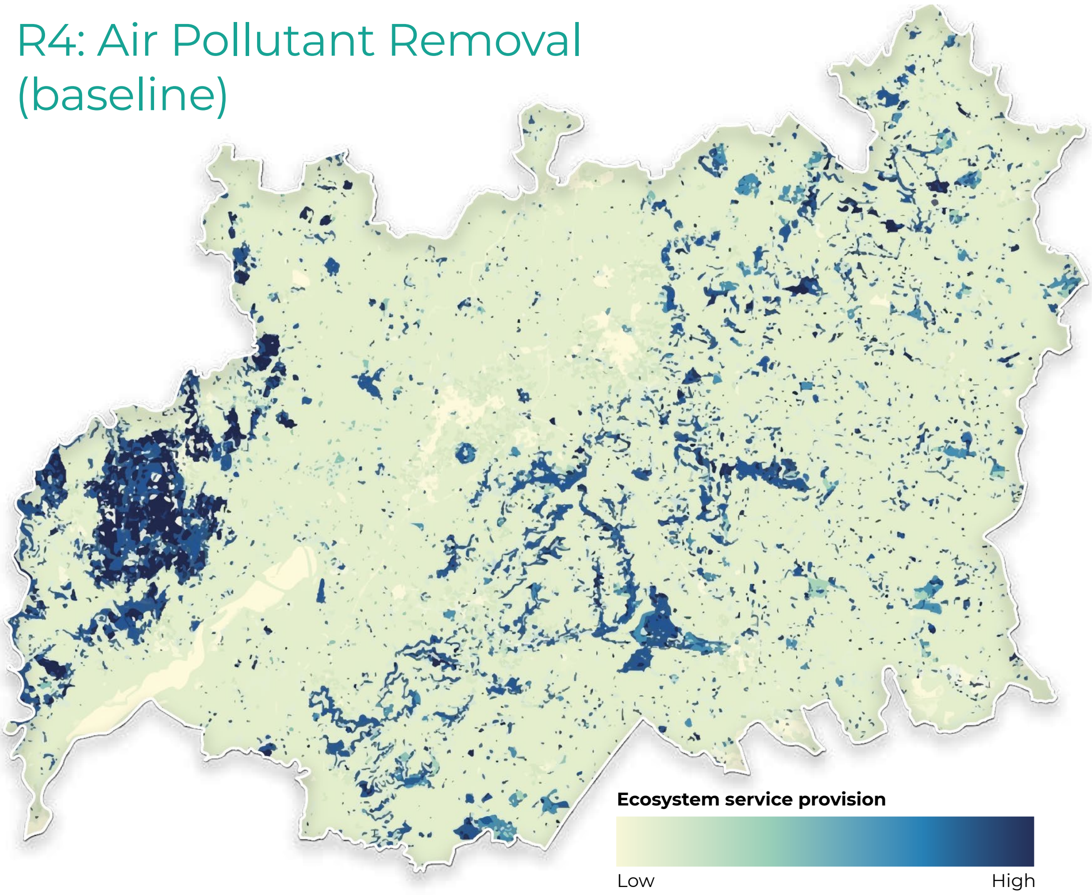
14.5. References

Natural England, 2016. The ecological effects of air pollution from road transport: an updated review. Ricardo AEA, Harwell, Didcot.

Smith, A., 2020. Natural capital in Oxfordshire: Short report. Environmental Change Institute, University of Oxford.

R4: Air Pollutant Removal (baseline)

Figure R4.1: Air Pollutant Removal Baseline (non-relational)

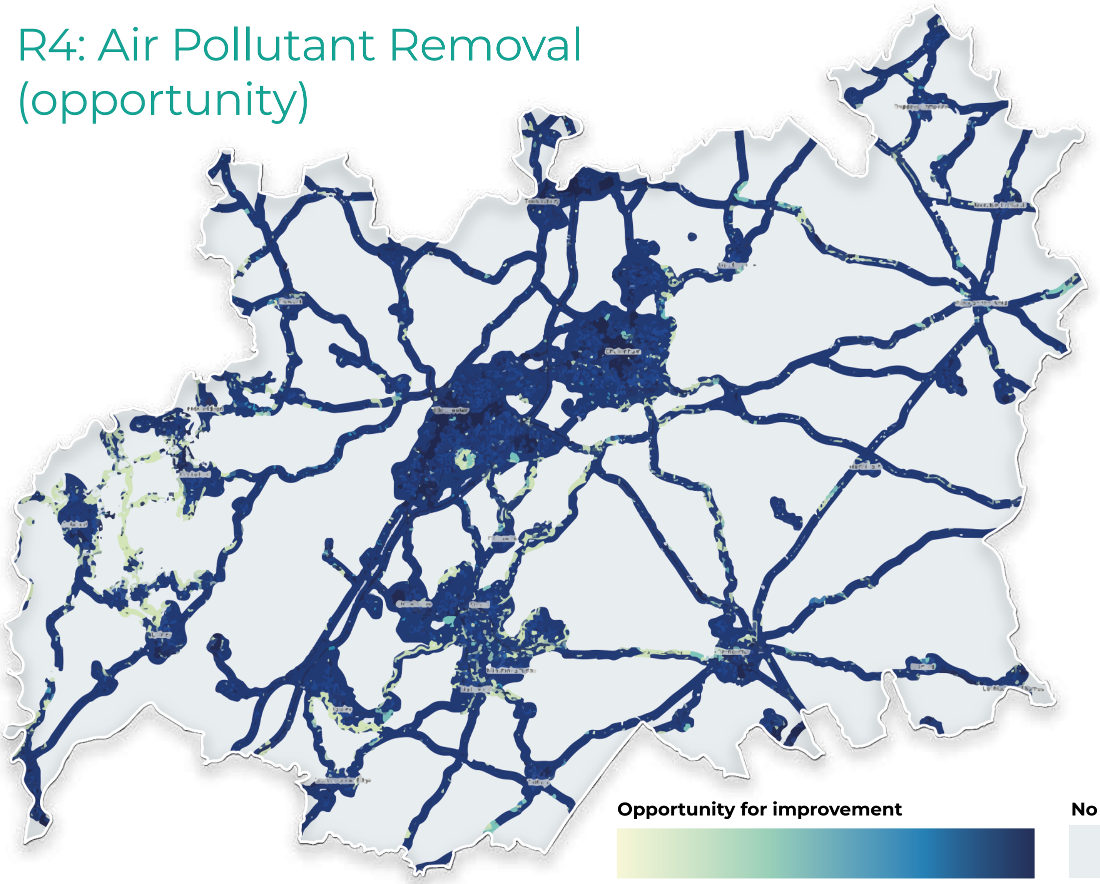


Ecosystem service provision

Low High

R4: Air Pollutant Removal (opportunity)

Figure R4.2: Air Pollutant Removal Opportunity (relational)



Opportunity for improvement

Low High

No demand for service

15. B1: Biodiversity (Supplement to Gloucestershire NRN)

15.1. Ecosystem Service Definition

The ability of a habitat to support a diverse range of species, providing a variety of environmental, social, and economic benefits. These layers should be viewed in conjunction with the original Gloucestershire Nature Recovery Network.

15.2. Baseline Methods & Rationale

A relational dataset was produced to map the Biodiversity ecosystem service baseline within Gloucestershire. The modifier layer selected was the county's Nature Recovery Network (GWT, 2020), with modifier values based on existing connectivity, as per Table B1.1. The rationale for using these modifier values was that areas better connected to core habitat are likely to provide the biodiversity ecosystem service to a greater degree.

Existing Connectivity	Multiplier
Core	2.0
500m	1.4
Other	1.0

Table B1.1: Multiplier values applied for intersecting and non-intersecting habitats

15.3. Opportunity Methods & Rationale

A relational dataset was also produced to map biodiversity ecosystem service opportunity, also using the Gloucestershire Nature Recovery Network as a modifier layer. The Nature Recovery Network includes an assessment of where change of habitat type would give the greatest benefit to biodiversity and was therefore considered an appropriate modifier layer. Modifier values were based on potential connectivity within the county, as defined by the Nature Recovery Network, and are presented in Table B1.2, below.

Potential Connectivity	Multiplier
High	2.0
Medium	1.4
Low	1.2
Existing Priority Habitat	1.0

Table B1.2: Multiplier values applied for intersecting and non-intersecting habitats

15.4. Limitations and Further Development

The Gloucestershire Nature Recovery Network is currently in development and these layers should be updated periodically as the Nature Recovery Network is updated.

The Gloucestershire Nature Recovery Network currently does not identify opportunities for enhancing the size of contiguous habitat which contribute to recovering ecological integrity across the county. This will require additional analysis that links natural capital and ecological integrity mapping.

15.5. References

Gloucestershire Wildlife Trust, 2020. Nature Recovery Network

B1: Biodiversity (baseline)

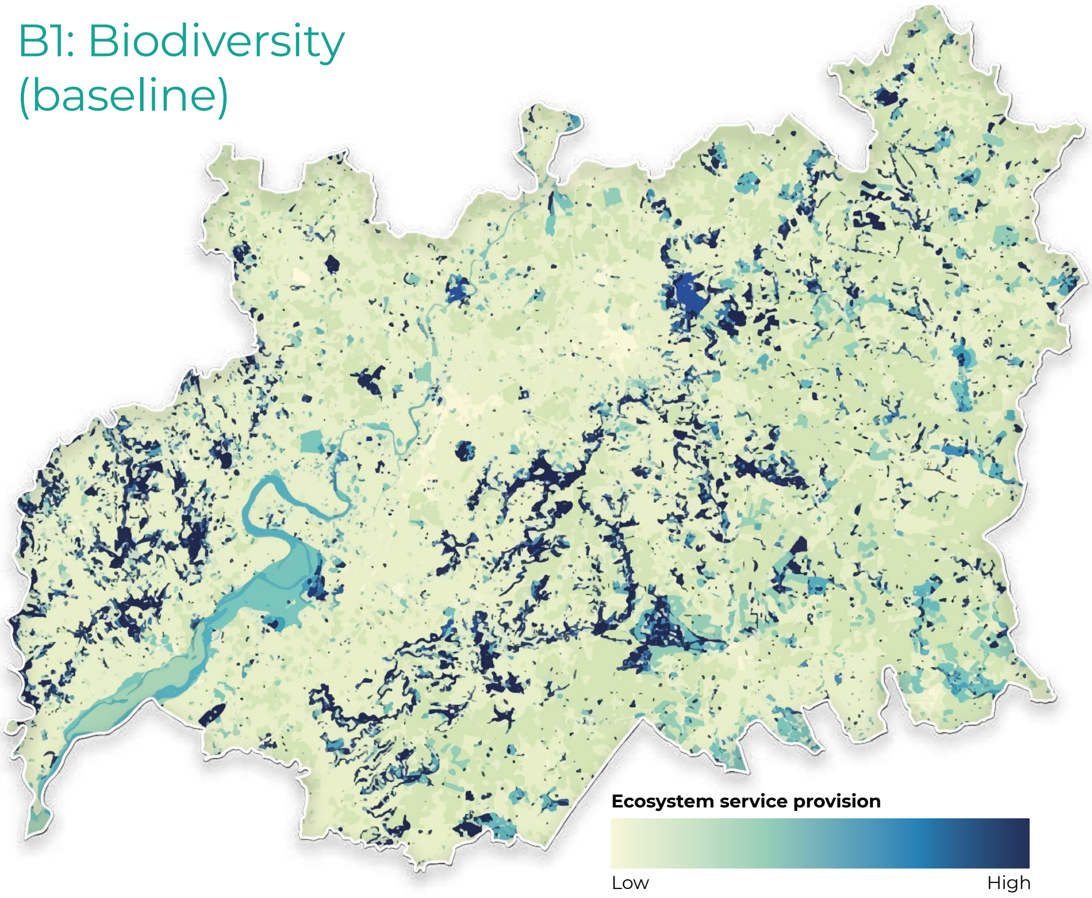


Figure B1.1: Biodiversity Baseline (relational)

B1: Biodiversity (opportunity)

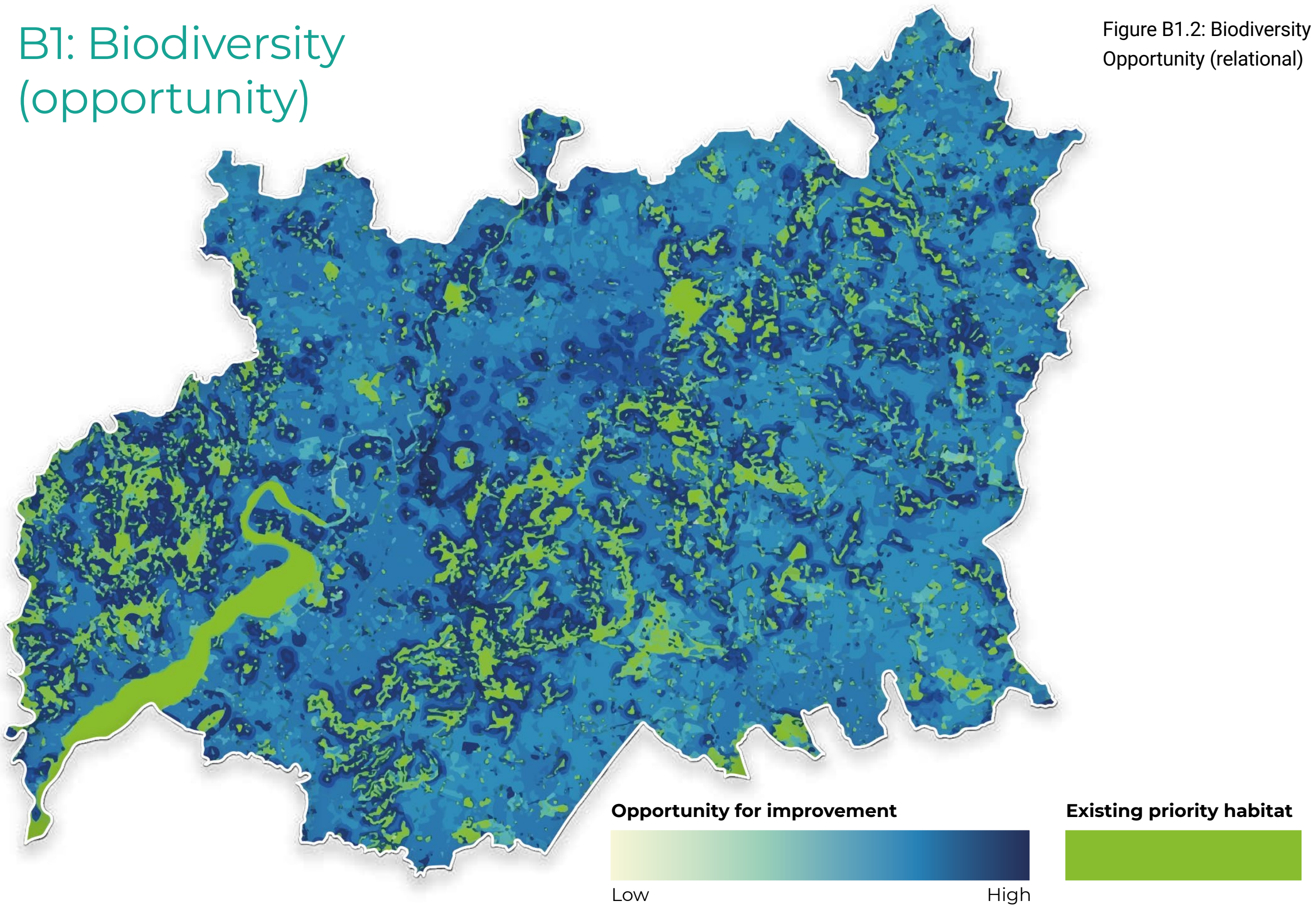


Figure B1.2: Biodiversity Opportunity (relational)

16. B2: Water Quality

16.1. Ecosystem Service Definition

Uptake of pollutants dissolved or suspended in water by vegetation, and the ability of vegetation to prevent pollutants reaching waterbodies through interception and filtration.

16.2. Baseline Methods & Rationale

A non-relational dataset was produced to map the Water Quality ecosystem service baseline within Gloucestershire. The rationale for not selecting a modification layer for the Carbon Storage baseline was (i) the absence of an appropriate available dataset that could be used as a spatial modifier for the ecosystem service and (ii) the complexity of interaction between a habitat's spatial configuration and its influence on water quality.

16.3. Opportunity Methods & Rationale

An opportunity dataset was not produced for the water quality ecosystem service due to the absence of a meaningful data that can be used to assess where the ecosystem service of water quality currently being delivered by natural capital assets is not meeting demand for delivery of the ecosystem service.

16.4. Limitations and Further Development

The water quality baseline assumes habitat is the only factor in determining how a given habitat influences water quality. The reality is much more complex with factors such as land management, topography and water flow rate, and underlying geology all influencing water quality. Water framework directive (WFD) data whereby water bodies are assessed for their quality based on a series of indicators, may be a useful supporting dataset for this analysis.

Inclusion of flow accumulation modelling may also allow detailed analysis of overland flows, in turn, further analysis of the potential of a given area of land to deliver the water quality ecosystem service.

B2: Water Quality (baseline)

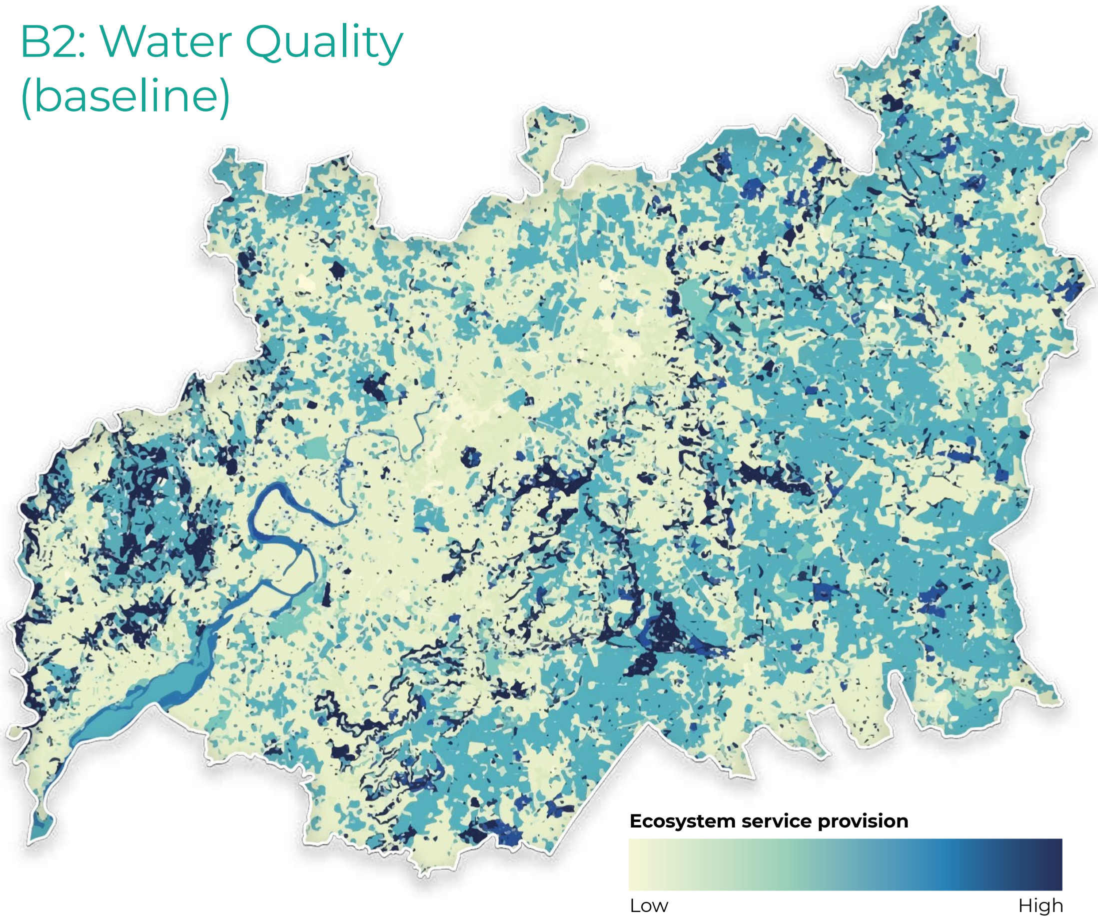


Figure B2.1: Water Quality (non-relational)

17. B3: Soil Health

17.1. Ecosystem Service Definition

Soil health is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans.

17.2. Baseline Methods & Rationale

A non-relational dataset was produced to map the soil health ecosystem service baseline within Gloucestershire. The rationale for not selecting a modification layer for the soil health baseline was the absence of an available dataset that could be used as a spatial modifier for the ecosystem service, whilst accounting for localised variation in soils.

17.3. Opportunity Methods & Rationale

Similar to water quality, an opportunity dataset was not produced for the soil health ecosystem service due to the absence of a meaningful dataset that can be used to assess where the ecosystem service of soil health currently being delivered by natural capital assets is not meeting demand for delivery of the ecosystem service.

17.4. Limitations and Further Development

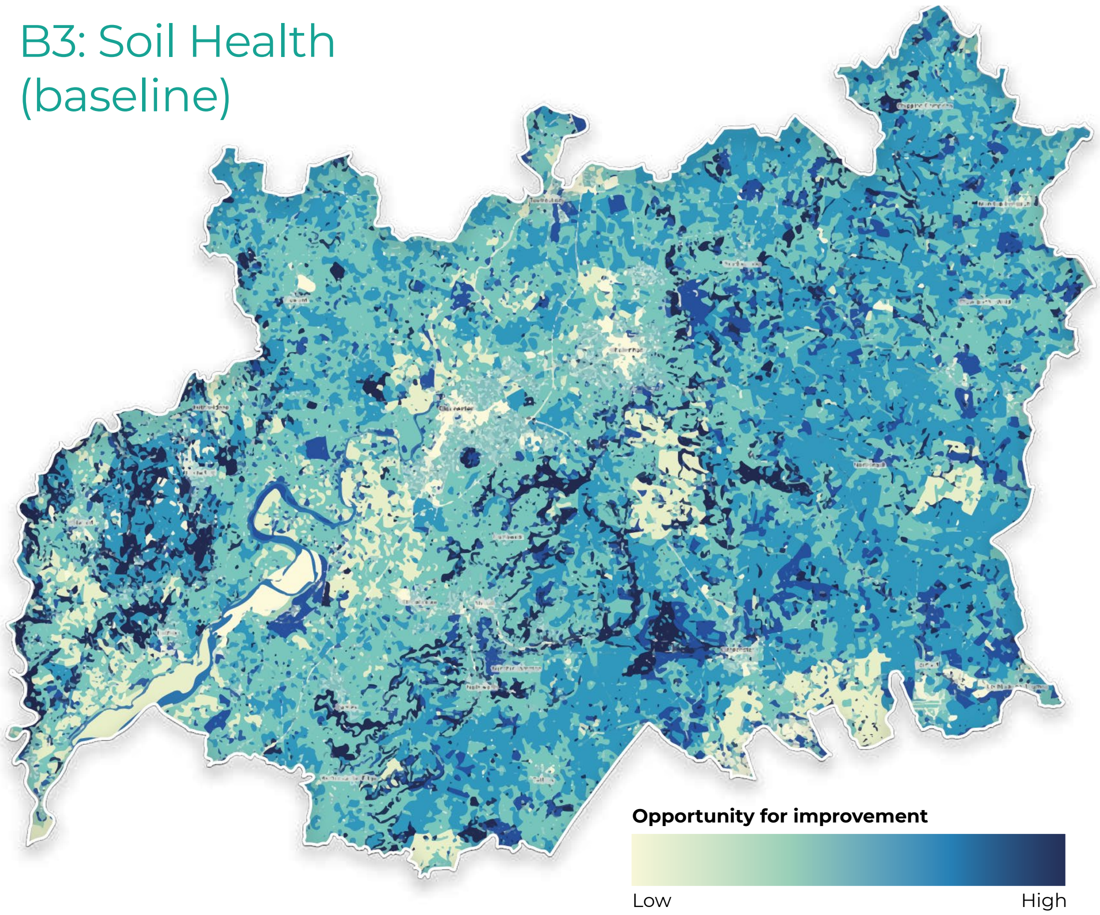
Due to imitations in available data containing soil chemistry parameters on a county scale for Gloucestershire, this dataset assumes that habitat is the only determinant of soil health. Whereas soil health is dependent on a complex series of additional factors: land management regimes, topography, and climate, for example.

Concentrations of phosphorous in soils may provide a useful indicator of soil health that could be applied as a modifier layer, should an appropriate dataset be identified.

An opportunity layer for soil health has not been developed due to the current lack of soil quality data which can be used at the scale required by natural capital mapping. Datasets which may allow the development of an opportunity layer may include point and diffuse sources of pollution. This data would allow an assessment of current areas of demand for improved soil health, in a similar manner to analysis undertaken for air pollution regulation in this project.

B3: Soil Health (baseline)

Figure B3.1: Soil Health Baseline (non-relational)



18. C1: Recreation

18.1. Ecosystem Service Definition

Provision of green and blue spaces that can be used for any recreational leisure activity e.g. walking, cycling, running, picnicking, camping, boating, games or relaxing.

18.2. Baseline Methods & Rationale

A relational dataset was produced to map the Recreation ecosystem service baseline within Gloucestershire. The rationale for selecting a modification layer for the baseline was in recognition that accessibility of land strongly influences the extent to which the Recreation ecosystem service is captured by people. The methods detailed below were derived from the Natural Capital in Oxfordshire study (Smith, 2020).

Land classed as 'open' was identified through land covered under Countryside Rights of Way Act (Natural England, 2020), National Trust open land, and land within the Outdoor Recreation Valuation (ORVal) dataset (Day and Smith, 2018).

Land classed as 'semi-restricted' was identified through applying a buffer of 50m to public rights of way within the county. These were identified through a combination of the ORVal path data (Day and Smith, 2018), Sustrans path network data (Sustrans, 2020), and Gloucestershire public right of way data. Community growing spaces and allotments, as well as limited access sports clubs (i.e. bowling greens, tennis courts, and other sport facilities) identified through Ordnance Survey (OS) Open Greenspace data (OS, 2020) and limited access National Trust land were also classed as 'semi-restricted'. Surface water was also classed as 'semi-restricted' access, as it can be used for water-based recreation activities, however, has limitations to access through the requirement for equipment (e.g. for boating) or training (e.g. for swimming).

Land classed as 'restricted' was classed as sports clubs where membership is more expensive (e.g. golf clubs) – these were also identified through the Open Greenspace data (OS, 2020).

Land Access Class	Modifier
Open	1.00
Semi-Restricted	0.75
Restricted	0.50
Other	0.00

Table C1.1: Weights assigned for modification of the recreation baseline dataset

18.3. Opportunity Methods & Rationale

To produce a relational recreation opportunity dataset, the inverse of the baseline dataset was modified by index of multiple deprivation (IMD) data at the lower-layer super output area (LSOA) level. The rationale for using IMD data is that in areas of high deprivation individuals are likely to be less able to travel to access areas where the interaction with nature ecosystem service is provided.

The weighting factor applied to the IMD dataset was calculated by dividing the decile of IMD within a given LSOA by 10 and adding this value to one to produce a range of values from 0.1 to 1.0. Deciles scored 10 for the most deprived LSOAs, and 1 for the least deprived. These deciles were calculated based on data for the whole of England to ensure the outputs are compatible on a national scale, should these methods be applied elsewhere.

IMD Decile	Multiplier
1	0.1
2	0.2
3	0.3
4	0.4
5	0.5
6	0.6
7	0.7
8	0.8
9	0.9
10	1.0

Table C1.2: Weights assigned for modification of the interaction with nature opportunity dataset (1st decile is least deprived, 10th most)

Natural England's Accessible Natural Greenspace Standard (ANGSt) was then used to identify areas that currently do not meet ANGSt requirements, with these areas subsequently being weighted by population density. This data identifies deficits in current access to green space, and thus, when combined with a proxy for ability of people to access local green space allows areas of demand for recreational green space to be identified. Here, areas of high deprivation (as per the index of multiple deprivations (IMD)) were used as a proxy for ability to travel.

ANGSt requirements specify that a given household should have access to one accessible natural greenspace of (i) at least 2ha within 0.3km of home, (ii) at least 20ha within 2km, (iii) at least 100ha within 10km of home, and (iv) at least 500ha within 10km. The standards also specify a minimum of 1ha of statutory Local Nature Reserve per 1000 population, although this is not factored into this analysis.

ANGSt Criteria Fulfilled	Modifier
0	1.0
1	0.8
2	0.6
3	0.4
4	0.0

Table C1.3: Weights assigned for modification of the recreation baseline dataset

18.4. Limitations and Further Development

Gardens included as an additional 'private' land access category in the Oxfordshire report (as private land with a weight of 0.25), but not factored in here due to constraints in processing power.

As described in Section 2, cultural ecosystem service scores were clustered using K-nearest neighbour classification. Though this better reflects rural areas where the ability of a given natural capital asset (habitat) to provide a given ecosystem service is impacted by surrounding natural capital assets. A result of this, however, is that existing urban green space – often small parcels surrounded by low habitat service scores urban areas – is not fully represented in the classification.

This limitation applies to all four cultural ecosystem services and may be resolved through creating a composite eco-metric dataset, where rural areas are classified through K-nearest neighbour analysis, and urban areas remain unclassified as per the raw eco-metric dataset.

Future work may also investigate including population data to calculate the amount of Local Nature Reserves available per 1000 population.

18.5. References

Day, B. H., and G. Smith, 2018. Outdoor Recreation Valuation (ORVal) User Guide: Version 2.0. Land, Environment, Economics and Policy (LEEP) Institute, Business School, University of Exeter.

Ordnance Survey, 2020. OS Open Greenspace. Available at: https://www.ordnancesurvey.co.uk/business-government/products/open-map-greenspace

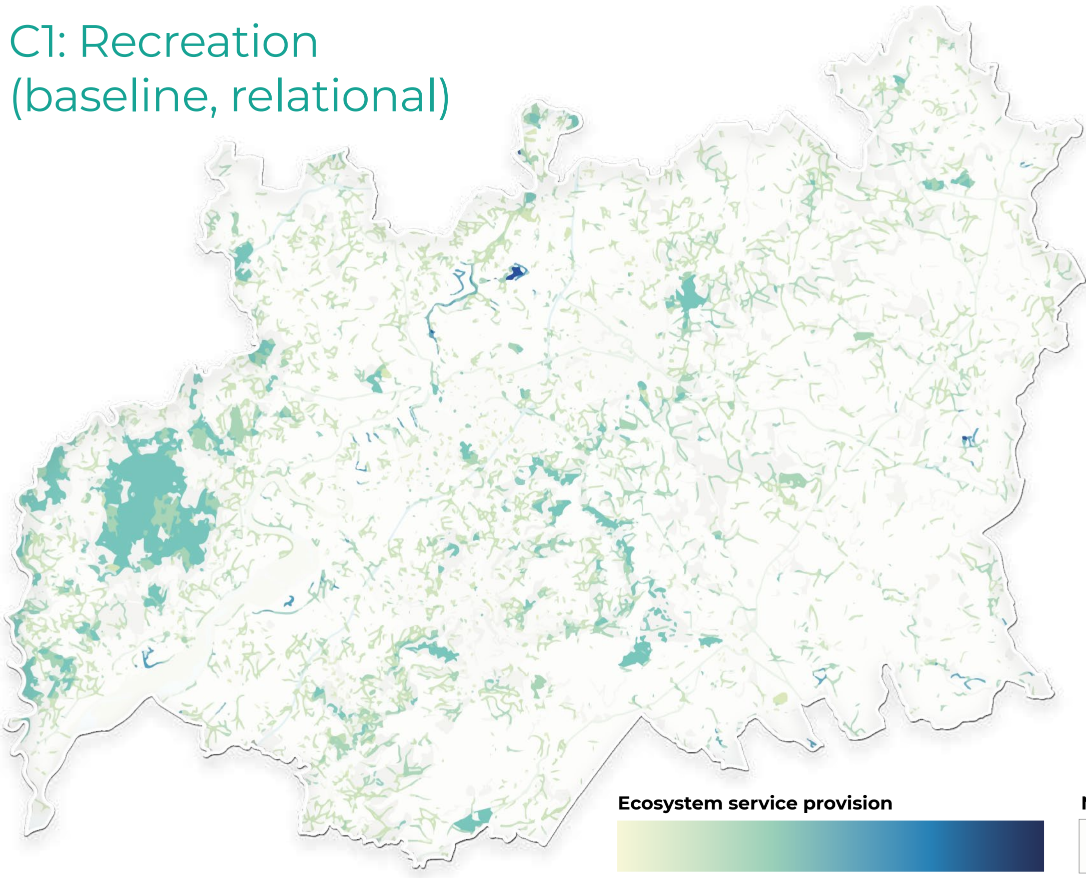
Natural England, 2020. CRoW Act 2000 - Access Layer. Available at: https://data.gov.uk/dataset/05fa192a-06ba-4b2b-b98c-5b6bec5ff638/crow-act-2000-access-layer

Smith, A., 2020. Natural capital in Oxfordshire: Short report. Environmental Change Institute, University of Oxford.

Sustrans, 2020. Sustrans' Open Data. Available at: https://data-sustrans-uk.opendata.arcgis.com/

C1: Recreation (baseline, relational)

Figure C1.1: Recreation Baseline (relational)



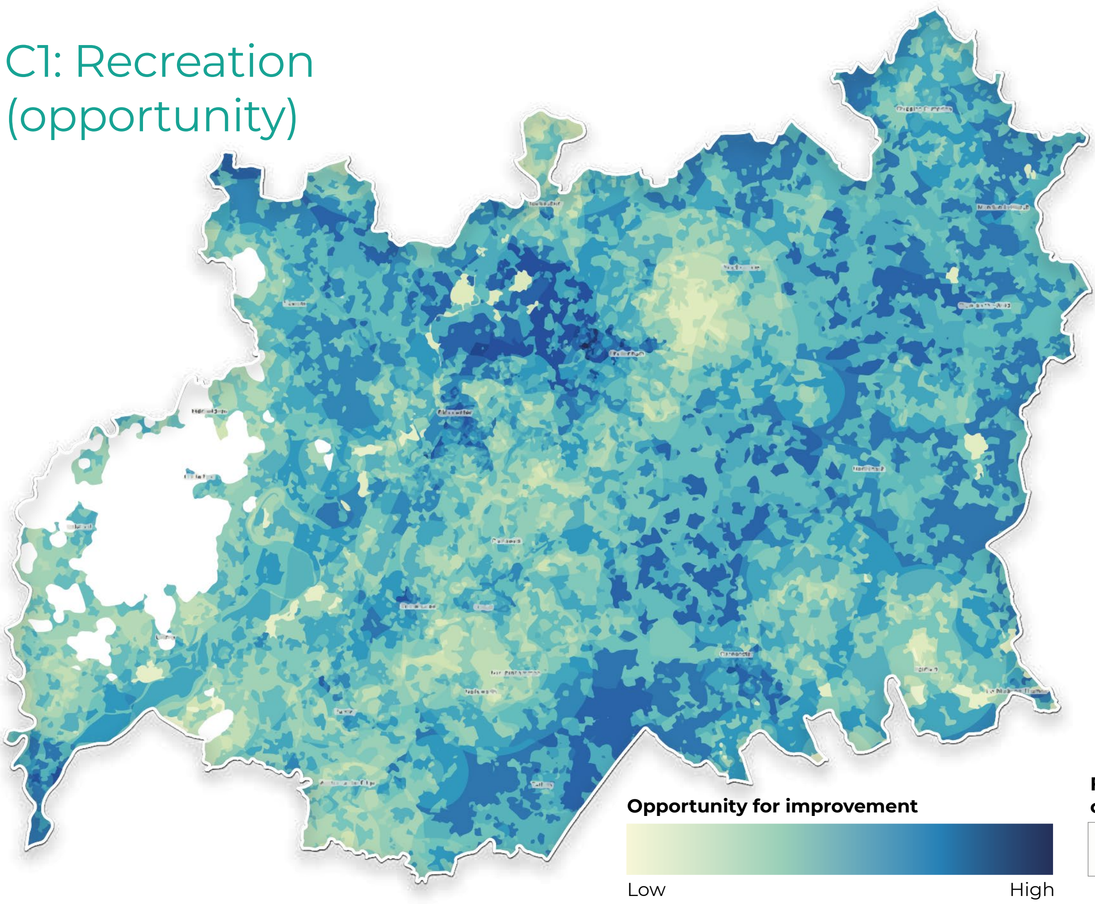
Ecosystem service provision

Low High

No land access

C1: Recreation (opportunity)

Figure C1.2: Recreation Opportunity (relational)



Opportunity for improvement

Low High

Four ANGSt distance criteria met

19. C2: Education

19.1. Ecosystem Service Definition

Provision of green and blue spaces that can be provide educational benefit.

19.2. Baseline Methods & Rationale

A primary dataset gathered from questionnaires distributed to natural visitor sites within the county of Gloucestershire and surrounding area. Questionnaires sought to obtain insights into the level of visitor infrastructure present at each site, for example, visitor centres, interpretation boards, toilet facilities, and car parks.

The locations of natural visitor sites were then analysed in conjunction with road and footpath infrastructure to identify areas within a 10-minute (0.8km) walk and 10-minute drive (4km) from site. This analysis aimed to quantify natural visitor centres accessibility and identify where access is most limited. Network analysis of these pathways was used to create three tiers within the modifier layer, summarised in Table C1.2, below.

Natural Visitor Site Access Class	Modifier
> 10-minute walk or drive	0.50
<= 10-minute drive	0.80
<= 10-minute walk	1.00

Table C1.2: Weights assigned for modification of the education baseline dataset

A lower modifying value for a 10-minute drive reflects driving generally being a less accessible transportation medium than walking, due to training (driving licence) and additional cost (vehicles, insurance, fuel, etc.).

19.3. Opportunity Methods & Rationale

A relational opportunity dataset was produced to map opportunities to improve the education ecosystem service in Gloucestershire. This dataset was produced through multiplying the inverse of the baseline dataset by index of multiple deprivation (IMD) data at the lower-layer super output area (LSOA) level. The rationale for using IMD data is that in areas of high deprivation individuals are likely to be less able to travel to access areas where the interaction with nature ecosystem service is provided.

The weighting factor applied to the IMD dataset was calculated by dividing the decile of IMD within a given LSOA by 10 and adding this value to one to produce a range of values from 1.0 to 1.9. Deciles scored 10 for the most deprived LSOAs, and 1 for the least deprived. These deciles were calculated based on data for the whole of England to ensure the outputs are compatible on a national scale, should these methods be applied elsewhere.

IMD Decile	Multiplier
1	1.0
2	1.1
3	1.2
4	1.3
5	1.4
6	1.5
7	1.6
8	1.7
9	1.8
10	1.9

Table C3.2: Weights assigned for modification of the interaction with nature opportunity dataset (1st decile is least deprived, 10th most)

19.4. Limitations and Further Development

Currently the extents of natural visitor sites are not included within the data, with each visitor centre represented by points. Inclusion of this data would increase the accuracy and allow analysis of habitats within or around each natural visitor site. In addition, analysis of the number of natural visitor sites accessible from a given area may provide further insights and allow analysis of the diversity of highly accessible natural visitor sites, where the education ecosystem service can be captured. Future work here could also explore fees of access for the centres to allow further insights into accessibility to be gained. Public transport data could also be used to further develop insights into the accessibility of natural visitor sites.

The natural visitor centre dataset is also not an exhaustive list of such centres within the county and consists of those which were identified through a data search who responded to the survey. The outputs should be viewed in recognition of this limitation and as future work is developed, this dataset should be updated to ensure data remains current and expanded to include additional centres.

The network analysis undertaken assumes a 50km per hour driving speed and 5km per hour walking speed. Driving speeds are not based on actual speed limits and are based on an average speed limit of 30 mph, in addition to time associated with parking, for example. Further work could consider parking infrastructure data (obtained through the natural visitor sites dataset) to further assess accessibility to adjust the network analysis for specific natural visitor sites.

The use of IMD data assumes that the demand for interaction with nature is greatest in LSOAs where deprivation is highest. However, there are also likely to be additional factors that impact this accessibility alongside deprivation. These may include demographic and public transportation data.

19.5. References

Ministry of Housing, Communities & Local Government, 2019. English indices of deprivation 2019. Available at: https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019

C2: Education (baseline, relational)

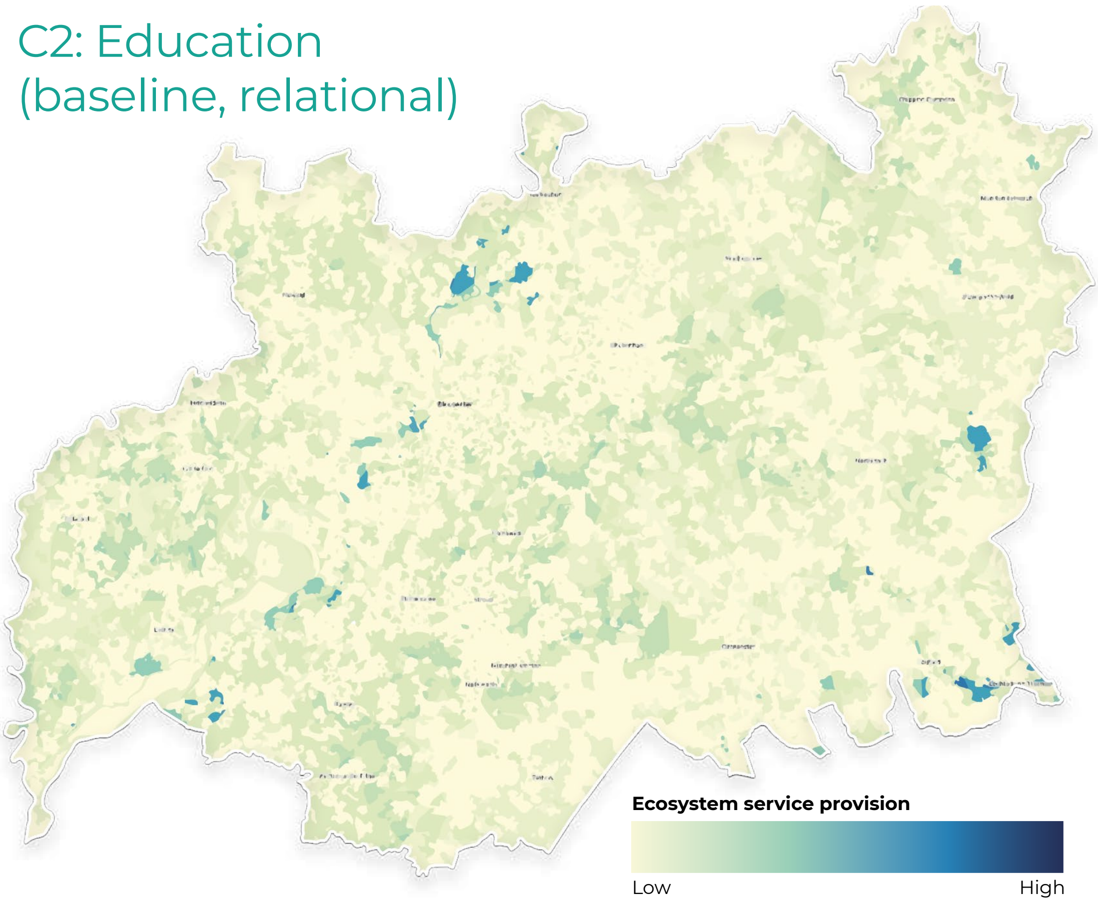


Figure C2.1: Education Baseline (relational)

C2: Education (opportunity, relational)

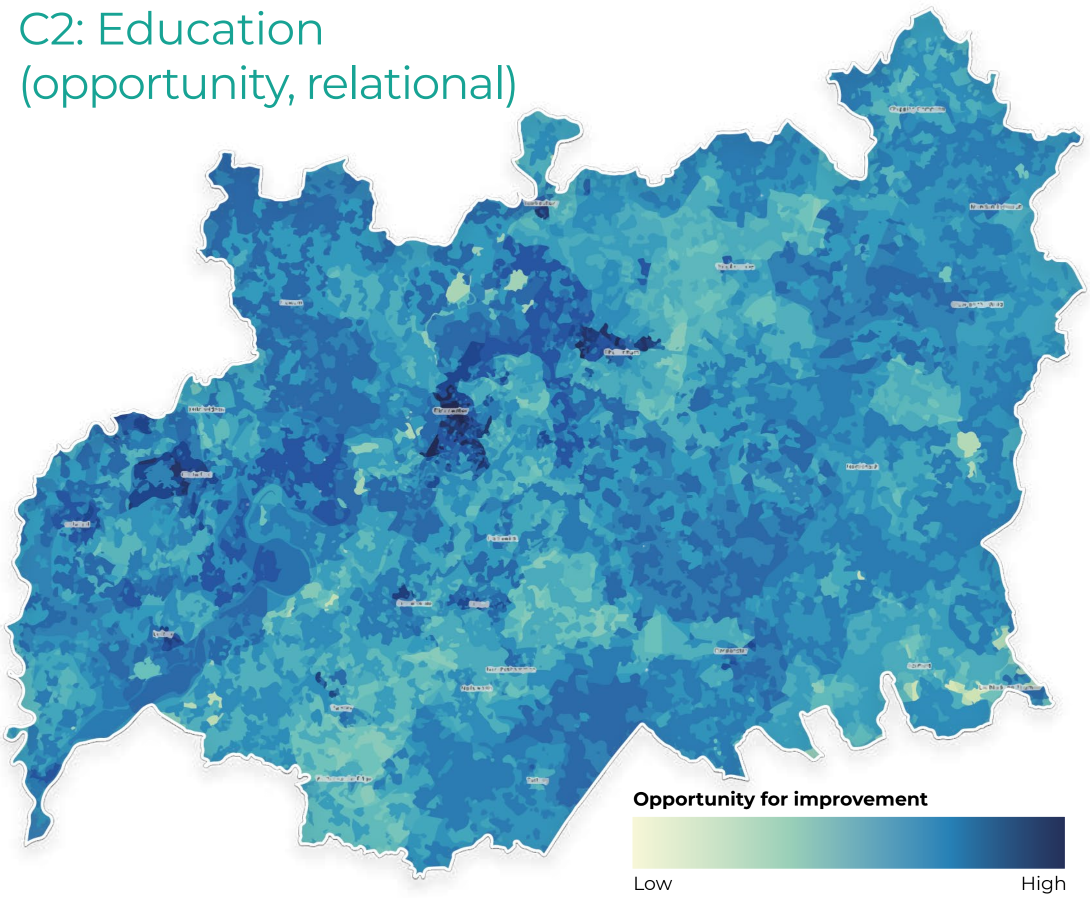


Figure C2.2: Education Opportunity (relational)

20. C3: Interaction with Nature

20.1. Ecosystem Service Definition

Provision of opportunities for formal or informal nature-related activities, (e.g. birdwatching, random encounters with wildlife, or feeling 'connected with nature'). There is some overlap with biodiversity, but access by people can have negative impacts on some wildlife habitats. Excludes recreational fishing, hunting, shooting, intrinsic value of nature and existence value.

20.2. Baseline Methods & Rationale

A relational dataset was produced to map the interaction with nature ecosystem service baseline within Gloucestershire. Overlapping designated sites were used as a modifying dataset following the methods of (Smith, 2020) who states that protected areas are more likely to support a greater amount and diversity of wildlife. Some designated sites may also preserve other natural or semi-natural features of interest (i.e. geological features). Designated sites included: local nature reserves (LNRs), national nature reserves (NNRs), sites of special scientific interest (SSSIs), and special areas of conservation (SACs).

Greater modifier values were applied where a greater number of designated sites overlapped. These values are given in Table C3.1 and are also derived from Smith (2020).

Number of Designated Site Overlaps	Modifier
>=3	1.20
2	1.15
1	1.10
0	1.00

Table C3.1: Weights assigned for modification of the interaction with nature baseline dataset

20.3. Opportunity Methods & Rationale

A relational opportunity dataset was produced to map interaction with nature opportunity in Gloucestershire. This dataset was produced through multiplying the inverse of the baseline dataset by index of multiple deprivation (IMD) data at the lower-layer super output area (LSOA) level. The rationale for using IMD data is that in areas of high deprivation individuals are likely to be less able to travel to access areas where the interaction with nature ecosystem service is provided.

The weighting factor applied to the IMD dataset was calculated by dividing the decile of IMD within a given LSOA by 10 and adding this value to one to produce a range of values from 1.0 to 1.9. Deciles scored 10 for the most deprived LSOAs, and 1 for the least deprived. These deciles were calculated based on data for the whole of England to ensure the outputs are compatible on a national scale, should these methods be applied elsewhere.

IMD Decile	Multiplier
1	1.0
2	1.1
3	1.2
4	1.3
5	1.4
6	1.5
7	1.6
8	1.7
9	1.8
10	1.9

Table C3.2: Weights assigned for modification of the interaction with nature opportunity dataset (1st decile is least deprived, 10th most)

20.4. Limitations and Further Development

Using designated sites assumes that greater wildlife amount and diversity are supported by designated sites, however, the condition of these sites has not been accounted for within the analysis.

The use of IMD data assumes that the demand for interaction with nature is greatest in LSOAs where deprivation is highest. However, there are also likely to be additional factors that impact this accessibility alongside deprivation. These may include demographic and public transportation data.

20.5. References

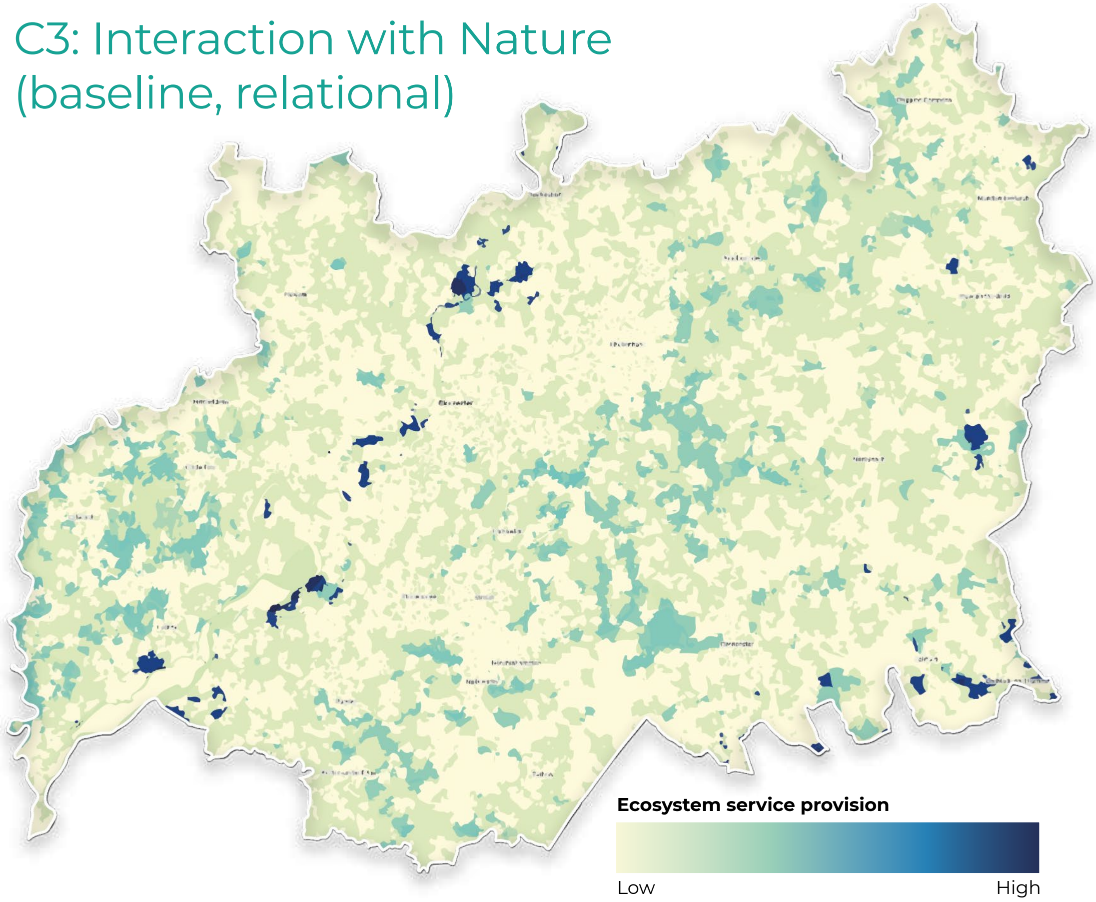
Ministry of Housing, Communities & Local Government, 2019. English indices of deprivation 2019. Available at: https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019

Natural England, 2003. Accessible Natural Green Space Standards in Towns and Cities: A Review and Toolkit for their Implementation (ENRR526). University of Manchester.

Smith, A., 2020. Natural capital in Oxfordshire: Short report. Environmental Change Institute, University of Oxford.

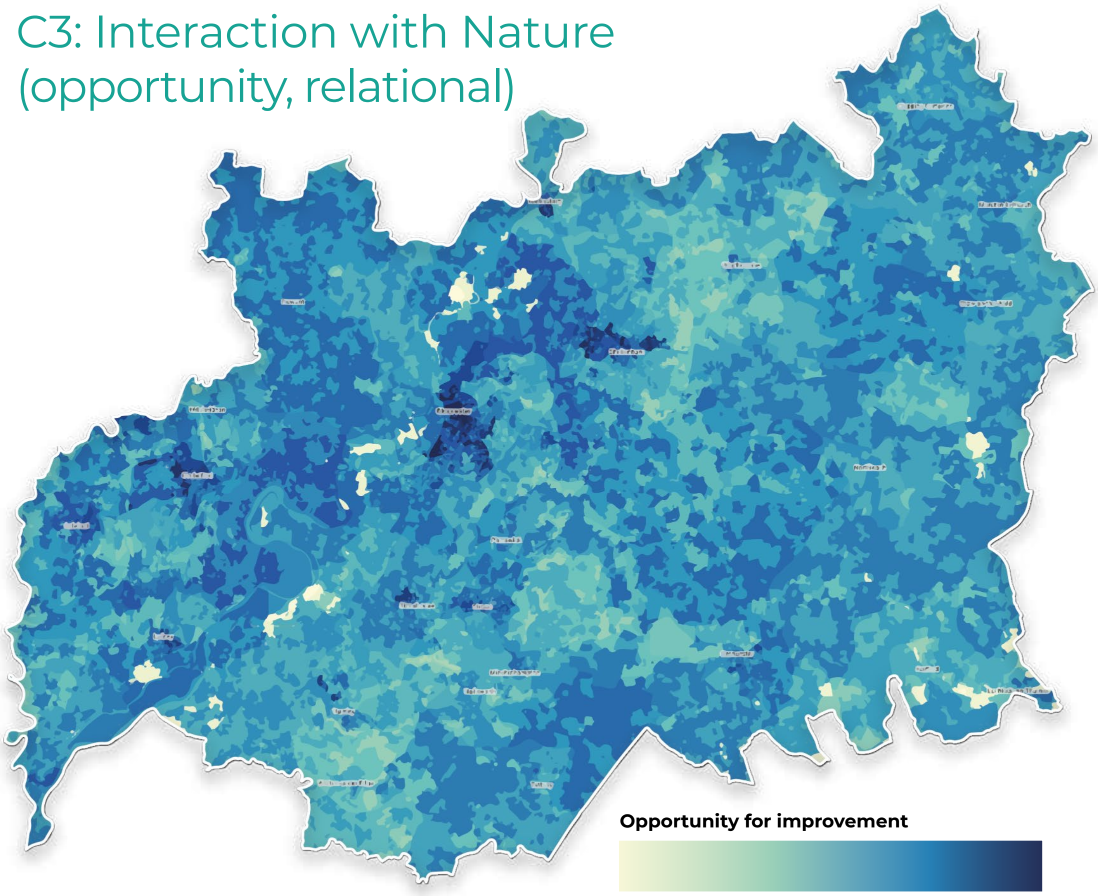
C3: Interaction with Nature (baseline, relational)

Figure C3.1: Interaction with Nature Baseline (relational)



C3: Interaction with Nature (opportunity, relational)

Figure C3.2: Interaction with Nature Opportunity (relational)



21. C4: Sense of Place

21.1. Ecosystem Service Definition

The aspects of a place that make it special and distinctive – this could include locally characteristic species, habitats, landscapes, or features; places related to historic and cultural events, or places important to people for spiritual or emotional reasons.

21.2. Baseline Methods & Rationale

A relational dataset was produced to map the interaction with nature ecosystem service baseline within Gloucestershire. Overlapping designated sites were used as a modifying dataset following the methods of (Smith, 2020) who states that protected areas are more likely to support a greater amount and diversity of wildlife. Some designated sites may also preserve other natural or semi-natural features of interest (i.e. geological features), and features of cultural or historical importance (i.e. scheduled monuments). Designated sites included: local nature reserves (LNRs), national nature reserves (NNRs), sites of special scientific interest (SSSIs), and special areas of conservation (SACs), areas of outstanding natural beauty (AONBs), country parks, Millennium Greens, Doorstep Greens, registered battlefields, registered parks and gardens, and scheduled ancient monuments.

Greater modifier values were applied where a greater number of designated sites overlapped. These values are given in Table C3.1 and are also derived from Smith (2020).

Number of Designated Site Overlaps	Modifier
>=3	1.20
2	1.15
1	1.10
0	1.00

Table C4.1: Weights assigned for modification of the sense of place baseline dataset

21.3. Opportunity Methods & Rationale

An opportunity dataset was not produced for the sense of place ecosystem service due to the absence of meaningful data that can be used to assess where sense of place currently being delivered by natural capital assets is not meeting demand for delivery of the ecosystem service.

21.4. Limitations and Further Development

Using designated sites assumes that greater wildlife amount and diversity are supported by designated sites, however, the condition of these sites has not been accounted for within the analysis. Likewise, the analysis assumes that all designated sites are of equal value in contributing to the sense of place ecosystem service.

As described in Section 2, cultural ecosystem service scores were clustered using K-nearest neighbour classification. Though this better reflects rural areas where the ability of a given natural capital asset (habitat) to provide a given ecosystem service is impacted by surrounding natural capital assets.

A result of this, however, is that existing urban green space – often small parcels surrounded by low eco-metric scoring urban areas – is not fully represented in the classification. This may be resolved through creating a composite HSSM dataset, where rural areas are classified through K-nearest neighbour analysis, and urban areas remain unclassified as per the raw HSSM dataset.

21.5. References

Smith, A., 2020. Natural capital in Oxfordshire: Short report. Environmental Change Institute, University of Oxford.

Natural England, 2003. Accessible Natural Green Space Standards in Towns and Cities: A Review and Toolkit for their Implementation (ENRR526). University of Manchester.

C4: Sense of Place (baseline, relational)

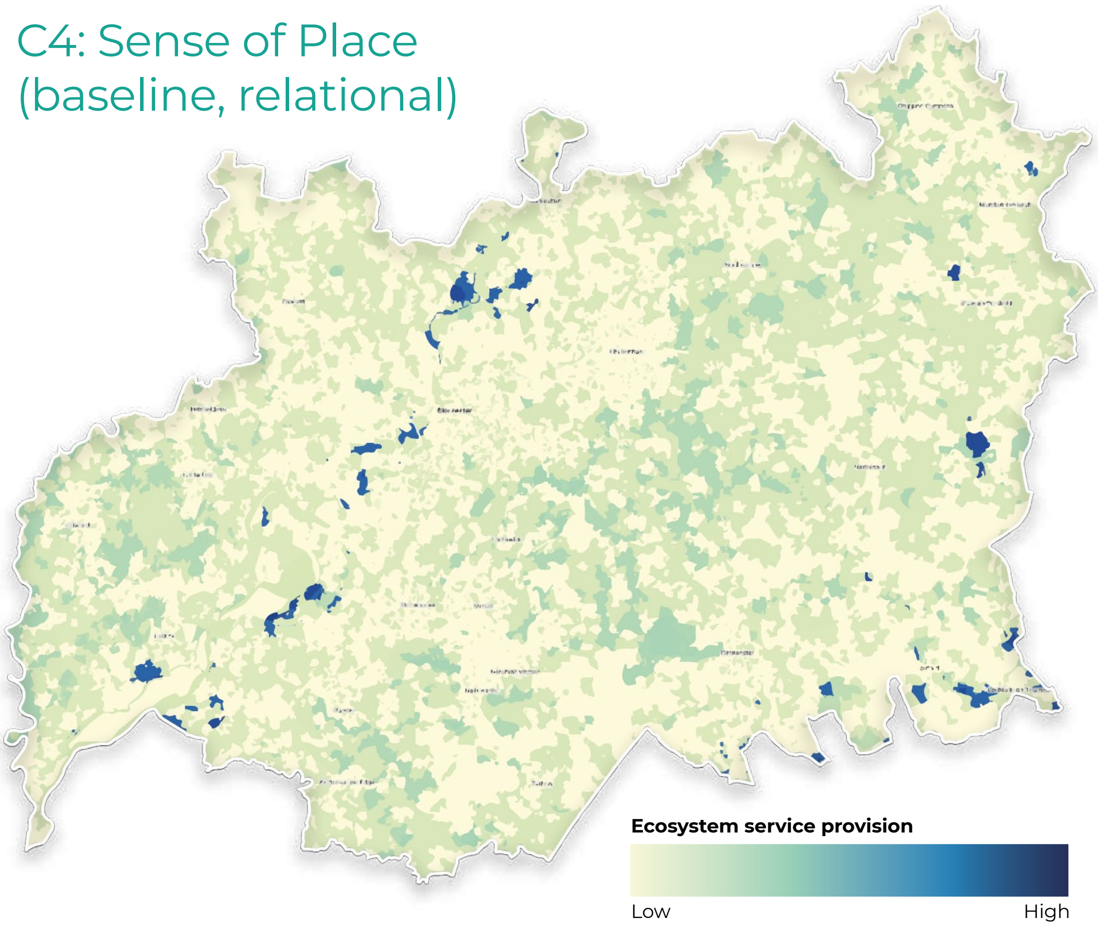


Figure C3.1: Interaction with Nature Baseline (relational)

Appendix 1: Gloucestershire Habitat service scoring matrix

(modified from the Oxfordshire HSSM supplied by A. Smith, ECI)

Page 1

			PROVISIONING		CULTURAL				REGUALTING				BUNDLED BENEFITS		
LEVEL 1 HABITAT	**CODE**	**HABITAT DESCRIPTION**	Food Provision	Water Supply	Recreation	Education	Interaction with Nature	Sence of Place	Carbon Sequestration	Water flow Regulation	Local Climate Regulation	Air Pollutant Removal	Biodiversity	Water Quality	Soil Health
G **Grassland**	g	Grassland	6	7	1	1	1	1	3	3	2	1	2	1	4
	g1	Acid Grassland	6	9	6	8	3	3	4	8	2	1	8	4	8
	g1a	Lowland Dry Acid Grassland	6	8	7	10	3	3	5	8	2	1	10	4	8
	g1c	Bracken	1	8	1	1	1	1	4	8	2	1	5	5	8
	g2	Calcareous Grassland	6	9	4	5	3	3	3	8	2	1	10	4	8
	g2a	Lowland Calcareous Grassland	6	9	4	5	3	3	3	8	2	1	10	4	8
	g3	Neutral Grassland	6	9	5	5	3	3	4	8	2	1	8	4	8
	g3a	Lowland Meadows	6	9	5	5	3	3	4	8	2	1	10	4	8
	0120	Wet Grassland	3	9	4	4	4	3	4	9	2	1	9	5	8
	0119	Seasonally Wet Grassland	4	9	4	5	3	2	4	9	2	1	9	5	8
	g4	Modified Grassland	10	5	3	5	2	2	3	3	2	1	2	1	4
	0021	Traditional Orchard	5	7	4	4	4	3	5	8	8	4	9	8	8
W **Woodland and Forest**	w	Woodland	0	1	2	2	3	2	8	10	10	10	2	5	6
	w1	Broadleaved Mixed and Yew Woodland	1	3	5	5	5	4	10	9	10	8	10	10	10
	w1g	Other Woodland	5	7	6	10	4	4	5	6	6	3	10	8	8
	0011	Broadleaved Scattered Trees	5	7	4	5	5	4	5	6	6	3	10	8	8
	0020	Wood Pasture	5	7	5	4	6	5	9	9	8	6	9	8	8
	w2	Coniferous Woodland	0	1	3	3	3	2	8	5	10	10	2	5	6
	w2a	Native Pine Woodland	0	3	4	4	5	4	7	9	10	8	8	6	8
	w2c	Other Coniferous Woodland	0	1	3	3	3	2	8	10	10	10	2	5	6
	0053	Felled Woodland	0	4	2	2	3	2	1	1	1	0	2	0	0
H **Heathland and Shrub**	h	Heathland	1	8	1	1	2	1	4	7	2	4	8	7	8
	h1	Dwarf Shrub Heath	1	8	4	4	5	4	4	7	2	4	8	7	8
	h1a	Lowland Heathland	1	8	4	4	5	4	4	7	2	4	10	7	8
	h1a7	Wet Heathland with Cross-Leaved Heath	1	9	3	3	4	4	5	7	2	4	10	7	8
	h2	Hedgerows	1	4	3	3	4	3	5	8	6	8	10	7	8
	h3	Dense Scrub	1	4	1	1	2	1	6	8	6	7	5	7	8
F **Wetland**	f	Wetland	1	10	1	1	1	1	10	6	4	1	10	8	8
	f1	Bog	1	10	1	1	2	2	10	6	4	1	10	8	8
	f2	Fen Marsh and Swamp	1	10	1	1	2	2	6	6	4	1	10	8	8
	f2e	Reedbeds	0	10	1	1	1	1	4	6	4	1	10	8	8

Appendix 1: Gloucestershire Habitat service scoring matrix

(modified from the Oxfordshire HSSM supplied by A. Smith, ECI)

Page 2

			PROVISIONING		CULTURAL				REGUALTING				BUNDLED BENEFITS		
LEVEL 1 HABITAT	CODE	HABITAT DESCRIPTION	Food Provision	Water Supply	Recreation	Education	Interaction with Nature	Sence of Place	Carbon Sequestration	Water flow Regulation	Local Climate Regulation	Air Pollutant Removal	Biodiversity	Water Quality	Soil Health
C Cropland	c1	Arable and Horticulture	10	8	0	0	0	0	1	4	2	1	4	5	6
	c1a	Arable Margins	0	8	3	3	3	3	2	4	2	1	7	5	8
	c1b	Temporary Grass and Clover Leys	7	8	3	3	3	3	1	5	2	1	7	5	8
	c1c	Cereal Crops	10	7	1	1	1	1	1	2	2	1	2	1	1
	c1d	Non-Cereal Crops	2	3	0	0	0	0	4	4	2	1	5	1	2
	c1e	Intensive Orchards	10	3	1	1	2	2	5	8	8	4	2	1	6
	c1f	Horticulture	7	7	3	3	4	3	3	5	2	2	8	1	1
	0900	Small-Scale Food Growing	7	7	3	2	3	3	3	5	2	2	8	1	1
	0920	Orchard	7	7	2	3	2	2	3	5	2	2	8	1	1
U Urban	u1	Built Up Areas and Gardens	0	0	0	0	0	0	0	0	0	0	0	0	0
	u1a	Open Mosaic Habitats on Previously Developed Land	1	5	3	3	3	3	1	2	2	1	8	1	4
	u1b	Sealed Surface	0	0	4	7	2	2	0	0	0	0	0	0	0
	u1c	Artificial Unvegetated Unsealed Surface	0	4	0	0	0	0	0	1	0	0	1	1	0
	u1d	Suburban/Mosaic of Developed/Natural Surface	1	7	2	1	2	2	2	3	2	2	3	2	5
	u1e	Built Linear Features – Cyclepath And Footpath	0	5	7	12	7	6	2	2	2	1	2	1	3
	u1e	Built Linear Features - Road Verge	0	5	0	0	0	0	3	3	2	1	2	2	4
	0200	Parks and Gardens	0	7	6	9	4	4	4	3	4	3	6	2	5
	0011	Scattered Trees	0	1	4	5	5	4	7	6	8	6	5	2	6
	0740	Open Space/Amenity Grassland	0	7	4	6	3	2	3	3	2	1	2	2	4
	0711	Natural Sports Pitches/ Playground	0	7	2	2	1	1	3	3	2	1	2	2	3
	0800	Cemeteries/Churchyards	0	7	2	2	3	2	4	3	2	2	5	2	4
	0017	Ruderal and Tall Herb	1	8	0	0	0	0	4	8	2	1	3	5	8
	1210	Other Natural Functional Green Space	0	7	4	5	2	2	3	3	2	1	4	2	3

Appendix 1: Gloucestershire Habitat service scoring matrix

(modified from the Oxfordshire HSSM supplied by A. Smith, ECI)

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			PROVISIONING		CULTURAL				REGUALTING				BUNDLED BENEFITS		
LEVEL 1 HABITAT	CODE	HABITAT DESCRIPTION	Food Provision	Water Supply	Recreation	Education	Interaction with Nature	Sence of Place	Carbon Sequestration	Water flow Regulation	Local Climate Regulation	Air Pollutant Removal	Biodiversity	Water Quality	Soil Health
S Sparsely Vegetated Land	s	Sparsely Vegetated Land	0	0	0	0	0	0	0	1	2	0	6	0	0
	s1	Inland Rock	0	0	7	6	9	8	0	0	0	0	8	0	0
	s2	Supralittoral Rock	0	0	4	3	4	4	0	1	2	0	6	7	3
	s3	Supralittoral Sediment	0	0	4	3	4	4	4	5	3	1	8	7	3
	0073	Bare Ground	0	1	2	3	1	1	1	1	1	0	1	1	0
	0105	Quarry - Hard Rock	0	0	3	3	4	4	0	1	2	0	5	5	3
	0106	Quarry - Sand and Gravel	0	0	0	0	0	0	0	1	2	0	5	5	3
R Rivers and Lakes	r	Rivers and Lakes	0	10	8	6	10	9	0	1	4	0	8	1	0
	r1	Standing Open Water and Canals	0	10	8	6	10	9	1	4	4	0	8	1	0
	r2	Rivers and Streams	2	10	9	7	10	9	0	1	4	0	8	1	0
T Marine Inlets and Transitional Waters	t	Marine Inlets and Transitional Waters	0	0	0	0	0	0	0	1	2	0	6	5	1
	t1	Littoral Rock	0	0	0	0	0	0	0	1	2	0	6	7	1
	t2	Littoral Sediment	0	0	0	0	0	0	4	5	3	1	8	7	3
	t2a	Coastal Saltmarsh	4	0	1	3	0	0	10	9	4	1	10	5	5
	t2d	Intertidal Mudflats	0	5	2	4	1	0	10	5	4	1	10	7	7

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