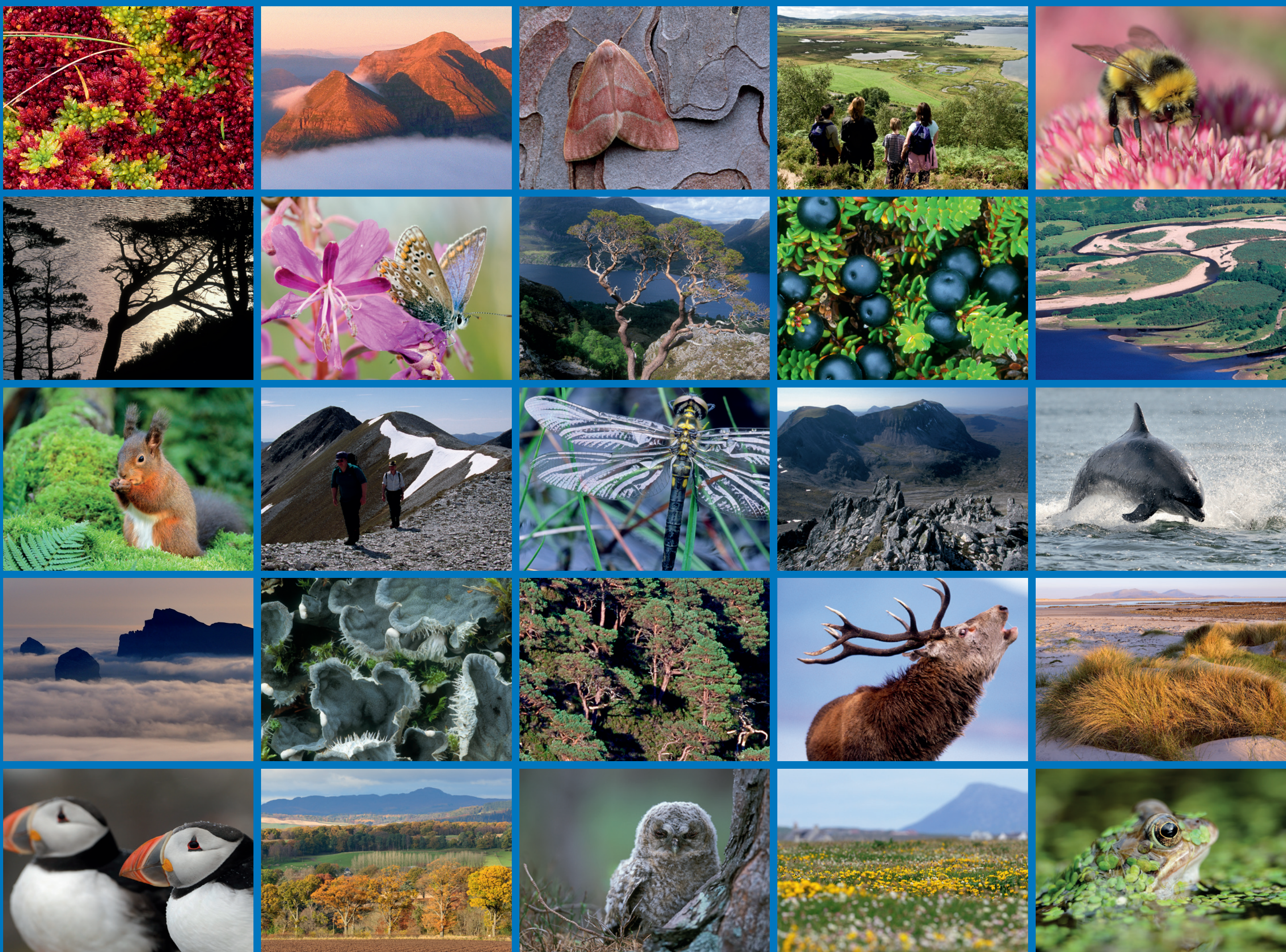
Scottish Natural Heritage
Research Report No. 954

EcoServ-GIS v.3.3: A toolkit for mapping ecosystem services (GB scale)



RESEARCH REPORT

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RESEARCH REPORT
Summary

EcoServ-GIS v.3.3: A toolkit for mapping ecosystem services (GB scale)

Research Report No. 954
Project No. 015287
Contractor: Winn, J.P, Bellamy, C.C., Fisher, T.
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Keywords

Ecosystem Services; GIS; Conservation planning; Mapping; Green Infrastructure.

Background

EcoServ-GIS is a toolkit to map ecosystem services at a county and region scale. The toolkit generates maps illustrating the need for each service as well as the capacity for service provision, using scientifically-based, standardised methods and widely available datasets. It provides users with the facility to overlay these maps to show how well demand and capacity coincide in space, highlighting those natural areas providing high levels of service delivery that should be conserved, as well as those that are most in need of measures aimed at improving single or multiple service delivery.

Version 3.3 includes tools to map nine services, including ones that grade greenspace according to the opportunities they provide for enjoying nature and wildlife. The toolkit requires OS MasterMap and a range of optional data. The toolkit has been produced using ArcGIS ModelBuilder and requires ArcGIS version 10.2+, Advanced license and Spatial Analyst. It is designed for areas between 500 and 5,000 km^2 and requires from one to four months of experienced GIS staff time to create all outputs. Individual ecosystem service tools are independent and can be run alone or as part of a multiple service assessment.

Main findings

- EcoServ-GIS can produce maps illustrating the benefits of nature at a city to region scale
- The toolkit runs with OS MasterMap as the only source data but is greatly improved by the use of additional, optional datasets
- Multifunctional sites are identified where several ecosystem services are delivered
- Management Zones indicate where actions can maintain or enhance ecosystem services
- The toolkit can be run with default settings or can use local knowledge
- EcoServ-GIS has been used in an applied way with habitat connectivity mapping within the EcoCoLIFE to help identify the most beneficial places for habitat management and improving Ecological Coherence (report forthcoming on www.ecocolife.org.uk/)

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Table of Contents **Page**

Acknowledgements

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1. INTRODUCTION

1.1 What are ecosystem services and why should we map them?

Ecosystems affect our daily lives; contributing to our health, security, social relations, freedom, choice and prosperity (MA 2003). Their positive impact on society can be categorised in terms of the benefits, or “ecosystem services”, they provide. Development (construction of grey infrastructure, e.g., roads, buildings) reduces and fragments natural habitats, and can decrease the number or quality of the services these habitats provide. Such changes may for example reduce opportunities to relax in, learn from, and enjoy nature. Careful planning, with the consideration of how development and land use change may affect the provision of ecosystem services, can help minimise impacts on human well-being. The development of integrated and standardised “ecosystem services aware” planning strategies and policies are increasingly important. The UK Government plans to build 3 million new homes by 2020 to meet the demands of a rising population, and current changes in climate, land use, and human consumption are likely to increase the frequency and magnitude of environmental stressors, such as pollution and extreme events (de Chazal & Rounsevell 2009; Pankhurst 2010). This importance is being recognized by policy makers, who are encouraging an "ecosystems approach" (MA 2003; Ashworth et al. 2007; CEP with GeoData Institute 2007; Defra 2007; CBD 2009; Watson et al. 2011; Department for Communities and Local Government 2012). The ecosystem approach involves integrating social, economic and ecological perspectives into environmental valuations and assessments, providing decision makers with more transparent and holistic information on the wide-ranging consequences of the way we use and manage our natural environment, and the resources it provides.

It is critical that decision makers are equipped with tools to generate detailed information on the state of ecosystem services across their region, allowing them to take an ecosystems approach, and deliver substantiated policies and frameworks for large-scale housing development, green belt reviews, and green infrastructure strategies. This approach is widely recognised: all respondents to a recent survey hosted by the Birmingham and Black Wildlife Trust stated that an ecosystem approach will be important for their future Wildlife Trust work (Hoelzinger 2011). The Scottish Wildlife Trust (SWT) also advocated an ecosystems approach driven by the goal to “safeguard and enhance the natural components of our ecosystems” (Hughes & Brooks 2009).

Although much debate on the theory of ecosystem services has been published over recent years, there remains a need for tools to carry out assessments at the scales which are relevant to decision making (Daily et al. 2009). The production of such tools is one of the main goals of the UK NEA follow on project. Geographic Information Systems (GIS) provide a powerful platform for the visualisation and analysis of ecosystem services. By overlaying geographically-linked datasets describing biophysical, abiotic and socio-economic properties, and integrating these into a common spatial framework, GIS allows users to estimate and map service provision and demand (CUDEM 2006; Fisher et al. 2011). This spatially-explicit, quantitative approach provides an evidence-base for decision making, facilitates comparisons between regions and sites (Layke 2009), and the monitoring of provision over time, improving our ability to forecast services under different scenarios. The anthropocentric nature of ecosystem service evaluations also prompts society to acknowledge the vital role of the natural environment in ensuring human well-being, encouraging sustainable practices and efforts to minimise human driven environmental stressors.

1.2 What does EcoServ-GIS do?

EcoServ-GIS overlays spatial datasets describing aspects of the landscape, such as habitat type, grey infrastructure and socio-economic factors, in order to estimate the likelihood of ecosystem service provision. The toolkit is based on the Ordnance Survey (OS) MasterMap layer.

The first stages of the toolkit create the “BaseMap”, a fine scale map of habitats, land use, population density and socio-economic variables, such as health deprivation. These outputs are used by the subsequent tools, which each focus on mapping the delivery of an individual ecosystem service.

The toolkit uses widely accessible data inputs, such as Digital Terrain Models (DTM) and Open Space or Green Infrastructure Surveys, to ensure that the methods are transferrable to other regions, providing a standardized and transparent mapping method. Areas can be re-assessed with new or updated data for sensitivity analysis or scenario modelling.

The emphasis of the resulting maps is on locating where ecosystem services occur, and indicating where there is relatively high demand for a service, or high capacity to deliver a service. The toolkit concentrates on spatial locations and relative measures and does not attempt to quantify the actual impact of each service. For example, the air pollution service does not measure the actual amount of pollutant trapped per unit area of habitat, instead it grades the predicted ability of habitats in the study area to trap pollutants from high to low and compares this to measures of predicted air pollution demand (need) among human populations.

1.2.1 Which ecosystem services does EcoServ-GIS map?

The Millennium Ecosystem Assessment (2005) is a widely recognised standard reference for ecosystem service language and classification (Blogg et al. 2007). It groups ecosystem services into four broad themes:

Provisioning: services providing natural materials and products directly used or harvested by humans e.g. food

Regulating: services obtained directly from ecosystem processes which impact directly on human well-being e.g. local climate regulation

Cultural: the mental, physical and other intangible benefits provided to people through access to Greenspace e.g. opportunities for leisure and recreation

Supporting: those services that underpin the production of all other services e.g. nutrient cycling

A review of previous ecosystem service mapping projects revealed a long list of services for consideration. These were narrowed down to twenty one services that are applicable to a local scale and for which spatial indicators could be developed with the data and scientific knowledge currently available (Table 1). The supporting services were omitted because the delivery of many ecosystem services is reliant upon these and incorporating measures of both of these services could lead to “double counting”, compromising the usefulness of the multi-functionality maps for making decisions regarding land management (Hein et al. 2006; Wallace 2007; Fisher & Turner 2008; UK National Ecosystem Assessment 2011). Additionally, supporting services typically cannot be linked spatially to beneficiaries, and so do not fit well within an ecosystem service spatial planning framework.

The services were classified using the hierarchal structure suggested by the Common International Classification for Ecosystem Services (CICES; version 4.1) (Haines-Young & Potschin 2011; Haines-Young & M. Potschin 2010) (Table 1). This was designed to help standardise classifications, providing an approach that avoids the double counting of benefits and improves the accuracy and efficiency of their economic valuation.

EcoServ-GIS includes tools for mapping several regulating and cultural ecosystem services. The services mapped were selected according to the following criteria, in order of priority (Table 2, Table 3):

1. Cultural and wildlife-related services were given high priority because these are often neglected in similar ecosystem assessments, but information on where the benefits of wildlife and accessible nature are delivered to people is often a priority for conservation organisations.

2. Services were assessed based on the likelihood that land use and land management decisions may result in marginal change in human well-being. This was to ensure a focus in relation to decision making, land use planning and policy. Some services are more directly and spatially linked to potential management of human well-being than others.

3. Services were ranked on the availability of current and widely accepted scientific knowledge on factors driving ecosystem service demand and capacity, and the spatial scales over which these operate. To map service delivery over an area, we first need to understand how the biophysical and biotic properties of ecosystems determine what services they are capable of providing, and how these services are valued and used by society.

4. To ensure that the tools were geographically transferrable and delivered useful maps, services were only mapped if geospatial indicators were: available, up-to-date, and relevant at the county to region scale. Geospatial indicators are geographically-linked datasets that inform us about the functioning of an ecosystem and help us map the ecological and socio-economic factors driving the requirement and demand for a service. However, the availability and reliability of such data varies. Data which were not freely available were avoided.

5. Services were selected where there was a logical link between natural environment capacity and the benefits to people at a neighbourhood, county or region capacity scale. Several services occur across national scales and such services cannot meaningfully be mapped using the EcoServ-GIS method. Examples include long distance water supply transport for drinking water, and long-distance flood impact.

Table 1. CICES ecosystem service classification

	Group	Class	Ecosystem service
Provisioning	Terrestrial plant & animal	Crops	Food provision
	Water for human consumption	Drinking water	Water supply
	Plant and animal fibres and structures	Plant and animal materials for fabrication in industrial or domestic settings	Timber
Regulating	Atmospheric regulation	Global climate regulation (incl. Cs sequestration)	Carbon storage
		Local & Regional climate regulation	Local climate regulation
			Air purification
	Noise regulation	Buffering & screening	Noise regulation
	Water quality regulation	Water purification and oxygenation	Water purification
	Lifecycle maintenance & habitat protection	Pollination	Pollination
	Pest and disease control	Biological control mechanisms	Biological control
	Water flow regulation	Storm protection	Wave attenuation
		Attenuation of runoff and discharge rates	Water flow regulation
	Mass flow regulation	Erosion protection	Erosion regulation
Cultural	Non-extractive recreation	Natural and cultural ecosystems and landscapes used for physical activity	Wildlife watching
			Accessible nature experience
			Green travel corridors
			Outdoor recreation spaces
	Information and knowledge	Educational	Education and knowledge
		Heritage	Heritage
	Aesthetics	Visual amenity	Aesthetics
	Societal relations	Community cohesion	Community cohesion

Table 2. Links between local ecosystem service occurrence and human well-being

Ecosystem service	M.apped in EcoServ-GIS v.3.3	Link between service and well-being	Proportion of local population affected	Impact of land management on well-being
Accessible nature	*	Medium / High	Medium	High
Green travel	*	Medium	Medium	Medium
Outdoor recreation spaces		Medium / High	Medium	High
Education knowledge	*	Medium / High	High	Medium
Heritage		Low	Low	Low
Aesthetics (Visual amenity)		Medium / High	High	Medium
Community cohesion		Low / Medium	Low	Low
Wildlife watching		Low	Low	Low to Medium
Carbon storage	*	Low	Low	Low
Local climate regulation	*	Low / Medium	Low	Medium
Air purification	*	Low / Medium	Low	Medium
Noise regulation	*	Low / Medium	Low	Medium
Water purification	*	Low	Low	Low
Pollination	*	Low / Medium	Low	Low
Biological control		Low	Low	Low
Wave attenuation		Low to High	Low	Low to High
Water flow regulation		Low to High	Low to Medium	Low to High
Erosion regulation		Low	Low	Low
Food provision		Low	Low	Low
Water supply		Low / Medium	High	Low
Timber		Low	Low	Low

Caveats and assumptions: The references for this assessment were the local human population, services and ecosystems within the Study Area and a timescale of one generation. Study area is assumed to be a typical UK county or region. The assessment assumes that most of the population resides in the area for a significant proportion of their lifetime. Land management also refers to management of ecosystems within the Study Area. The importance of services would differ if the assessment scale was larger or smaller.

Table 3. Definitions of EcoServ-GIS services

Service name	EcoServ-GIS Service definition
Accessible Nature	Areas where people benefit from opportunities to experience and enjoy natural places and landscapes within their living, working, and commuting space. The capacity of the natural environment is mapped by identifying public accessibility status and scoring areas by their level of perceived naturalness. The demand (need) for accessible nature is mapped by estimating the number of people likely to travel to an area and their relative need for the related health benefits, based on current Index of Multiple Deprivation health scores.
Education	Opportunities for young students to develop skills and learn within the natural environment. The capacity of the natural environment to provide education / knowledge opportunities is mapped by identifying accessible areas and assuming that natural sites with a greater variety of broad habitats have greater capacity, as these provide more opportunities for education. Demand (need) is mapped based on local and landscape population density, the distance to local and regional schools and the number of schools within driving distance.
Green Travel	Green travel routes and corridors occur within urban areas where people benefit from a range of positive features of habitats and vegetation cover. Benefits may include: encouraging more frequent active travel behaviour, safer traffic-free routes, calm, relaxing and inspiring locations, and buffer zones away from traffic related pollution. The capacity of the natural environment to provide green travel routes is mapped by assigning perceived naturalness scores to habitats along different types of travel corridors. Societal demand (need) for these routes is identified by mapping the location of key travel destinations or starting points. These include schools, towns centres and train stations. Least cost modelling is used to determine those corridors most connected to the key travel destinations.
Carbon	The storage of carbon in above and below ground biomass. The capacity of the natural environment is mapped by assigning potential carbon storage values per mapped habitat type based on peer-reviewed literature. Values map typical habitat storage levels and levels within the upper 30 cm of soils. The demand (need) for carbon storage is considered to be constant across the entire study area as there are global benefits in the storage of carbon.
Local Climate Regulation	Areas where the natural environment may help to mitigate the urban heat island effect due to the cooling impact of the types and configurations of habitat that are present. The capacity of the natural environment is mapped based on presence of water bodies and various types of green space within the local environment. The regulatory demand (need) for local climate regulation is mapped by calculating the proportion of urban landcover within the local environment. Societal demand (need) for local climate regulation is mapped based on population density, and population vulnerability to raised temperatures and heat waves, based on age.
Air Purification	Urban areas where people benefit from vegetation cover that helps to remove vehicle emissions from the air. The capacity of the natural environment to provide air purification is mapped by assigning air purification scores to broad habitat types based on their ability to trap pollutants, and then identifying areas around the vegetation where air pollution may be reduced. Societal demand (need) for air purification is mapped by calculating population density in urban areas. The regulatory demand (need) for air purification is mapped by estimating traffic based air pollution levels. These are calculated using reverse distance from roads, by road type, assuming higher traffic use on higher category roads.

Service name	EcoServ-GIS Service definition
Noise Regulation	Urban areas where people benefit from vegetation that helps to diffuse and absorb traffic noise. The capacity of the natural environment is mapped by assigning a noise regulation score to vegetation types based on height, density, permeability and year round cover. The demand (need) for noise regulation is mapped by estimating noise volume levels and the potential societal impacts of noise. Potential noise volumes are calculated based on Euclidean distance from roads, railways and airports. Volume is estimated based on distance from noise source, weighted according to source type. The societal need is mapped based on population density and health IMD scores.
Water Purification	Areas where habitats and vegetation help trap sediment in water runoff in locations where pollutants are likely to be mobilised. The capacity of the natural environment for water purification is mapped by calculating surface resistance based on vegetation type and slope gradient. The regulatory demand (need) is calculated based on fine scale erosion risk (likelihood to contribute pollutants) and the proportion of the watershed covered by agricultural or urban landuse (sources of pollution).
Pollination	Allotments, orchards and areas of agricultural land where natural pollinators may contribute to crop yield and stability. The capacity of the natural environment to provide pollination is mapped based on the likelihood of pollinator visitation, calculated using likely travel distance from pollinator habitat. The demand (need) for pollination is mapped by identifying allotments, orchards and areas of agricultural land where crops may occur which may benefit from insect pollinators.

1.3 Why was EcoServ-GIS produced and what was the rationale?

Many conservation projects involve mapping or spatial analysis. Recent examples include the identification of Living Landscape areas, Habitat Networks and Biodiversity Opportunity areas. These projects have been conducted by many organisations and partnerships. Using Habitat Network maps as an example many projects have produced reports and mapped networks. However coverage across Great Britain is patchy and the methods used are inconsistent. Most projects are not easily repeatable. Where methods have been published they remain in report form, as step-by-step instructions, with repeat analysis or replication requiring the conversion of the methods into GIS analysis. Such step-by-step analysis takes considerable time to conduct, however many GIS operations can be automated. There are few such automated methods available in the UK, and where they exist they are not freely available or supported by User Guides.

EcoServ-GIS was initiated by Jonathan Winn in 2012 following work on landscape scale conservation initiatives and involvement with the UK National Ecosystem Assessment. The rationale behind EcoServ-GIS was that Ecosystem Services (and its equivalent in urban areas: Green Infrastructure) are of key interest to conservation organisations, and a standard method to map these would be useful. Ecosystem Services touch on many areas of conservation activity, from education to land management. The area was considered to be of increasing policy interest and it was felt beneficial for organisations to be able to include Ecosystem Services in their work, e.g. for inclusion in funding bids, policy responses and input to site-scale projects. Already funders such as the Heritage Lottery Fund are requesting consideration of Ecosystem Services in funding applications. Questions relevant to use of ecosystem services in conservation projects are:

- Which sites, nature reserves or green infrastructure areas are important for current ecosystem service delivery?
- Where are more ecosystem services needed?
- What are the ecosystem service benefits of proposed conservation or habitat creation actions?

The rationale behind the project was therefore to produce a toolkit that can be used "in-house" by conservation organisations or partnerships to produce Ecosystem Service maps that will be of use to project planning, landscape management, funding bids, education work and publicity. The project produced a standardised method that can be freely shared, amended or updated in the future. This aimed to save time and costs on the repetitive nature of GIS mapping projects. This rationale however is conditional on such partnerships containing GIS staff support, and also valuing the flexibility, ownership and repeatability this method provides, in contrast to contracting out such work to consultancies.

Project development was led by Jonathan Winn at Durham Wildlife Trust. Two project officers (Chloe Bellamy, Tom fisher) were employed to conduct literature reviews, model development and support the use of the toolkit at partner organisations. Initial toolkit versions were trialled in Durham (v1), then with partners across England (v2). The current version (v3) was expanded to also apply in Wales and Scotland in partnership with the Scottish Wildlife Trust, Scottish Natural Heritage, Scottish Environment Protection Agency, and the Glasgow and Clyde Valley Green Network Partnership.

1.3.1 Specific issues addressed by EcoServ-GIS

The toolkit identified and addressed the following key barriers to mapping ecosystem services:

- A lack of digital habitat or ecosystem mapping data at a county or region scale

- A range of GIS data without a central system to coordinate its use
- A lack of socio-economic data and analysis to link people to nature
- Lack of GIS expertise and ecosystem service knowledge

1.4 Where and when can EcoServ-GIS be applied?

The toolkit is more applicable to some projects, locations, and landscapes than others (Tables: 4, 5). The main factors affecting suitability are: country, study area, project type, focal ecosystem services, and availability of digital habitat mapping.

Country: The toolkit has been developed based on OS MasterMap and is therefore applicable across mainland Great Britain. The toolkit is not suitable for use in Northern Ireland, the Isle of Man or the Channel Islands.

Study Area: size and composition: The toolkit is appropriate for landscapes between 1,500 and 5,000 km^{2,} that span a range of urban and rural conditions. The toolkit is not appropriate for exclusively urban or rural landscapes or solely upland areas (e.g. where mean elevation > 350 m). Once the toolkit has been run, smaller sub areas can be examined and compared using the “StudyAreaScales” boundary file (in ES1BaseMap\Outputs).

Project type and lead organisation: The toolkit is aimed at applied conservation projects related to spatial planning, within a partnership context. Examples may include Local Nature Partnerships, Landscape based partnerships (Living Landscapes, Futurescapes, National Parks, AONBs), Catchment Planning Partnerships or Biodiversity Action plan partnerships.

Focal services: single versus multiple ecosystem services: The toolkit is designed to be used where multiple services are of interest. This is due in part to the time required to produce the BaseMap in contrast to the time required to run each service model. The time vs. results trade-off is less efficient if fewer services are mapped. If only certain services are of interest, then other toolkits are likely to be more suitable (e.g. InVEST, SciMap, STAR Tools) (Natural Capital Project 2011; Milledge et al. 2012; The Mersey Forest 2015)

Extent and resolution (Study Area): EcoServ-GIS is designed to produce maps for “county” sized regions at a fine resolution, and spatial indicators have been selected and measured at scales appropriate to these specifications (within the limitations of available data). The default cell size is 10 m. With further funding and support alternative resolutions (5 m or 50 m) could be tested, however these are currently untested. The time taken for each model to run for several different landscapes at a 10 m resolution has been recorded for reference (Annex 1).

Study Area buffer distances: A buffer distance is recommended around the study area. Many service models measure conditions around a focal, central cell, therefore the "edge" of the mapped results can be considered unreliable because they are not based on data from the full search distance. For this reason a buffer zone is recommended for which data is collected and used to calculate the results, but will not be included in the final service maps. Because the toolkit considers several services and each is mapped using indicators at different spatial scales there is not one buffer distance that is appropriate for all services. Some services can be influenced by measures up to 10 km from a central cell, others such as air pollution only measure over hundreds of metres. Generally a larger buffer distance is preferable, however this will incur significant costs in acquiring and processing data, the ideal buffer distance is thus a compromise. Suggested distances in decreasing order of priority are: 5, 3, or 1 km.

Table 4. Service application by landscape type

Ecosystem service	Urban	Urban-fringe	Rural	Uplands
Air purification	✓	✓	✗	✗
Carbon storage	✓	✓	✓	✓
Local climate	✓	✓	✗	✗
Noise regulation	✓	✓	✗	✗
Pollination	✓	✓	✓	✗
Water purification	⚠	✓	✓	⚠
Accessible nature	✓	✓	⚠	✗
Education	✓	✓	⚠	✗
Green travel	✓	✓	⚠	✗

✓ : applicable use, ⚠ : use with caution, ✗ : not suitable for use

Table 5. Service application by planning scale

Ecosystem service	Site to neighbourhood to 1 km^2	Catchment to 100 km^2	Strategic / County to 5,000 km^2
Air purification	⚠	✓	✓
Carbon storage	⚠	✓	✓
Local climate regulation	✓	✓	✓
Noise regulation	✓	✓	✓
Pollination	⚠	✓	⚠
Water purification	✓	✓	✓
Accessible nature experience	✓	✓	✓
Education	✓	✓	✓
Green travel corridors	✓	✓	✓

✓: applicable use, ⚠ : use with caution

Note: Planning scale refers to ecosystem service maps, statistics and data being used to report on or inform strategies or decision making at, or between, planning units of this size.

EcoServ-GIS has been used in an applied way within the EcoCoLIFE project to help identify the most beneficial places for habitat management. This project, funded through the EU LIFE programme, is implementing restoration and management within Scotland's Central Scotland Green Network area (http://www.centralscotlandgreennetwork.org/) in order to improve ecological coherence. EcoServ-GIS layers have been used along with habitat connectivity mapping to pinpoint key intervention areas – the Ecological Coherence Protocol (report forthcoming). See https://www.ecocolife.org.uk/ for more information.

1.5 What types of data are required to run EcoServ-GIS?

The toolkit requires OS MasterMap Topography layer to build a BaseMap (Habitat Map). This is the main *user provided* GIS data required. However using only OS MasterMap data will produce an analysis and will not allow all Ecosystem Service models to be run. A number of further *optional* data inputs either help to create a more detailed BaseMap or allow more service models to be run.

The optional data that has the most impact on the toolkit is the use of habitat data (e.g. Phase 1 survey digital mapping, or Land Cover Map (LCM 2007). The use of alternative data sources to include in the toolkit and to map habitat types has implications for the speed of analysis, and the issue of data accuracy, quality and consistency.

The toolkit was designed for use with Local Authorities, utilising locally available free data. Therefore the assumption was that a range of habitat mapping, Landscape Character, Open Space Survey or Green Infrastructure mapping would be available. Although data editing to allow the use of these data, and checking of the results can have significant time costs this significantly adds to mapping accuracy of the toolkit results, especially in urban areas. Although this User Guide includes instructions on how to use, check and amend these inputs a project may determine that buying in habitat landuse data may be more appropriate, although it may not include local scale habitat types. For example, for ease of application LCM 2007 data may be used.

If local information (habitats, land-use, Open Space Survey, Green Infrastructure) is used within the toolkit then one of the results of EcoServ-GIS is a Phase 1 Habitat Survey digital habitat map. This in itself may be a significant output of the process, but in situations where such data already exists this may influence the desirability of running these optional sections of the toolkit. For further information see Section 4 and 4.4 on the project timescales.

1.6 Who can use EcoServ-GIS?

EcoServ-GIS is freely available. See the licence for details. Users should ensure they have appropriate data licences in place. Organizations wishing to use the toolkit are asked to approach their local Wildlife Trust and Local Authorities to develop a joint project plan and to share data, although this is not a pre-requisite to use of the toolkit. Information on downloading the toolkit is available by email at ecoserv-gis@outlook.com

2. METHODS

2.1 EcoServ-GIS: complexity & limitations

No accepted, standardised approach to mapping ecosystem services currently exists. This area of research is rapidly expanding and various strategies have been suggested for identifying and using ecosystem service spatial indicators (Boyd & Wainger 2002; Linstead et al. 2008; Layke et al. 2010; Bastian et al. 2011; Haines-Young & Potschin 2010; Medcalf et al. 2012; van Oudenhoven et al. 2012). Ecosystem service mapping studies vary in their approach according to the scale at which they are operating, the landscape in question and the stage of service delivery they aim to map.

A “habitat-service matrix approach” involves using expert opinion to create a look-up table of associations between habitats or land use types and expected service provision (Haines-Young et al. 2011; Burkhard et al. 2011; Troy & Wilson 2006; Dales et al. 2014). Once the land use classes have been mapped, then potential service delivery across an area can easily be illustrated using the links in the table. One approach used expert opinion to rank each of the 44 land use categories available for Corine land cover data according to their perceived capacity to provide various ecosystem service (0 - 5; no capacity – very high capacity) (Burkhard et al. 2011). They later introduced seven “ecological resilience indicators” to help illustrate how different land use categories can provide structures and processes that help to support the functionality of an ecosystem (Burkhard et al. 2011). This straightforward approach to ecosystem service mapping is useful for providing an insight into multiple ecosystem services over large areas (e.g. continental or global) and may provide a useful, rapid assessment technique for estimating the economic value of an area (Naidoo & Ricketts 2006; Troy & Wilson 2006), but it is arguably too simplistic to provide useful estimates at local spatial scales (Hermann et al. 2011).

A “service-based approach” involves selecting indicators by investigating the processes involved in the delivery of each individual service. These indicators extend beyond habitat composition and may include landscape structure, land use, grey infrastructure and socio-economic variables, allowing more realistic estimates of ecosystem service delivery to be generated across space. This added complexity increases the time involved in producing models of ecosystem services compared to employing the habitat-service matrix approach (Figure 1).

EcoServ-GIS provides a standardised approach to mapping ecosystem services at a *county to region scale*, generating output that is sufficiently detailed to inform local scale decision making. The methods employed therefore needed to be geographically transferrable and easily implemented by organisations with varying levels of GIS expertise, IT resources and ecosystem service knowledge. To ensure the toolkit output’s validity and usefulness, the analysis steps and the information upon which these were based need to be transparent, repeatable, and scientifically-grounded. Within this remit not all services have been able to be mapped to the same standard. Limitations of particular service mapping models are highlighted where relevant (Tables 4, 5).

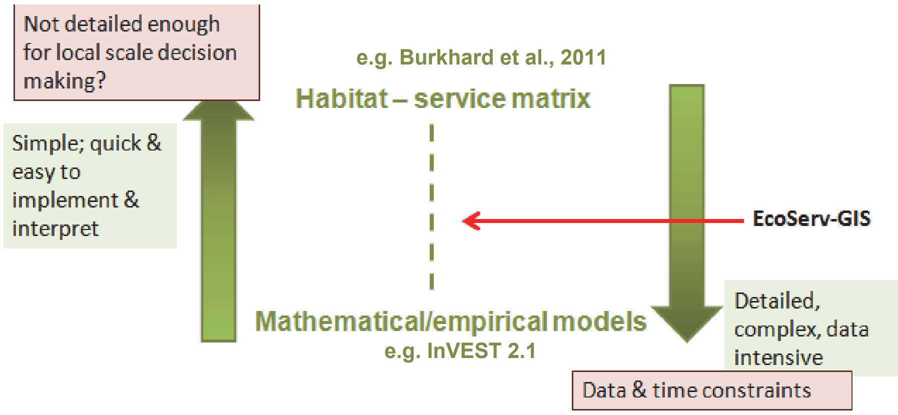


Figure 1. The complexity of EcoServ-GIS analysis methods.

When EcoServ-GIS was initially developed in 2012 other GIS tools were available which could estimate service delivery, but none were wholly suitable for the project. None addressed the range of services that were listed as a high priority during EcoServ-GIS steering group consultations. The wildlife-related services, such as accessible nature, tended to be neglected. Although the Multiple Benefits Mapping Toolbox (version 1.2), an ArcGIS toolbox developed by UNEP-WCMC for REDD+, allows users to map biodiversity, the only other service it mapped was carbon storage (Ravilious et al. 2011). Other toolboxes are not applicable to the United Kingdom: the Artificial Intelligence for Ecosystem Services (ARIES) aims to illustrate the flow of services to the societal beneficiaries, but it is currently only available for seven case study regions (Villa & Ceroni 2009). Others operated at too broad a scale to be useful for within-county decision making (e.g. the web based tools, Co$ting Nature and WaterWorld work at a global scale (1 km resolution) (Bruijnzeel et al. 2010; Mulligan et al. 2010). InVEST (version 2.1) is an ArcGIS toolbox that allows in-depth and detailed service-based analysis of a range of ecosystem services, and is applicable to local scales (Kareiva *et al.* 2011; Natural Capital Project 2011). However, the models often require information and decisions to be made that require input from academics or specialists (e.g. to map water purification, users need data on annual potential evapo-transpiration rates per cell and water quality coefficients for different land use types in the study area). The data and staff time inputs are therefore great.

No model is an accurate representation of reality. EcoServ-GIS aims to provide useful information upon which discussions and decisions can be informed, using the data and resources generally available to conservation organisations or Local Authorities. EcoServ-GIS is based on a service-based approach, but in comparison to InVEST it uses more simplified and generalised models of the relationships between landscape variables and services (Figure 1). For example, indicators are often assumed to have a linear effect on service capacity or demand and an equal weighting system is used in most cases to sum the effects of multiple indicators. Only current service delivery is modelled, information is not incorporated on ecological resilience or habitat state to allow estimates of long-term, sustainable provision of the service. Model simplification allows analysis at fine resolutions to be completed within a reasonable project time frame, without the need for particular expert knowledge (other than GIS experience). The models are also limited by the accuracy and resolution of the data that are available and accessible. The decisions and scientific rationale upon which geospatial indicator selection was based are logged in this guide, which aims to make the methods clear and reproducible, highlighting any uncertainties, limitations, and data or knowledge gaps. As GIS data availability and accuracy continues to increase over time, EcoServ-GIS could be updated to use this information to generate more accurate and reliable results.

An issue that users should be aware of prior to running an EcoServ-GIS project is the status of habitat-service links made within the toolkit. Initially the toolkit collates available habitat information and this is used to link to particular habitat and land use types of service capacity or demand. During this process, the availability of habitat information will impact on the reliability of the links. Often, within the literature, only coarse habitat-service links are possible and therefore for some services only coarse habitat categories are used to map the service. These issues must be borne in mind when interpreting maps. Such issues have been summarised when the suitable scale of application of each service map is recommended (Table 5).

2.2 Linking capacity and demand: mapping service flow to beneficiaries

The ecosystem approach puts people at the heart of the picture: what services do we receive from our natural environment and how do these vary over space? This can be illustrated by mapping the final benefits received by people e.g. the pollutants removed by a wooded stream buffer. However, some benefits, particularly those arising from cultural services, can be very difficult to fully quantify. Therefore an alternative option is to model this environment-to-people relationship by estimating both the ability of an ecosystem to deliver a service to an area, as well as the likelihood of that service being realised and having a positive impact on the health and well-being or livelihoods of people. For example, a belt of trees may be capable of buffering air pollution, but is it within an area that is likely to be affected by high air pollution? Furthermore, is this air pollution considered to be causing a problem – do people live nearby and how likely are they to benefit from a reduction in pollution? This example is illustrated in Figure 3 and Figure 7.

EcoServ-GIS explicitly models the “flow” of ecosystem services, from the natural environment to people (refer to the Glossary for definitions, and Box 1 for an outline of the method). See Figure 2 for an analysis flowchart. The following stages are conducted for each mapped ecosystem service:

Ecosystem Service Capacity: Ecosystems capable of providing a particular service are identified. These areas of capacity are graded according to the predicted level or quality of the service they may be able to provide, using service-specific geospatial indicators. For certain services there may be features that restrict the capacity of an ecosystem to deliver a service, for example if an area is publicly or easily accessible or not. In such cases maps of both unrestricted capacity (e.g. only within accessible areas), and restricted capacity (all areas, even if not accessible) are produced. See Table 6, Table 7, Figure 3.

GI assets: A version of the capacity score is created for each service mapping only areas of capacity that occur within areas of demand. This is termed the GI_assets for each service, as areas of capacity outwith areas of demand do not significantly contribute to population well-being for each service.

Ecosystem Service Demand: The level of societal demand for a particular service is estimated by measuring the relative number of potential beneficiaries, and the possible level of improvements to health and well-being that a service could provide to them (e.g. the Index of Multiple Deprivation Health scores are used to estimate the demand for the health benefits of the accessible nature service). For those ecosystem services that relate to the regulation of hazards, the hazard areas are identified first and then only these areas are graded according to demand by combining the likelihood of the hazard occurring (regulatory need) and levels of societal demand. See Table 6, Table 8, Figure 3.

Scoring levels: The grading of both capacity and demand are relative to the Study Area and indicate a range from Low to High (1 to 100). The toolkit will always grade areas from 1 to 100 even if there is relatively little variation in levels within a Study Area, which is one reason why the toolkit is less suitable in smaller Study Areas with more uniform habitat or socio-economic conditions. Where resources are available this information should be combined with local expertise or additional data to identify locally meaningful cut offs or values that represent local examples of Low or High Capacity and Demand.

Table 6. Summary of indicators used to map each service

Service	Environmental capacity indicators	Regulatory Demand and Societal Need indicators
Accessible nature	Site accessibility, Perceived naturalness score	Societal: Health IMD, Population, Likelihood of use (travel distance). At 3 spatial scales.
Education	Site accessibility, Habitat diversity	Societal: Number of young people, Education IMD, Distance from Schools. At 3 spatial scales.
Green travel	Perceived naturalness score, Access routes	Societal: Cost distance from origin and destination travel locations. Urban areas. Access routes only.
Carbon storage	Carbon content per habitat	Regulatory: None (all assumed to have demand) Societal: None.
Local climate	Cover of woodland	Regulatory: Urban areas and domestic houses. Societal: Population at risk from heat events.
Air purification	Purification score per habitat	Regulatory: Predicted air pollution (road type, distance), sealed surfaces. Societal: Population, health IMD.
Noise regulation	Regulation score per habitat	Regulatory: Predicted noise levels (Cumulative). Societal: Population, health IMD.
Water purification	Roughness score, slope angle	Regulatory: Soil erosion risk (USLE), Pollution risk (urban and agricultural cover). Distance to watercourses. Societal: None.
Pollination	Pollinator visitation likelihood	Regulatory: Distance to arable, orchards and allotments. Societal: None.

IMD: index of multiple deprivation (England, Scotland and Wales versions). USLE: universal soil loss equation.

Table 7. Summary of capacity indicators used to map each service

Service	Environmental capacity indicators	Capacity threshold (ha)	Site (cell) analysis	Local Scale (search radius) (km)	Other thresholds	Accessibility Analysis
Accessible nature	Perceived naturalness score	> 0.05	*	0.3		*
Education	Habitat diversity	> 0.5		0.3	> 1 Broad habitat variety	*
Green travel	Perceived naturalness score	> 0.1	*	0.3	> 2 km length connected travel route	*
Carbon storage	Carbon content per habitat	n/a		n/a		No
Local climate	Cover of woodland	None		0.2	Patch buffers <2 ha (20 m), 2-5 ha (40 m), 5 to 10 ha (80 m), > 10 ha (100 m)	No
Air purification	Purification score per habitat	> 0.05	*	0.1	< 20 m from GS patches	No
Noise regulation	Regulation score per habitat	> 0.05	*	0.1		No
Water purification	Roughness score per habitat, slope	> 0.05	*	n/a		No
Pollination	Predicted pollinator visitation	None		0.6		No

Note: although recommended default settings are applied by the toolkit, the majority of these can be altered by toolkit users to fit local situations. GS: greenspace

Table 8. Summary of demand indicators used to map each service

Service	Demand thresholds (ha)	Popn density	IMD scores	Age Groups	Scale (search radius) (km)			Access analysis	Other	Coverage
					Local	Landscape	Region			
Accessible nature	0.1	*	Health		0.6	2.4	12.8	*	GS thresholds: 0.1, 10, 100 ha	GS only
Education	1	*	Education	<15	0.6	3	8	*	GS thresholds: 1, 10, 100 ha	GS only
Green travel	No							*	< 4.5 km cost distance	Access routes
Carbon storage	No							No		All
Local climate	No	*		<10, >65	0.2			No	< 250 m from land or houses	Urban areas
Air purification	No	*	Health		0.3			No	Sealed surfaces at 0.4 km. Distance to roads at 0.3 km	All
Noise regulation	No	*	Health		0.3			No	Distance to noise sources (0.55, 0.6, 0.65, 0.8, 1.5 km)	All
Water purification	> 0.05							No	< 250 m from watercourses	All
Pollination	No				0.68			No		Selected areas

Where population density has been calculated, analysis scale thresholds have been applied to remove areas of sparse population where health statistics and population mapping would be unreliable. These are Local > 50, Landscape > 500, Region > 1000. GS: greenspace. IMD: index of multiple deprivation (England, Scotland and Wales versions).

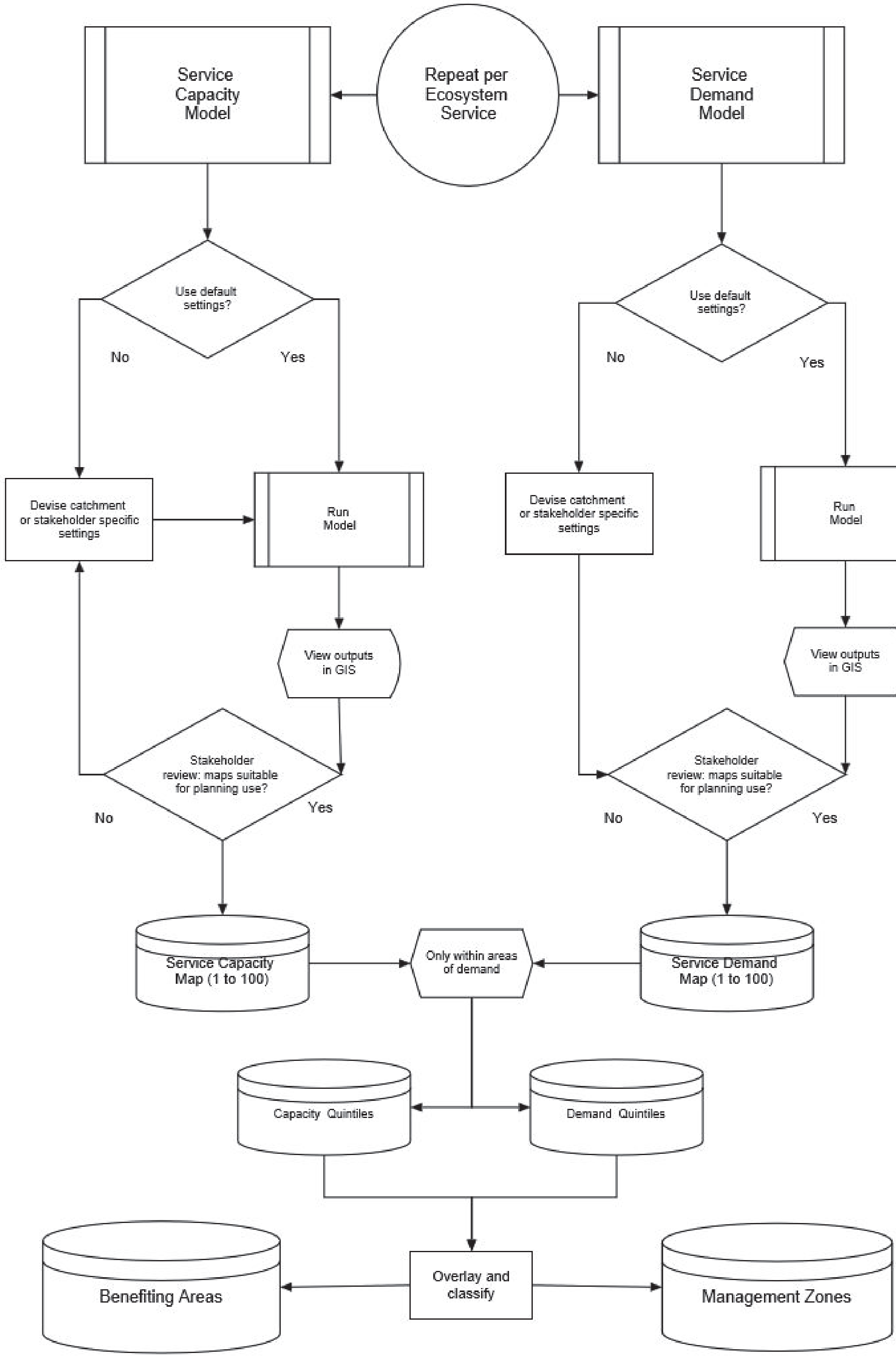


Figure 2. Ecosystem service classification flowchart

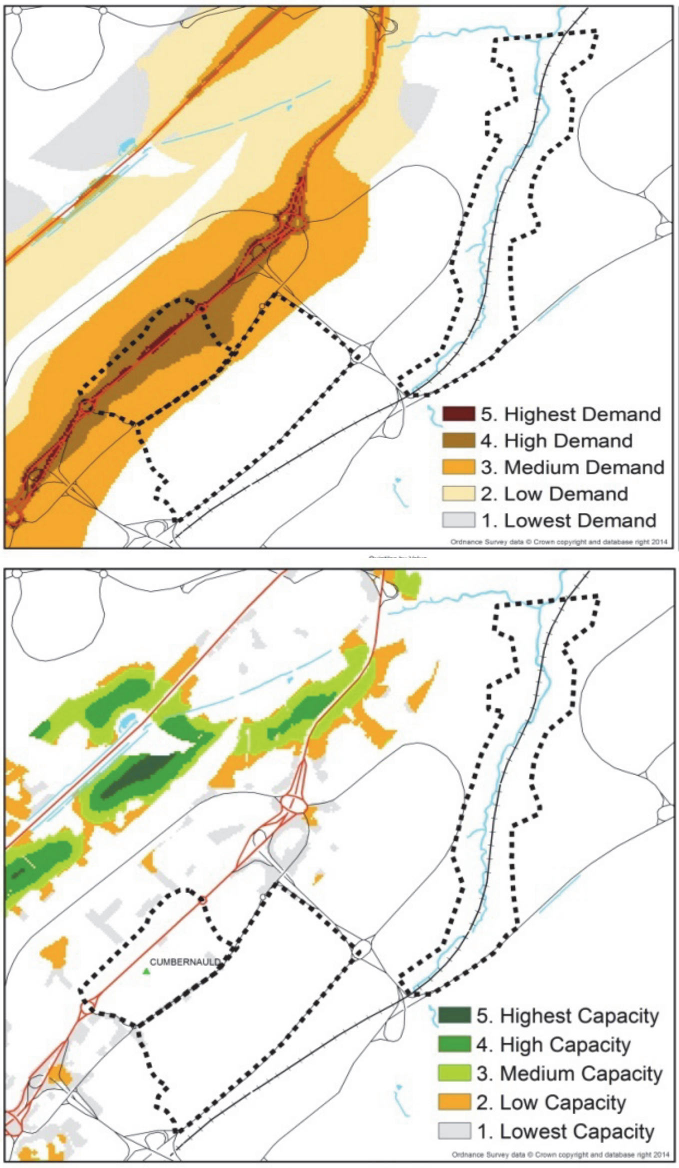


Figure 3. Service capacity and demand map examples

To inform an ecosystems approach, mapping tools need to consider both the environment and society. A particular ecosystem can only be considered to provide a service if it is capable of providing a particular service (measured in terms of "ecosystem service capacity") and, it is located in an area where the service is received by people, having a positive impact on their health and well-being (measured in terms of "ecosystem service demand"). Overlaying these maps illustrates where services are provided and what actions need to be taken to optimise service delivery.

Air Purification Demand indicates areas where high densities of people, with lower population level health scores, live close to busy roads. Populations that are already of lower health and who live in high density areas close to busy roads are most at risk of air pollution impacts to their health.

Air Purification Capacity indicates where woodland occurs with sufficient size to be effective in removing air pollutants. Large and wide woodlands are most effective. Capacity quintiles are only mapped within areas where demand occurs. Those woodlands which are beyond the influence distance from roads are not shown.

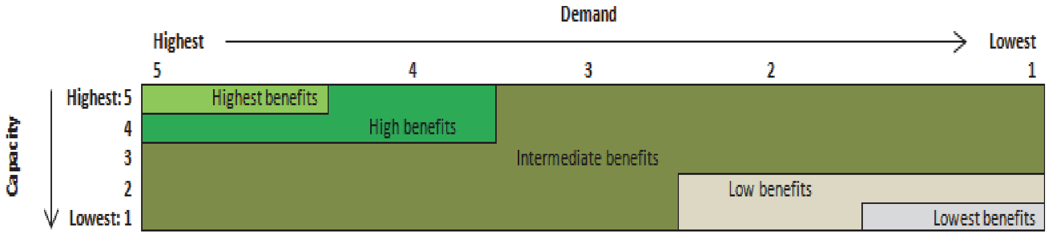


Figure 4. Classification of service benefiting areas

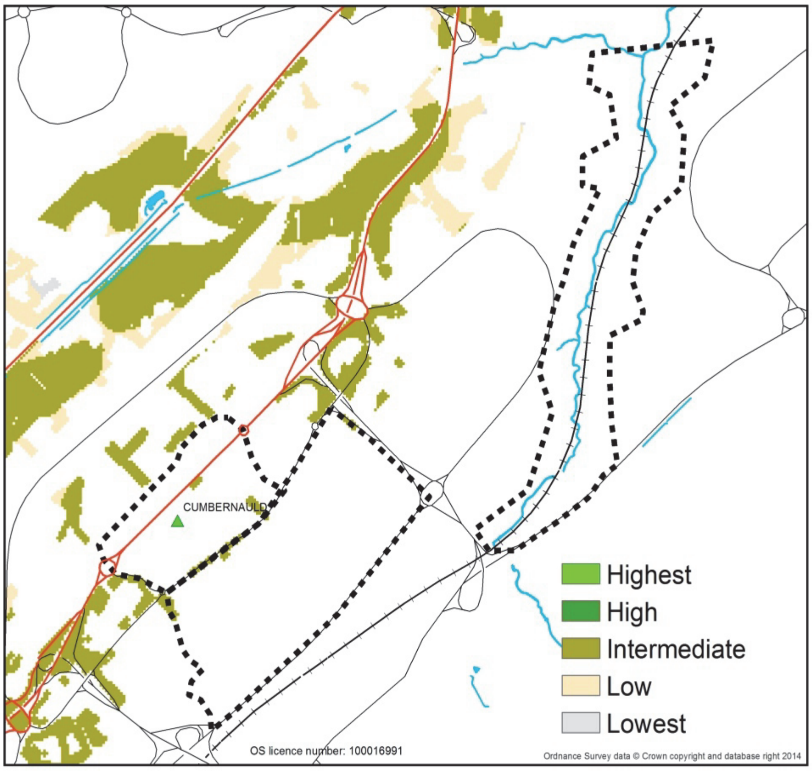


Figure 5. Service benefiting areas map example

Air Purification Benefiting Areas: Demand and Capacity quintiles are overlaid to define benefit categories. Due to the uncertainties involved five simple benefit categories are mapped. In this example most of the woods are considered to deliver intermediate level benefits to the local population. A further set of urban woodlands are considered to deliver low benefits to people, either because they are too small or narrow to affect air pollution, or because they are in areas where the impact of air pollution is likely to be low.

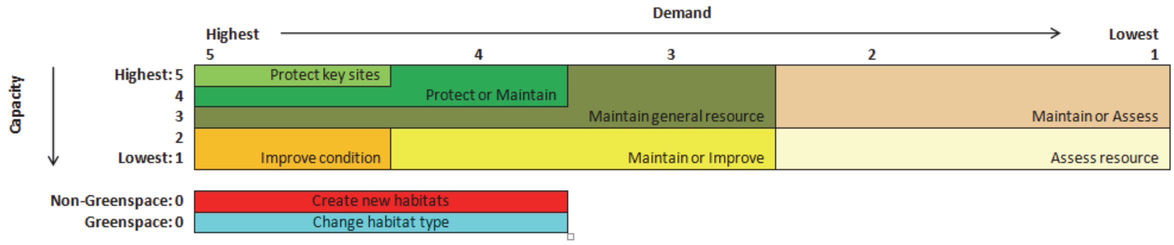


Figure 6. Classification of management zones

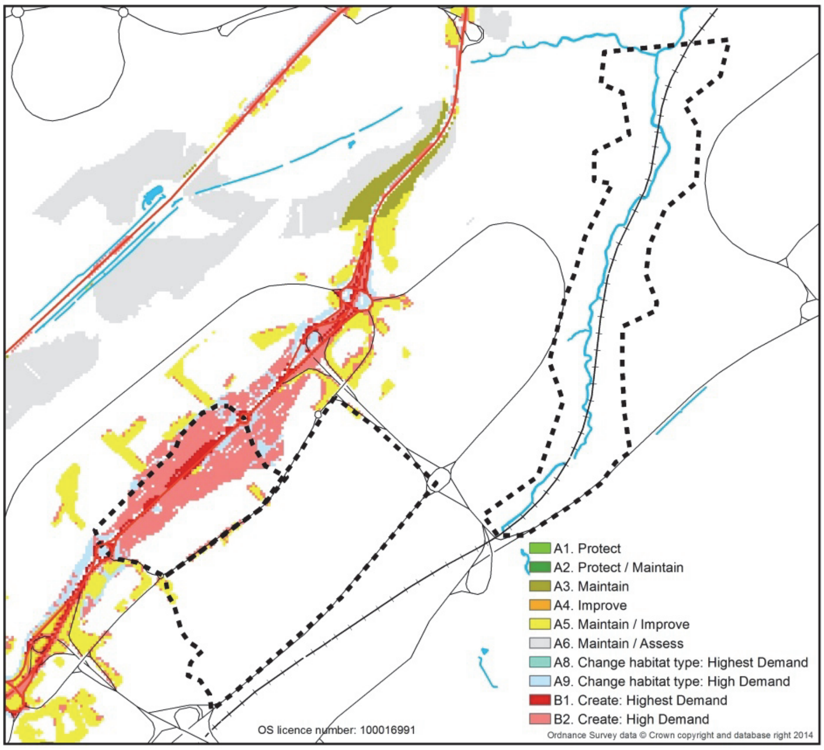


Figure 7. Service management zones map example

Air Purification Management Zones: Demand and Capacity Quintiles are overlaid to define a range of management zones. The focus is to inform landscape or greenspace managers of how areas could be prioritised in relation to this ecosystem service. Due to the uncertainties involved the categories should be considered as a broad guide, to which local knowledge can be added. The management zones distinguish between areas where the current habitat composition is delivering benefits and ongoing management is appropriate, from areas where change could deliver additional benefits. This could be in the "improve" areas where wider or larger woodlands could deliver higher benefits. A distinction is made between areas with zero capacity but no greenspace, from greenspace areas with zero capacity but where the current habitat cover has no capacity for the service in question. For example with air purification the "create habitat" areas indicate where street trees, hedges, living walls could be created in areas of sealed surface. In contrast the "change habitat" areas indicate where areas of amenity grass could be converted to woodland, hedges or scrub to aid air purification. These categories are mapped separately because the likelihood of management change in each area will differ.

Ecosystem Service Flow, Service Benefiting Areas: The demand and capacity maps are overlaid to illustrate how well they coincide in space, highlighting areas where there is a likely flow of the ecosystem service to society (Figure 4, Figure 5). These are termed “Ecosystem Service Benefiting Areas” (ESBA) (Palomo et al. 2012). The Ecosystem Service Benefiting Areas are classified according to the levels of service capacity and demand, helping to target decision making. To allow this, the capacity and demand maps are split into five quintiles. Whilst the data on capacity and demand scores are produced across the whole Study Area, the capacity quintiles are only mapped within areas of demand, as any areas with capacity but outwith areas of mapped demand are not relevant to service delivery. At the two extremes of this classification areas of "Highest Demand, Highest Capacity" indicate where there is the highest likelihood that the ecosystem service benefits are being delivered to people. In contrast, areas of "Lowest Demand, Lowest Capacity" have the lowest likelihood that ecosystem service benefits are being delivered to people.

Ecosystem Service Flow: Management Zones: In order to help inform management the demand and capacity maps are also overlaid to identify "Management Zones" (Figure 6, Figure 7). This classification considers the levels of capacity and demand for each service in relation to a set of possible management options. Although many areas of a particular ecosystem, such as woodland may be considered to deliver an ecosystem service, it is unlikely that all areas will be managed with a particular ecosystem service in mind. By prioritising those areas that may be most or least important, different management priorities can be recognised.

The three categories of "Protect key sites", "Protect / Maintain" and "Maintain general resource" help to rapidly map those areas with intermediate or higher levels of capacity and demand, where management of the ecosystem would help to continue the delivery of a particular service. The category "Improve condition" identifies those areas where there is the highest level of demand but low or lowest capacity. In these areas management intervention such as habitat area expansion or restoration could improve service delivery. Additional areas also occur where there is high or highest demand but where there is no capacity. In areas with no existing greenspace these are mapped as "create habitat" management zones. Creating particular habitats in these areas is likely to deliver an ecosystem service. In areas with no capacity but where some type of greenspace already occurs the "change habitat" management zone is mapped to indicate that converting the habitat into a different type (e.g. from grassland to woodland) would help deliver service benefits.

For several services there may be human-related barriers or restrictions that prevent the flow of a service from ecosystems to people. For example, accessible nature areas that are privately owned cannot be accessed by the majority of potential beneficiaries. Where there is highest or high demand for a service but no access, these are mapped as the management zone "provide access". In these areas providing new access points, new footpaths or enhancing currently present desire lines is likely to lead to increase service benefits.

Other categories such as "assess resource" map areas where it is unlikely that management of these sites in terms of the particular ecosystem service being assessed, would be a priority. However these additional categories provide insight into additional management options and would ideally be tailored to produce locally appropriate maps by highlighting or omitting particular categories.

Quintiles classification: By default the quintiles are produced using the values of the Capacity and Demand scores, however they can optionally be produced by area coverage (e.g. splitting each capacity and demand map into equal area classes across the Study Area). The quintiles allow the prioritised maps (ESBA, Management zones) to be quickly and easily produced. As a rapid assessment and across wider geographic areas this method is appropriate. Ultimately the quintiles values must be considered against information to identify locally relevant thresholds for high levels of capacity and demand for each service. *The full quintiles data is supplied in the toolkit and users may wish to examine alternative combinations, to create local defined ESBA and Management Zone maps*. This method of using quintiles is one reason why the toolkit is less suitable for smaller or more uniform geographic areas.

Multi-functionality: Once all ecosystem services of interest have been mapped, the “Multi-functionality” toolbox assess multiple service delivery. A range of information is produced to highlight the range of multiple benefits being delivered across the Study Area. These can be used as a starting point for further analysis. Models calculate the following for the services mapped: mean capacity, mean demand, mean GI assets capacity, multi-functionality score, priority multi-functionality score, number of ESBA types, and number of Management Zones. The “multi-functionality” score sums the number of services where there is demand in each cell and then calculates the proportion of these that are met with some level of ecosystem service capacity. Because this assessment includes the full range of capacity and demand in this calculation it may be considered too simplistic, as the delivery of a service in areas of low demand or capacity may not be considered important (for example in terms of influencing land management or policy). To allow landscape managers further data to compare, a “Priority multi-functionality” score is also produced using only those capacity and demand quintiles of intermediate and above in the calculation. Therefore a service is considered to be delivered at a cell if both demand and capacity are at least of intermediate quintile level. This focuses the mapping on those areas with a higher certainty in the benefits being delivered to people, or of the need for such benefits to be present.

Full details of the service summary data are included under the toolbox descriptions.

Box 1: Technical overview of the mapping process

Standardising geospatial indicators

Each indicator of ecosystem service capacity and demand was standardised to a 1 – 100 scale, following: (Laterra et al. 2011) :

- **Thresholds** are applied to some indicators below which their effects are assumed to be zero.
- **Normalisation:** by subtracting the mean and dividing by the standard deviation (Z scores).
- **Standardisation:** indicators are re-scaled to give a score range of 1 – 100.
- **Negative indices:** if an indicator has a negative effect, the inverse score is calculated.

If multiple indicators are used to model demand or capacity then after they have been standardised they are summed together using an equal weighting (unless stated). The resulting score is then also standardised to provide a 1 – 100 score. Because of a variation in conditions between Study Areas, the range of values that have not had a threshold applied to them will differ. This means the results are relative to the Study Area and they can only be used for within (not between) Study Area comparisons.

Overlaying ecosystem service demand and capacity

To compare demand and capacity over space the maps are split into discrete classes. The quantile method is used, splitting the data into 5 quintiles. This creates five classes of demand and capacity. Spatial overlays of the quintiles then allow the study area to be split into different zones, which are used to model ecosystems service flow:

1. Bottom quintile – lowest demand or capacity
2. Low demand or capacity
3. Medium demand or capacity
4. High demand or capacity
5. Top quintile – highest demand or capacity

3. APPLICATION OF ECOSERV-GIS

The completion of an EcoServ-GIS project produces GIS data, an accompanying set of pre-prepared ArcMaps and a range of PDF maps.

3.1 Results: GIS data outputs

The following data files are created after the analysis has been run.

Table 9. GIS data files, content, and definitions

Filename and (categories or values)	Definition
_Capacity (1 to 100)	Capacity to deliver the ecosystem service
_Capacity_0_100 (0 to 100)	Capacity to deliver the ecosystem service (including areas with no capacity)
_Capacity_5Quintiles_by_Area (1 to 5)	Capacity score split into 5 quintiles by equal area
_Capacity_5Quintiles_by_Value (1 to 5)	Capacity score split into 5 quintiles by equal interval
_Demand (1 to 100)	Relative demand for the ecosystem service
_Demand_0_100 (0 to 100)	Relative demand for the ecosystem service (including areas with no demand)
_Demand_5Quintiles_by_Area (1 to 5)	Demand score split into 5 quintiles by equal area
_Demand_5Quintiles_by_Value (1 to 5)	Demand score split into 5 quintiles by equal interval
_Demand_All_One (1)	All areas with any level of service demand
_ESBA_and_Gaps	
(A. ESBA potential benefits)	There is some demand for a service and some capacity to provide it
(B. No benefits: service gap)	There is some demand for the service, but there is zero capacity to provide a service (no functioning ecosystem present)
(C. Restricted service)	Areas where there is some capacity to deliver a service and some demand for the service, but restrictions prevent society from receiving the benefits
_ESBA_and_Gaps_Prioritised	
(A1. Highest)	Highest demand for a service and highest capacity to provide it
(A2. High)	High demand for a service and high capacity to provide it
(A3. Intermediate)	Low to Intermediate demand for a service and Low to intermediate capacity to provide it
(A4. Low)	Low demand for a service and low capacity to provide it
(A5. Lowest)	Lowest demand for a service and lowest capacity to provide it
(B1. None: Highest Demand)	Highest demand but no capacity
(B2. None: High Demand)	High demand but no capacity

Filename and (categories or values)	Definition
(B3. None: Int+Low Demand)	Intermediate or low demand but no capacity
_ESBA_Management_Zones_Prioritised	
(A1. Protect)	Highest demand and highest capacity
(A2. Protect / Maintain)	High demand and high capacity
(A3. Maintain)	Intermediate demand and intermediate capacity
(A4. Improve)	Highest demand and low or lowest capacity
(A5. Maintain / Improve)	High or intermediate demand and low or lowest capacity
(A6. Maintain / Assess)	Low or lowest demand and low or lowest capacity
(A7. Assess)	Lowest demand and lowest capacity
(A8. Change habitat type: Highest demand)	Highest demand but no capacity, in areas of greenspace
(A9. Change habitat type: High demand)	High demand but no capacity, in areas of greenspace
(B1. Create: Highest demand)	Highest demand but no capacity (no greenspace)
(B2. Create: High Demand)	High demand but no capacity (no greenspace)
(B3. Create: Int+Low Demand)	Intermediate or low demand and no capacity (no greenspace)
(C1. Provide access: Highest Demand)	Highest demand and access is restricted
(C2. Provide access: High Demand)	High demand and access is restricted
(C3. Provide access: Int+Low Demand)	Intermediate and low demand but
_GI_assets (1 to 100)	Relative capacity to deliver the ecosystem service, within areas of demand
ESBA Higher Tertiles per cell (1.Lowest number of highest ESBAs) (2.Medium number of highest ESBAs) (3.Highest number of highest ESBAs)	Category recording the relative number of ESBA categories of this type, per cell
ESBA Intermediate Tertiles per cell (1.Lowest number of intermediate ESBAs) (2.Medium number of intermediate ESBAs) (3.Highest number of intermediate ESBAs)	Category recording the relative number of ESBA categories of this type, per cell
ESBA Lower Tertiles per cell (1.Lowest number of lower ESBAs) (2.Medium number of lower ESBAs) (3.Highest number of lower ESBAs)	Category recording the relative number of ESBA categories of this type, per cell
Multi-functionality per cell (0 to 1)	Proportion of the services in each cell with any level of mapped demand that are met with any level of mapped capacity
Priority multi-functionality (0 to 1)	Proportion of the services in each cell with >= intermediate demand that are met with >=

Filename and (categories or values)	Definition
	intermediate capacity
Number of Gaps per cell (0 to 9)	Mapped “B. No benefits: service gap” per cell
Number of Services per cell (0 to 9)	Mapped “A. ESBA potential benefits” per cell
Zones 1 Protect Tertiles per cell (1.Lowest number of Protect Zones) (2.Medium number of Protect Zones) (3.Highest number of Protect Zones)	Category recording the relative number of Management Zones of this type, per cell
Zones 2 maintain Tertiles per cell (1.Lowest number of Maintain Zones) (2.Medium number of Maintain Zones) (3.Highest number of Maintain Zones)	Category recording the relative number of Management Zones of this type, per cell
Zones 3 Improve Tertiles per cell (1.Lowest number of Improve Zones) (2.Medium number of Improve Zones) (3.Highest number of Improve Zones)	Category recording the relative number of Management Zones of this type, per cell
Zones 4 Create Tertiles per cell (1.Lowest number of Create Zones) (2.Medium number of Create Zones) (3.Highest number of Create Zones)	Category recording the relative number of Management Zones of this type, per cell

Note: all individual service files are prefixed by the service name.

3.2 Where are the results stored?

All the results of the EcoServ-GIS analysis are stored under the folder "Model Outputs", folder by each service folder, and then within the geodatabase "Outputs.gbd". Copies of most of the outputs are also optionally produced in shapefile format within each folder "shapefile". Example storage of results for mapping of the Air Purification service.

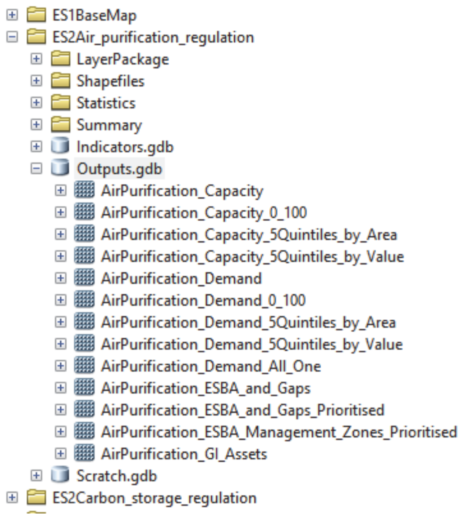


Figure 8. Example service outputs folder content

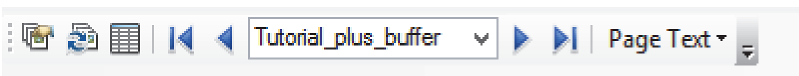
3.3 Map presentation

3.3.1 ArcMaps

Pre-prepared ArcMaps are used to display the results once the analysis has been conducted. The ArcMaps use "data driven pages" functionality, and are prepared with titles, legends and text to describe each map, the indicators used, and a summary of the potential map uses and limitations. The ArcMaps are located in the following folders:

- ArcMaps0AnalysisProgress
- ArcMaps1HabitatBaseMap
- ArcMaps2aEcosystemServicesMain
- ArcMaps2bEcosystemServicesSupplementary
- ArcMaps3aMultifunctionality
- ArcMaps3bMultifunctionalitySupplementary
- ArcMaps4EcologicalNetworks
- ArcMaps5BiodiversityOpportunityAreas

Use the “Data Driven Pages” Toolbar to view each map scale by clicking the Left or Right arrows.



The following maps are present within the folders:

ArcMaps 0: Analysis Progress

These maps are not intended for printing or export, but are set up to allow each stage of the BaseMap analysis to be viewed, as the steps of the toolkit are followed. These ArcMaps can be opened to view input data, and to view the results of each stage during the BaseMap creation.

ArcMaps 1: Habitat BaseMap

These set of maps detail the habitat BaseMap created by EcoServ-GIS, using different habitat level classification legends. A map is also included to highlight the relative certainty of the habitat classification of each mapped polygon, in order to inform the resulting interpretation of the mapped ecosystem services.

ArcMaps 2a: Ecosystem Services Main

Ecosystem Service Capacity and Demand Maps (Scores: 1 to 100): These maps identify areas where there is high or low capacity or demand for a service. This information can be used within funding bids, and site or spatial plans to highlight areas where habitat conservation, restoration or creation projects would benefit this ecosystem service.

ESBA and Gaps Prioritised: This map indicates where there may be a flow of the service from the environment to people, and categorises this by likelihood of the levels of benefits received, from Highest to Lowest. Although gaps and restricted service areas are mapped and included within the data, by default these categories are not included within the map legend displays. These maps are useful in that they can focus on the more important areas for current delivery of the mapped service. For example these can be used to identify those greenspace areas where local residents are most likely to receive health benefits from access and recreation, or those woodlands where local residents are most likely to receive health benefits of reduced air pollution from the woodlands present.

ESBA Management Zones: This map highlights the management options present in the landscape in order to maintain or improve ecosystem service delivery. A range of categories may be mapped (Figure 6, Figure 7), however not all categories will be present in every landscape. These maps consider both the current habitats that are present, as well as the potential benefits that could be delivered by habitat creation, restoration or improvement.

Green Infrastructure Assets: This map highlights the areas of existing green infrastructure that are currently helping to deliver the service. This map is based on the ecosystem service capacity map, however it only shows green infrastructure sites that occur within areas of demand, because areas that occur beyond areas of mapped demand do not represent an asset for this service.

ArcMaps 2b: Ecosystem Services Supplementary

Capacity or Demand Quintiles by area: These maps illustrate the quintiles classification versions of the 1 to 100 score, classified into 5 equal area classes.

Capacity or Demand quintiles by value: These maps illustrate the quintiles classification versions of the 1 to 100 score, classified into 5 equal interval classes.

ESBA and Gaps: This version of the benefiting areas map shows only the simple service classification, without any categorisation of priority or importance levels. It can be useful when it is more important to show the presence of all areas that may deliver a service, rather than the levels of benefits likely to be delivered.

ArcMaps 3a: Multi-functionality

Priority multi-functionality: The "Multi-functionality" maps provide a more holistic insight into the benefits we receive from our environment. They allow decision makers to take an "ecosystems approach", by considering the multiple benefits of ecosystems rather than focusing on a particular service or ecosystem. These maps can be used to asses which areas of greenspace deliver several different ecosystem services. This can help to indicate areas that are particularly valuable for several different services and functions. These maps are more useful when they are based on a high number of services. Although a variety of services are included in the toolkit this is not comprehensive, and this must be recognised when interpreting these multi-functionality maps. This priority version of the multi-functionality score is calculated using a threshold of service "delivery" where only those areas with >= intermediate level supply and demand are considered.

Priority ESBAs: This map illustrates the number of the different ESBA categories recorded per cell among the services that have been mapped. This allows areas to be identified where higher benefits are expected to be delivered to people from several different services, compared to areas delivering fewer services.

Management Zones: This map illustrates the occurrence of Management Zones among the services that have been mapped. This allows areas to be identified where management can be targeted to the protection, improvement or creation of multiple benefits to people.

GI assets mean capacity: This map shows the selection of areas of GI assets that are important for multiple service delivery and categorises these by their mean capacity score. A threshold is applied so that only areas with > 3 services are shown, to help distinguish multi-functional sites.

ArcMaps 3b: Multi-functionality supplementary

Multi-functionality: This map shows the main multi-functionality score that uses the simple occurrence of mapped multiple services, rather than considering the different levels of supply and demand of each mapped service. In contrast to the priority multi-functionality map described above, this produces a broader interpretation of multi-functionality and may be more appropriate where the wider capability of areas to deliver services is of interest or where managers are more critical of the assessment of the levels of capacity and demand used to identify priority areas.

Mean multi capacity: This map shows the mean capacity score across all the mapped services.

Mean multi demand: This map shows the mean demand score across all the mapped services.

Number of services and gaps: This map shows the recorded number of ESBA services and gaps across all the mapped services.

ArcMaps 4: Ecological Networks

Various: These set of maps illustrate the source habitat areas and the resulting mapped networks for each of several habitat types, using the least cost focal species method.

ArcMaps 5: Biodiversity Opportunity Areas

Lowland wetlands and Woodland: These example maps illustrate the outputs of the pre-set biodiversity opportunity areas models and are provided to show the example outputs that can be further modified with local knowledge and user defined settings.

3.3.2 Layouts and PDFs

Models are included within the toolkit to automate the export of the ArcMaps to PDFs. These honour the data driven pages functionality and use the "StudyAreaScales" dataset to produce separate maps for each polygon within these mapped areas. The models export selected folders of ArcMaps to create appended PDFs. By default the PDFs are exported to: %Toolkit folder%/PDFs

- ES1HabitatBaseMaps
- ES2EcosystemServices
- ES3Multifunctionality
- ES4EcologicalNetworks

3.3.3 Map and layout use restrictions

The following restrictions apply to the use of the pre-formatted ArcMaps and exported PDFs

- If the toolkit is used in a commercial setting the small photographic “images” that represent each service should be removed
- The data attribution licences currently refer to Scottish data and would need to be altered for use in England or Wales (see Annex 6, 7)
- Users should note that several datasets will require different licences to those listed in this User Guide, if the toolkit is used in a commercial setting

3.4 Results: Using the maps for targeted decision making

The output maps from the EcoServ-GIS toolkit can be used to help inform strategic and local scale decision-making (Table 11). The maps can be used in conjunction with many additional data types (Table 13). As the maps are derived from OS MasterMap data, users should ensure they have the necessary license to cover use of the maps in reports, publications or when copying data within a project partnership.

The maps indicate where particular services occur and the extent to which service flow from the environment to people is likely. Ultimately the way this information is used will be project and landscape specific. A summary of the potential uses is provided below. The key issues relevant to the use of the mapped outputs are:

- Available local knowledge
- Additional mapped evidence and data
- Opportunities to verify, assess, or grade the mapped prioritisations
- Preference for identifying broad areas of ecosystem service, versus focussing in detail on prioritised zones

3.4.1 Applying the toolkit and outputs

EcoServ-GIS provides spatially explicit, quantitative measures to compare between subareas, scales or situations, within a mapped landscape. It enables decision makers to take an evidence-based approach by considering the multiple benefits we receive from the environment. Rather than being seen as a barrier to development, these maps should be viewed as a tool to stimulate innovative landscape planning and strategic conservation efforts (Hughes & Brooks 2009). There are also a number of ways that EcoServ-GIS can be applied as a research tool to investigate theoretical questions focussing on people and the environment.

1) Scenario modelling for planning, development or conservation projects
The automated and standardised nature of the toolkit lends itself to scenario modelling, which involves re-running the toolboxes with data representing potential future or theoretical scenarios in order to quantify differences in the resulting ecosystem service capacity, demand, or flow. Planners and developers could use these outputs to fine tune their plans and select between scenarios to ensure that any negative impacts on the environment and the population's health and well-being are minimised or potentially counterbalanced. Policy makers and conservationists can also run this kind of analysis to establish how to optimise future plans so that single or multiple ecosystem service delivery is maximised.

2) Opportunity mapping
Conservationists can use the maps to target funding and effort in areas where they would most benefit service delivery. Further analysis of the output could identify "opportunity areas", those ecosystem service deficit and improvement areas that are most suitable for land use or management change to provide or improve an ecosystem service. For example, to enhance wave attenuation, wetlands expansion could be targeted by assessing the suitability of the surrounding land and weighing up ecosystem service trade-offs, such as the resulting loss of areas which provide a valuable outdoor recreation service. In these situations the overlaying of biodiversity opportunity mapping and ecological network mapping against the EcoServ-GIS maps would be particularly useful.

3) A discussion prompt and education tool

Because maps are generally easily interpreted, user-friendly and accessible forms of displaying data and communicating results, ecosystem service maps provide useful visual education tools, convincing people of the value of ecosystems and sites and promoting sustainable practises. Their geographically-linked nature and accessibility also helps to facilitate discussions between experts and members of the public (CUDEM 2006).

Table 10. Potential uses of output maps

Ecosystem service	Promotion: raise awareness of the wider benefits of nature	Strategic: inform planning (conservation, restoration or development planning)	Site planning: Influence site scale development or management
Air purification	✓	✓	⚠
Carbon storage	✓	✓	⚠
Local climate regulation	✓	✓	✓
Noise regulation	✓	✓	⚠
Pollination	✓	⚠	✗
Water purification	✓	✓	✓
Accessible nature	✓	✓	✓
Education knowledge	✓	✓	✓
Green travel corridors	✓	✓	✓

✓ : applicable use, ⚠ : use with caution, ✗ : not suitable for use

3.5 Map interpretation: limitations and reliability

The maps are only a representation of ecosystem service delivery. The maps rely on the accuracy and resolution of the data inputs and the limitations of the logic behind the models. When interpreting any of the maps consider the following:

- The models use the data you have supplied and placed into the toolkit, any errors or omissions in the input data will be reflected in the output maps.
- The models are relatively simplistic.
- Capacity, Demand and Flows are only a proxy of service delivery.
- Levels of uncertainty have not been measured.
- The models do not calculate absolute values of ecosystem service supply, the results are relative to the Study Area. It is very important to clearly understand the implications of this.
- Changing the extent of your Study Area will impact the results. Because each cell receives a score relative to the rest of the area, the removal or addition of high or low scoring sites will alter the scores of the rest of the output.
- Combining the "Capacity" and "Demand" maps to reflect service delivery is simplistic and allows priority areas to be rapidly identified. However this remains an arbitrary method. Users may wish to devise their own method for combination and identification of service benefiting areas.
- It has not been possible to grade Demand for several of the services. In such cases the flow maps reflect the influence of the relative Capacity for the service within the Study Area.

Map reliability: Table 12 summarises service map reliability based on several factors:

- Methods from previous published, peer reviewed studies vs. expert opinion methods developed by the EcoServ-GIS team.
- Availability of data and indicators.
- Availability of knowledge and research from which to extract rules that could be mapped (even if such applied mapping has not been practised in the literature).
- Extent to which the scale of knowledge, data or map indicators matches a useful scale of mapped outputs in GIS.

The assessment assumes input data has been quality controlled before use in the toolkit.

Table 11. Service model reliability status

Ecosystem service	High	Medium	Low
Air purification		✓	
Carbon storage		✓	
Local climate		✓	
Noise regulation		✓	
Pollination			⚠
Water purification		✓	
Accessible nature	✓		
Education	✓		
Green travel		✓	

3.6 Map usage and potential projects per service

The mapped services can be used in practice to support a range of decision making or inform specific projects. Table 13 highlights a number of uses for each set of ecosystem service maps.

Table 12. Map usage and potential projects per service

Service	Map usage	Potential projects and management options
Air purification	Identify important woods and urban tree cover helping to ameliorate air pollution. Compare to known air quality management areas and local measured air quality.	Ensure that the service is considered when managing urban woodlands, wildlife sites and nature reserves. Consider woodland creation, and planting of green walls or street trees in mapped creation or improvement areas.
Carbon storage	Highlight locally important areas for carbon storage. Compare the rank order of different habitat types for storage capacity. Highlight that many areas have carbon storage, even urban habitats.	Illustrate the benefits of habitat management or restoration projects by comparing before and after maps of carbon storage. (e.g. peatland restoration, woodland creation). Promote the carbon storage value of nature reserves and wildlife sites.
Local climate	Identify urban areas benefiting from ameliorated urban heat island effects. Compare to recorded temperature maps or further health statistic mapping.	Ensure these benefits are recognised in management plans and funding bids for urban greenspace. Consider demand maps and improvement areas during large housing schemes and redevelopments.
Noise	Identify urban woods helping to reduce noise levels. Compare to locally available noise mapping.	Ensure noise regulation is considered in woodland management plans. Consider the demand and improvement maps in any large planning applications or redevelopment schemes to consider locations for creation of new urban woods.
Pollination	Use to illustrate where areas of semi-natural, linear or woodland edge habitat may be supporting pollinators that may support local crops. Use with local knowledge on key areas of pollinators, semi-natural habitats, and crops requiring pollination.	Survey linear habitats, woodland edge and semi-natural habitats near areas of high demand to examine if these areas support pollinators. Can habitat management be improved to increase or maintain pollinator populations? Survey mapped improvement areas. Can more linear habitats, field edge grassland or small woods be created to provide habitat that will support wild pollinators?
Water purification	Compare maps with known crop areas, nutrient or pollution management zones	Assess areas during agri-environment surveys and applications. Survey high demand areas in connection with Wildlife Trusts, Rivers Trusts or Angling Clubs. Consider if "Protect" areas could be included in PES schemes.

Service	Map usage	Potential projects and management options
Accessible nature	Compare maps with local knowledge of important path networks, visitor centres, access points and local recreation sites.	Ensure the benefits of sites to local community is recognised in management plans and funding bids for wildlife sites and nature reserves. Consider demand maps and improvement areas during large housing schemes and redevelopments. Assess if the funding available to support site management is in proportion to the predicted benefits to people at different sites, parks or reserves.
Education	Identify key resources for use by schools for site visits and outdoor education events. Compare maps against known sites used for education or areas targeted for school liaison.	Ensure the benefits of sites for education use is recognised in management plans and funding bids for wildlife sites and nature reserves. Ensure schools are using their nearby sites for education use, prioritising those areas with highest demand. Assess if site visits or school contact is in proportion to the predicted benefits to people at different greenspace sites, if not then promote use.
Green travel	Compare maps against known key strategic travel routes or planned improvement zones.	Survey important mapped green travel routes and determine if site management funding is in proportion to the benefits the site delivers to people. Consider the demand and improvement maps in any large planning applications or redevelopment schemes to consider locations for creation of new green travel routes. Ensure the benefit that green routes deliver are fully promoted in site management plans and funding bids for urban nature reserves and wildlife sites.

3.7 Exploring the BaseMap (Habitat Map) results

The ES1BaseMap toolbox models update MasterMap Topography polygons with new information on habitat type, land use, open space function and habitat linked measures, such as perceived naturalness. None of the original OS MasterMap boundaries are altered. Metadata on the full range of BaseMap_FINAL data fields is included in the BaseMap Technical Report.

Habitat cover statistics can be produced from the Ph1Code, HabBroad or HabClass attribute fields. Maps produced for summary documents should use the HabClass attribute field. The following notes highlight important data fields in the attribute table:

3.7.1 Green Infrastructure and Open Space typology

The GI_type field shows the primary function of areas of greenspace close to and around settlements ("green infrastructure"), if they have been identified and mapped by local authority data. Natural areas are classified as allotments, beaches, church yards, general amenity greenspace, play areas, outdoor sports facilities, parks, or unclassified (no function information available). Another field "GI_Type_Final" takes this greenspace information and conducts a quality control assessment to compare the mapped categories against underlying Ordnance Survey mapped features, resulting in areas classified as greenspace only for natural environment mapped areas (for example roads, buildings and sealed surfaces are removed). The "accessible" data field details the known or predicted level of public use or legal access, with "1" representing accessible.

3.7.2 Habitat classifications

Habitat classifications are based on an interpretation of MasterMap land cover descriptions, the extent of overlap with other datasets and also the structure and configuration of polygons (e.g. area, shape, isolation, elevation, slope etc). The rules used to update these fields are detailed in the accompanying Technical Report. The Ph1code and HabNmPLUS data fields give the finest habitat classifications.

- **Ph1code:** is populated with Phase 1 habitat codes (JNCC) that have been adapted to meet the purposes of EcoServ-GIS.
- **HabNmPLUS:** is the text interpretation of this code. This is the most detailed habitat type name field.
- **HabBroad**: is a habitat classification grouping with a maximum of 38 categories.
- **HabClass**: is the habitat classification grouping with a maximum of 15 categories.

3.7.3 Data Sources

This data field lists the BaseMap models that have been run, and that have contributed to the creation of the BaseMap. As several models are optional this will vary between Study Areas. The number refers to each BaseMap model and can be used to check that the expected range of data has been used when creating the BaseMap.

3.8 Sharing and using the data and maps

The outputs of the toolkit may be in the form of printed maps, PDFs, JPEG, raw GIS data or bespoke products created using the GIS data. Users of the toolkit and data should note that all the main results are derived from OS MasterMap data, and potentially other licensed datasets used during the creation of the BaseMap. Users should note any specific limitations of licence conditions within their particular project partnership. These may be project specific. General data licence conditions and limitations are noted within the Appendices. The following advice may be useful:

- **Viewing the BaseMap (Habitat map) and Ecosystem service maps on a web mapping service, or via ArcGIS Online:** *This may be possible provided the web maps were viewable only, via a service hosted by a government agency e.g. SEPA, EA, SNH or NE, or via data access and sharing portals (e.g. SEWeb).*

- **Printing the outputs of the toolkit:** *Public access would be limited to printing of view only/static map images or screenshots.*

- **Public download of raster data on each mapped Ecosystem Service:** *Providing the option to access downloadable raster files would require an exemption from Ordnance Survey in the case that raster layers were derived from OS MasterMap. Alternatively, the toolkit User organisation or partnership would need to apply for a licensed partner agreement.*

- **Public download of aggregated and reduced resolution raster data on each mapped Ecosystem Service:** *There is likely to be a level of aggregation and reduced resolution data that would be acceptable to share with reduced licence restrictions, for example at which underlying source OS MasterMap polygons cannot be identified. However this should be clarified by the project partnership. Providing any option to access downloadable raster files may require an exemption from Ordnance Survey in the case that raster layers were derived from OS MasterMap. Alternatively, the toolkit User organisation or partnership would need to apply for a licensed partner agreement.*

As a default method of accessing and sharing the result of an EcoServ-GIS analysis it is recommend that the resulting data is deposited with the nearest Local Environmental Record Centre, and the information is then re-licensed to users under the appropriate data licence agreements.

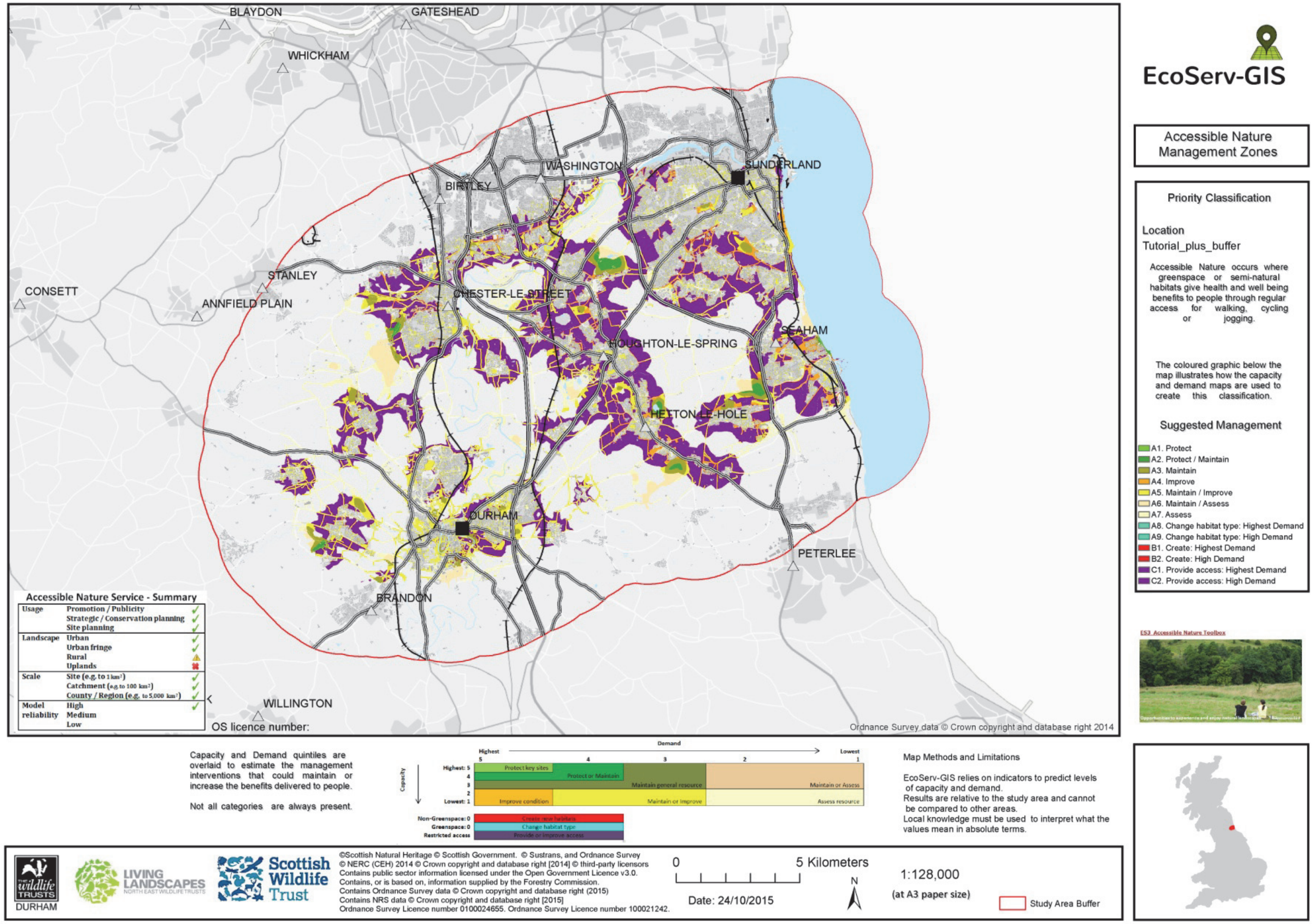


Figure 9. Example map layout presentation (accessible nature service)

4. PLANNING AN ECOSERV-GIS PROJECT

4.1 Software requirements

EcoServ-GIS requires the following:

- ArcGIS Version 10.2.2 (latest service packs installed)
- ArcGIS for Desktop Advanced level license
- ArcGIS Spatial Analyst extension enabled
- A PC with high processing power (e.g. CORE i5 equivalent or faster)
- Windows 64 bit operating system
- A PC with 12 GB RAM or higher
- At least 350 GB of free storage space for data inputs and outputs

4.2 Project stages

Before using EcoServ-GIS, make a project plan and consider the stages involved:

1) Form a project partnership

Confirm the partnership that will be responsible for running the toolkit and using the resulting information. This will typically involve the local Wildlife Trust, Local Authority and relevant government agencies (CCW, NE, SNH, EA, SEPA).

2) Collect all data inputs

Data are required for the Study Area plus a 5, 3 or 1 km buffer around this border, so that the models relying on indicators measured at large scales are accurate towards the boundary. A considerable amount of time is needed to gather the datasets and prepare them for use. This should ideally be done with the help of the Local Environmental Records Centre and each Local Authority in your Study Area. Although the government, Local Authorities, universities, and other organizations are beginning to recognize the value of sharing non-sensitive datasets through online portals such as MAGIC (http://magic.defra.gov.uk/), many resources remain difficult or expensive to access. Where possible, EcoServ-GIS relies on widely accessible datasets, although in some cases data may not be available for a particular area or it may only be available under the terms of a contractor's license. Even though data may be freely available, e.g. from Local Authorities it may require significant time to process, interpret or re-code.

The Study Area and buffer zones require full coverage of OS MasterMap data and this may limit the buffer zones that can be used, as access to OS MasterMap for neighbouring areas or counties may be a limitation. Many of the service models analyse data outside the Study Area boundary in order to place an ecosystem service in its local context. The toolkit has a default setting to produce a 3 km buffer around the Study Area. Wherever data is more readily available this should instead be set for 5 km. Certain service models will benefit from as wide a buffer zone as data sourcing allows, up to 10 km. In most cases however the trade off between data acquisition time and enhanced results will not support such wide buffer distances.

If OS MasterMap data is not available for the full Study Area buffer zone distance then the buffer zone will not be included by the models. In such cases the mapping in areas adjacent to the Study Area boundary should be treated with caution, and will be less reliable as it will have resulted from an examination of limited data.

In all cases where data is requested from a project partner or Local Authority the Study Area + buffer zone should be sent to the data supplier to ensure that data is cropped to the wider buffered area and not just to the original study area boundary. It is preferable to initially use a bigger buffer zone than needed, and later to scale this back, rather than finding that more data needs to be collected, part way through a project. Therefore, in order to plan data collection, use the following guide (especially relevant to OS MasterMap). If you plan to use the following buffer distances:

- Target distance of 1km: Buffer your Study Area by 4km and use this to source data
- Target distance of 3km: Buffer your Study Area by 6km and use this to source data
- Target distance of 5km: Buffer your Study Area by 8km and use this to source data

Note: the practicality of this will depend on your source contact for OS MasterMap.

3) Arranging license agreements:

The EcoServ-GIS BaseMap is derived from OS MasterMap data. This dataset is currently available to public sector organisations, including Local Authorities, central government departments, and health organisations, under the Public Sector Mapping Agreement (PSMA) or the One Scotland Mapping Agreement (OSMA). PSMA or OSMA members are able to provide these data to third parties for non-commercial projects, for a limited period, under the specifications of a contractor's license. Given the usefulness and applicability of the ecosystem service maps in many areas of Local Authority work, they may be interested in providing MasterMap data to a partner organisation. This is up to the discretion of the Local Authority, but it could cover the production of the maps, updates to the maps with new data, and the use of the maps to provide derived summary statistics, and other information and advice concerning ecosystem services. The Local Authority can then provide these derived data and maps to other PSMA or OSMA members and other end users (under a suitable license) who are supporting them in the delivery of their core business (Ordnance Survey 2011). All electronic copies of the maps produced must adhere to OS guidance (e.g. appropriate inclusion of the acknowledgements of copyright and database right ownership). Local or Environmental Record Centres should be a first point of call to discuss OS MasterMap supply and the deposition of the results of the EcoServ-GIS toolkit. There is a limit to the guidance that can be given in relation to the OS MasterMap data as the licensing situation will vary between partnerships.

The members of the partnership with PSMA or OSMA access should be able to download the OS MasterMap data for the whole study area (plus buffer) from the following website. http://www.ordnancesurvey.co.uk/business-and-government/public-sector/mapping-agreements/index.html

Significant time should be allocated to ensure the right data licensing agreements are in place, before starting the toolkit process.

4) Formatting the input data

All input data needs to be formatted appropriately so that the models will be able to successfully find and use the data. Details on how to prepare the data are provided in Section 6.2 of this guide. It is important to follow these steps exactly to ensure the correct output.

5) Producing the BaseMap

The first toolbox, "ES1BaseMap" generates a fine scale and detailed habitat and land use map, referred to as the BaseMap, as well as other key data layers used by the individual ecosystem services tools. BaseMap models must be run before creating any ecosystem service maps.

6) Running the ecosystem service toolboxes

A toolbox is available for modelling each individual ecosystem service. The ecosystem services are grouped into themes by number (ES2 = regulatory, ES3 = cultural, ES4 = provisioning). These ecosystem service toolboxes are independent of one another and can be run in any order. Users can therefore choose to run the toolboxes of interest. However, the models within a toolbox must be run in number order. These produce the ecosystem service capacity, demand and flow maps.

7) Running the Multi-functionality toolbox

This toolbox can be run to analyse multiple service delivery. The particular ecosystem service toolboxes of interest must have been run beforehand. The results become more meaningful as the number of ecosystem services mapped increases.

8) Presenting and interpreting the output

Once all the maps of interest have been successfully produced, time should be dedicated to map interpretation and presentation. It is important to consider the audience and the intended uses of the maps, and to focus on what each map represents. Relevant considerations include:

- What are the limitations of the data and analysis methods?
- At what scale was the service considered to be best applied?
- Are other data available that could be overlaid on top of the service maps?

GIS users can easily derive statistics from the maps to provide information to report on ecosystem service capacity, demand and delivery at selected sites or landscapes. Scores are standardised and can only be compared between sites within the same Study Area (not between different Study Areas where models have been run separately). Further guidance on map presentation and use is provided in Section 3.5 and 3.6.

4.3 Balancing the use of "best available data" vs. "data consistency"

When planning and initiating an EcoServ-GIS project it is very important to understand and acknowledge the relative impact of the use of best available information (typically on habitat type or land cover) vs. using consistent data. For example, high quality habitat surveys may only exist for certain habitats, or for selected localities in the Study Area, whilst full coverage may be available by a lower quality, or more coarse habitat dataset. The relative merits of using these must be understood.

When a Study Area covers different Local Authority boundaries, organisational areas, or landscape designations, then a variety of different data sources may be available. These will often differ in quality, reliability, resolution and accuracy. It is important to understand such differences and how these will impact the mapped toolkit outputs. Generally the aim of EcoServ-GIS is to compile the "best available" information and use this to build the Habitat BaseMap on which the individual service models are then based. Generation of this composite habitat BaseMap may be a useful product of the toolkit in its own right. However when the ecosystem service analysis occurs, the "link" between a mapped habitat and a predicted ecosystem service often uses a relatively coarse definition of habitat, because links across the full range of habitat hierarchies are not available from the literature. As an example although semi-natural broadleaved woodland cover can be included and mapped within the BaseMap most models do not use "semi-natural" status, and instead use the more coarse woodland habitat categories of Broadleaved, Coniferous and Mixed.

When working at a local scale and with Local Authority partners it was considered important to include as much known and surveyed information as possible so that such sites are reflected in the BaseMap, and no sites are missed. This issue can affect Local BAP data, Open Space Surveys, Green Infrastructure data and Landscape Character Assessment data. Ideally a standard level of high accuracy and consistent data would be available across the whole Study Area, but this will generally not be the case. The following options exist as possible solutions when data differs in quality between Local Authority areas (or other sub divisions):

- Reduce all data to a common and consistent standard (e.g. by deleting smaller sites below a size threshold, or deleting or editing categories only present in certain Local Authority areas)
- Retain all data as "best available" data but make sure that all resulting maps have a note or have areas of the map highlighted to show that different data inputs were used for different parts of the map (e.g. by adding data to each ArcMap).

Typically the use of consistent data will be best for the interpretation of the toolkit output maps, but users should investigate the implications of this on a *per service basis,* in order to decide the best approach.

4.4 Project timetable

We have estimated the time range to complete an EcoServ-GIS project, assuming dedicated staff time from an intermediate to expert level GIS user (Table 14). This is based on our experience but the exact workload and time involved will vary depending on a large number of factors, including:

- Major impacts
  - Status and activity level of the project partnership
  - Datasets available, formatted or verified
  - Relationships with potential data suppliers (e.g. existing named contacts)
  - The number of Local Authorities within the Study Area
  - Study Area size
- Minor impacts
  - The user's GIS and general IT experience
  - The presence of Local or Environmental Record Centres
  - Computer specifications

Table 13. Estimated EcoServ-GIS project timetable

Task	Estimated working days required		
	Possible maximum	Typical / average	Absolute minimum
Collecting data inputs & arranging license agreements, formatting data into the GIS	41	20	10
Producing the BaseMap	6	3	2
Running all service toolboxes	5	3	2
Running the Multi-functionality toolbox	4	1	N/A
Presenting & interpreting the output maps	12	5	3
TOTAL PROJECT TIME (working days)	68	33	17
Months to budget	4	2	1
Indicative Cost (£) (staff time)	14,000	7,000	3,500

This estimate is based on identified tasks and does not include the time that may be necessary whilst awaiting data to be delivered. In such cases the project would span a longer time period, although not all this time would comprise project working days. This aspect would not incur project costs if the staff members were working on other projects. Unfortunately these are very difficult to predict but they could total an additional one to six months over the course of a typical EcoServ-GIS project.

It cannot be overemphasised how important early contact and organising a physical meeting with a named contact at data suppliers is to successful project completion (particularly for OS MasterMap data and Local Authority Open Space Survey and footpath data).

Time estimates do not include production of summary reports or any synthesis and description of the map information, which is crucial to the results being accessed by decision makers.

5. RECOMMENDATIONS FOR FURTHER DEVELOPMENT OF ECOSERV-GIS

EcoServ-GIS was developed to address the situation where many different conservation organisations may begin ecosystem services mapping projects and to explore the efficiencies of a standardised approach. The development context was a small project team (between one and three) of ecologists and conservation managers. The project was specifically designed to utilise the advantages of the ModelBuilder visual programming software. This allows non-programmers to build complex models, using their knowledge of landscape ecology, conservation and ecosystem services without requiring programming skills, or a large development team. The ModelBuilder environment is an excellent tool for such work. With a steep but relatively short learning curve, complex models were able to be built. However the ModelBuilder environment has particular limitations that only become apparent with long-term use, or when complex models are created. These include that error messages are rarely informative and often report error codes that do not actually refer to the cause of the issue that requires fixing. Additionally the models cannot be easily debugged, and models can become unstable when complex. Frequent development errors were encountered relating to setting of the analysis extent. Cumulatively these issues can lead to long delays in model development and testing.

It is hoped the toolkit will be useful in its current format and that expert users may be able to further adapt the toolkit for their needs. Full details on the model limitations and potential improvements are listed under each model description. Further services could be added and there is considerable scope to extended the toolkit models to examine the potential services delivered by conservation opportunity areas mapping. If this were considered it is recommended that any such project should include a project team with a minimum staff of two, ideally three. Such a project should dedicate a staff member to model testing after initial development. The input of Python programmers would also be very useful, for example it would be possible to develop additional models using Python scripting that would fit within the EcoServ-GIS method, ArcMaps and terminology. Project development works best when there is also dedicated staff time within the wider partnership to advise or give feedback on the maps as they develop, for example from GIS officers or conservation staff who have time to review model results and give detailed feedback against known sites or landscapes. Such time should be explicitly detailed and committed within any project plans. Further development of the toolkit within the ModelBuilder environment is generally not recommended unless the above conditions are met.

It is hoped that any development or additions to the models or toolkit would be made freely available by any future developers for use alongside EcoServ-GIS.

6. TOOLKIT INSTALLATION

6.1 Summary steps to install the toolkit

To install EcoServ-GIS, follow the steps listed below:

1) Copy the toolkit contents to a selected location (e.g. Study Area named folder) on your main physical drive (typically C Drive), not a network drive

Once copied over the tools must remain in the same folder and should not be renamed. Making changes to the subfolder names or structure will alter the pathways to the inputs and outputs directories, preventing the tools from working.

If you will be running EcoServ-GIS for several different Study Areas then you may prefer to copy the main EcoServ-GIS folder multiple times into several different "project folders" with each main folder named by the Study Area. This will aid in locating the outputs files that are relevant to each Study Area. The toolkit should not be run over a network.

2) Change PC settings to avoid errors or crashes in ArcGIS

During the construction of the toolkit there have been technical issues encountered that can lead to errors within ArcGIS. The following changes to PC settings are required to avoid such issues, where known. These issues are frequently rectified by ongoing ArcGIS updates released via the ESRI website, and therefore this may be addressed in future ArcGIS releases.

- Uninstall Internet Explorer 11 (if present)
    - Control Panel / Programs and Features / Uninstall updates (exact location may differ between Windows versions)
    - This is a known issue which causes errors with the Simplify Line Tool (ESRI code NIM097058)

3) Open ArcCatalog

Open ArcCatalog, ready to view and run the toolkit.

4) Connect to the toolkit folder

Click the "Connect to Folder" icon (a folder icon with a plus sign). This will allow you to connect to the main toolkit folder in your ArcCatalog tree and will allow quick access.

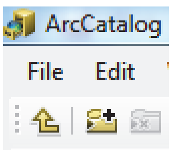


Figure 10. Connect to folder icon

5) Enable the Spatial Analyst extension

This is located on the Customize menu in ArcCatalog. Go to "Extensions" and tick the Spatial Analyst option. This will only have to be carried out once per machine, and may already have been done on your PC (Figure 6). Note that if the Extensions have "Not Authorised" listed against their names in the list then you will have to find and enter the License code to enable the extension. See your IT contact for the license code.

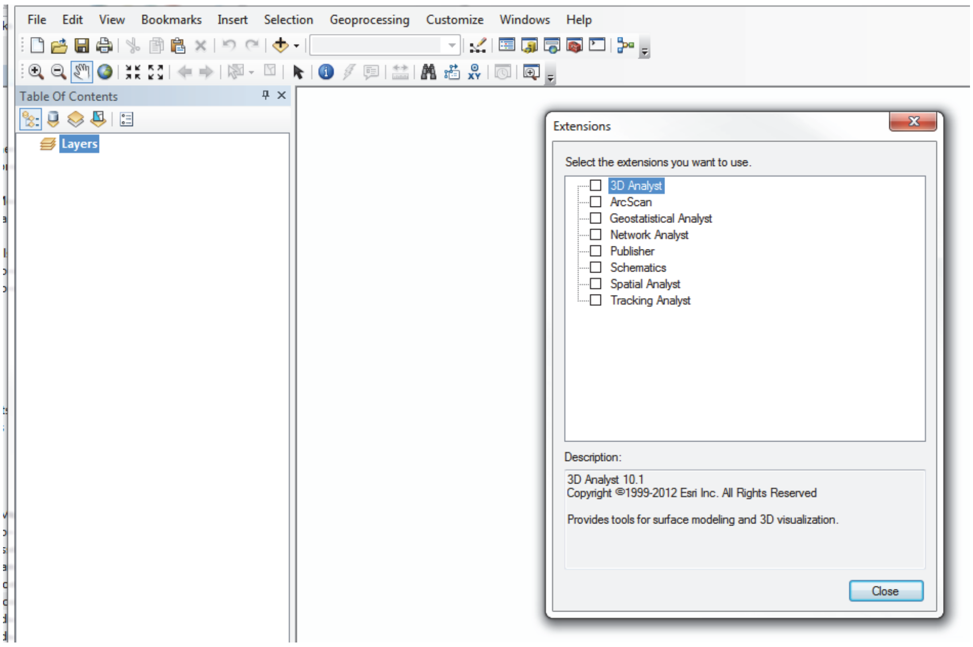


Figure 11. Authorising ArcGIS extensions

6) Allow data output to be overwritten

Go to the Geoprocessing menu bar in ArcCatalog, select "Geoprocessing Options" and tick "Overwrite the outputs of Geoprocessing operations"(**Figure 7**).

**** NOTE: Enabling this function means that any data produced and saved to the same location as data with an identical name will be over-written. You may want to disable this option when using Arc for other projects, but remember to re-enable it when using EcoServ-GIS ****

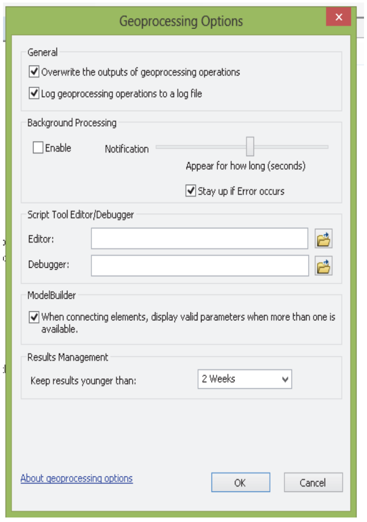


Figure 12. Geoprocessing options settings

7) Note the location of the Toolboxes

Toolboxes are located within a folder "Toolboxes_%Version%". Individual models can be run in ArcCatalog, or within Catalog in ArcMap. It is recommended to run the Tools from ArcCatalog.

Box 2: EcoServ-GIS folder structure: EcoServ-GIS (parent folder)

- **ArcMaps(various):** ArcMap documents that can be used to view the map results of the Toolkit. The ArcMaps are listed by BaseMap and by service. The service ArcMaps include pre-prepared Layouts that are ready to print at A3.
- **Documents:** contains documents that accompany the Toolkit e.g. this User guide.
- **LayerFiles:** apply set colours and legends to the map results. These are used by the ArcMaps but can also be used separately to colour code the map data.
- **Layouts:** folders within which to optionally store JPEG map layouts.
- **Logos:** Logos and images used by the layouts.
- **ModelInputs :** separate folders for the inputs of each toolbox. Several datasets are already present within the supplied toolkit. Other inputs must be sourced by the user and saved into Geodatabases.
- **ModelOutputs:** separate folders for the outputs of each toolbox. Each contains:
    - Shapefiles: outputs in .shp format for export to other software
    - Indicators: data indicators and are not a key output of the Toolkit, but may be of interest to advanced users.
    - Outputs: main folder holding the mapped results of each service model.
    - Scratch: Intermediate outputs are saved here.
- **ModelResults**: This folder is in development for future models. Not in current use.
- **OpenData:** This contains a range of OS data that may be used as background maps or to aid visualisation of the maps (This is in compressed format).
- **PDFs:** Subfolders hold PDFs created when the ArcMaps are exported, using the supplied model.
- **Scripts:** This folder contains any scripts used by the models.
- **Styles:** This folder contains map colour styles used by any of the ArcMaps and Layerfiles.
- **Submodels:** This folder contains a range of submodels used by the Toolkit. These do not have to be run by the user.
- **Toolboxes%Version%:** The Toolkit folder contains a separate Toolbox for each mapped service. Each Toolbox contains a set of models to be run in number order.

Figure 13. Toolkit folder structure examples

7. DATA PREPARATION

7.1 Sourcing input data

The tables below list the main and optional data required from the user to run the EcoServ-GIS toolkit and suggests potential sources of these data. Refer to the Annex 10 to assess the potential use of the optional datasets.

Data must be downloaded for your Study Area plus a buffer zone (e.g. 5, 3 or 1 km) so that models relying on indicators measured at large scales are accurate towards the edge of the study area.

Table 14. Data to be sourced by Toolkit Users

Data type	Suggested source	License?	Time to collect
MasterMap Topography (area, lines and points)	Local Authority, PSMA or OSMA partner	Requires OS license	Long
OS Open Data Vector Map data	Via OS Open Data website	Open Data license	Short
Boundary of Study Area	User specified	Depends on data source	Short

Table 15. Optional Data to be sourced by Toolkit users

Data and content	Suggested source	License	Time to collect
Fine resolution DTM 10m or 5m DTM (Digital Terrain Model) grid	Ordnance Survey	License required	Long
Distribution of locally important habitats or nationally mapped habitats (e.g. Natural England Priority Habitats). Re-classified according to EcoServ habitat classifications	Wildlife Trusts; Local Records Centre, NE, SNH, NRW	Free; license required	Long
Open Space Survey or Green Infrastructure Data Vector data on the function and use of Greenspace.	Local Authorities	May require license	Long
Landscape Character Areas Vector data describing land use (allotments, amenity grassland, arable land, cemeteries, pasture, golf courses, heath, industry/quarries/works/landfill, mixed farmland, parks & gardens)	Contact Local Authorities	May require license	Long
Local Wildlife Sites Vector data describing the distribution of Local Wildlife Sites.	Wildlife Trust; Local records centre	May require license	Short
Public Rights of Way (E,Wa) Core Paths (Sc)	Local Authorities	May require license	Long
European Soil Database (ESDB) v2.0 Request the vector raw data	Joint Research Centre	Free; license required	Short
Native woodland survey - Scotland	Forestry Commission	Government Open license	Short

7.2 Preparing the data inputs

Follow the instructions provided on formatting each data input before running the toolkit. If data for a particular layer is received from multiple sources, it may be important to check for and remove any spatial overlap before merging. All data should be projected using the British National Grid coordinate system.

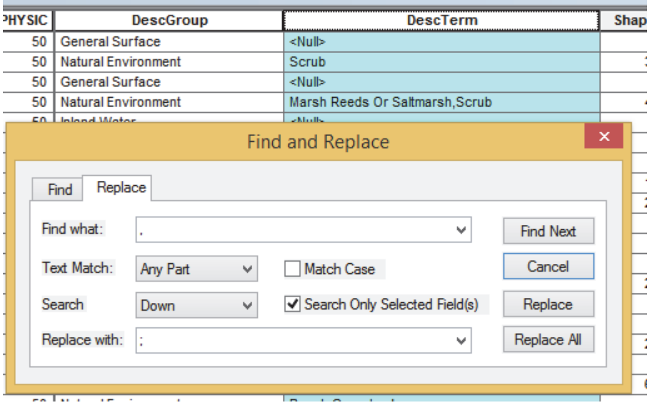
7.2.1 BaseMap inputs

The datasets required to create the BaseMap are: OS MasterMap, Study Area boundary and OS VectorMap. The remaining data are all optional, but in several cases will greatly add to the usefulness of the toolkit inputs. See further details in Annex 10 before sourcing data. See also the detailed descriptions in Annex 11, 12.

<table>
<tr><td>MasterMap
(OS MasterMap Topography layer) (area, line, point)</td><td>Required for toolboxes:
ES1BaseMap</td></tr>
<tr><td colspan="2">OS MasterMap® Topography Layer provides a detailed map of the GB landscape, including natural features, buildings and grey infrastructure. It is used to generate the BaseMap used by all EcoServ-GIS models.</td></tr>
<tr><td colspan="2">Best sourced as a single download or data supply to ensure full, up to date and consistent coverage across the Study Area. Use the Topographic Area data layer And the Topographic Line datasets. Note that although an example point dataset is included in the tutorial data and noted in the model dialogue box, it is not yet used in this version of the toolkit. If the data is sourced in Ordnance Survey .gml zip file format, then use "Interpose" or "Productivity Suite" software to remove any duplicate polygons during the data conversion process. (This will be quicker and more efficient than the similar process within ArcGIS). If data is supplied for separate areas (e.g. from separate Local Authorities) merge datasets into one layer (then check for and remove spatial overlap and duplicates). Check and Repair Geometry (This can be slow, up to 1 hour, on large study areas).

<u>Topographic Area</u>
Make sure the following fields are kept and that the field names exactly match this list:
• (OBJECTID) & (Shape)
• Toid, DescGroup, DescTerm, Make, PhysLev
• You may need to create new fields and calculate them based on other fields if different field names have been used. The field specifications are:
• TOID (text, string) can be calculated from FID. (Example entry = osgb100084599001)
• DescGroup (text, string, length 250) can be calculated from DescriptiveGroup
• DescTerm (text, string, length 150) can be calculated from DescriptiveTerm
• Make (text, string)
• PhysLev (short integer) can be calculated from Physical Level

Other fields can be deleted to speed up the toolkit.
Confirm that the text separator used between multiple DescTerm entries is a semi-colon and a space (;) not a comma with no space (,). If this is not the case, then view and edit the attribute table within ArcMap and use “Find and replace” on the selected DescTerm field to replace any instances of comas with a semi-colon and a space. Note that if an alternative separator has been used you will need to use an alternative find and replace. Repeat this process to check and verify that the Find and Replace has completed as expected.
• Index the “Toid” field to speed up searching and analysis
• Export to ModelInputs/ES1BaseMap/Inputs.gdb using the name “MasterMap_Area”</td></tr>
</table>



Topographic Line

Make sure the following fields are kept and that the field names exactly match this list:

- (OBJECTID) & (Shape)
- Toid, DescGroup, DescTerm, Make
- You may need to create new fields and calculate them based on other fields if different field names have been used. The field specifications are:
- TOID (text, string) can be calculated from FID. (Example entry = osgb1000084599001)
- DescGroup (text, string, length 250) can be calculated from DescriptiveGroup
- DescTerm (text, string, length 150) can be calculated from DescriptiveTerm
- Make (text, string)

Confirm that the text separator used between multiple DescTerm entries is a semi-colon and a space (;) not a comma with no space (,). If this is not the case, then view and edit the attribute table within ArcMap and use “Find and replace” on the selected DescTerm field to replace any instances of comas with a semi-colon and a space. Note that if an alternative separator has been used you will need to use an alternative find and replace. Repeat this process to check and verify that the Find and Replace has completed as expected.

- Index the “Toid” field to speed up searching and analysis
- Export to *ModelInputs/ES1BaseMap/Inputs.gdb using the name “MasterMap_Line”*

Topographic Points

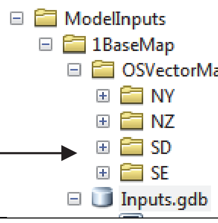
Make sure the following fields are kept and that the field names exactly match this list:

- (OBJECTID) & (Shape)
- Toid, DescGroup, DescTerm, Make
- You may need to create new fields and calculate them based on other fields if different field names have been used. The field specifications are:
- TOID (text, string) can be calculated from FID. (Example entry = osgb1000084599001)
- DescGroup (text, string, length 250) can be calculated from DescriptiveGroup
- DescTerm (text, string, length 150) can be calculated from DescriptiveTerm
- Make (text, string)

Confirm that the text separator used between multiple DescTerm entries is a semi-colon and a space (;) not a comma with no space (,). If this is not the case, then view and edit the attribute table within ArcMap and use “Find and replace” on the selected DescTerm field to replace any instances of comas with a semi-colon and a space. Note that if an alternative separator has been used you will need to use an alternative find and replace. Repeat this process to check and verify that the Find and Replace has completed as expected.

- Index the “Toid” field to speed up searching and analysis
- Export to *ModelInputs/ES1BaseMap/Inputs.gdb using the name “MasterMap_Point”*

StudyArea1 (Study area polygon)	Required for toolboxes: ES1BaseMap
"StudyArea1" is the boundary of your project for which you are undertaking ecosystem service mapping. This may be a Living Landscape boundary, County boundary, Vice County boundary, National Park or AONB. It is used to select MasterMap polygons which intersect with the boundary, creating a new study area boundary (StudyArea). A buffer is used to select data around the edge of this boundary (default 3 km buffer distance), so that ecosystem service maps are not inaccurate around this edge. • The Study Area determines the extent of the Ecosystem Service maps. • All results will be relative to the Study Areas boundary. Changes in the Study Area boundary may influence the results of the mapping, for example the decision as to whether to include large urban areas within or outside a Study Area. • Edge effects, and the often arbitrary nature of Study Area boundaries can partly be offset by using a larger buffer distance, which will ensure the ecosystem service maps extend over a wider area and use a wider range of collected data. By including maps within the buffer area the range of services at and beyond the initial Study Area boundary can be examined. • There is a trade off in time vs. results in acquiring additional data for a larger buffer area. By sourcing and processing data around your Study Area, the results will often be better. However, this process can be time consuming. • The Study Area boundary is buffered and drawn based on your available MasterMap data. If you do not have MasterMap data up to this buffer distance, the file that is created will not cover the full buffer distance.	
• Ensure the data is projected in British National Grid. • Export to *ModelInputs/ES1BaseMap/Inputs.gdb* using the name "StudyArea1"	

OS VectorMap (OS VectorMap District data)	Required for toolboxes: ES1BaseMap
The OS VectorMap® District data provides spatial information on grey infrastructure hubs and networks, habitat boundaries, and local amenities.	
• OS VectorMap District data can be downloaded in 10 km tiles. • Download the tiles that fall within your study area and save these to (unzipped) individual folders, into a folder called "OSVectorMap" in the ES1BaseMap folder (*ModelInputs/ES1BaseMap*).	

StudyAreaScales	Required for toolboxes: ES1BaseMap
Analysis can be used to create "Sub Areas" within the Study Area for which separate output maps can be produced. These "Sub Areas" need not be contiguous, they can be overlapping or nested, and can occur at different scales. Any area for which it is useful to separately examine or view output results can be used as a "Sub Area". A maximum number of 10 areas is likely to be suitable.	
• Source vector data that identifies the separate "Sub Areas". This can be a separate files per area, or a single file with several polygons. • Add a text field named "SubAreaName" • Ensure each area has a unique identification name in the "SubAreaName" field. This will appear on the ArcMaps to label each location • Use a concise name for each sub area this must NOT contain any spaces , special	

characters, or brackets.

- e.g. SubAreaName = “DurhamDistrict1”, or "DurhamDistB" is acceptable, NOT “Durham District 1”, and NOT "Durham(District)"
- Save as feature class or classes into ES1BaseMap geodatabase *ModelInputs/ES1BaseMap/Inputs.gdb*
- Each feature class must contain the following text within the filename "StudyAreaSub", e.g. StudyAreaSubTownCentre

GI data (<Local authority name> _GI) (Open Space Survey Data) including Greenspace Scotland	Required for toolboxes: ES1BaseMap

This data is optional but recommended. To encourage Local Authorities to consider greenspace availability and function in planning decisions, they are required to develop Open Space and Green Infrastructure strategies. Data are usually collected from site surveys. These greenspace monitoring and mapping exercises vary between regions according to their detail, resolution, nomenclature and coverage because no standard methodology is enforced (Pankhurst 2010; UKNEA 2011). However, Local Authorities often use the typology suggested by the Planning Policy Guidance Note 17, "Planning for Open Space, Sport and Recreation" (PPG17 2002) or Planning Advice Note 65, "Planning and Open Space" (Greenspace Scotland 2010; Scottish Government 2008) and map these to the MasterMap Topography layer. Whenever time or resources are available further local information, knowledge or the use of aerial photographs can be used to ensure the GI data is correctly classified into the recommended types (Greenspace Scotland 2010).
Within EcoServ-GIS this data has two uses:

- Firstly to use the information on land use / land cover / habitat type to classify polygons within the BaseMap.
- Secondly the information is used in all models that assess the public accessibility or likely public use of areas of land.

The way these two categories of information are able to be incorporated into the BaseMap may differ depending on the origin of the dataset, and whether its emphasis was the identification of only Publicly accessible Open Space (POS), or more broadly of Green Infrastructure.
Feedback from trials suggests there is a very wide variation in the coverage and quality of these datasets. The time taken to process this data can be considerable when there are many Local Authorities in a Study Area. This should be considered and may influence the decision of which Ecosystem Service maps can be produced for a particular Study Area.
The time taken to prepare a comprehensive dataset will be determined most by the poorest data source present, in situations where several Local Authorities occur in a Study Area. An assessment should therefore first be made of how long it will take to prepare the worst example of the supplied data in order to assess the possible data preparation time. If the data is poor quality then it may be decided not to use this data source. See the data preparation checklist in the Annex for further detailed notes on preparing this data, including time estimates. The methods differ between England and Wales and Scotland.

Information is extracted from these Local Authority surveys on the distribution of selected types of greenspace . To ensure that the terminology used to classify parcels of greenspace is consistent across each Local Authority, these must be updated. The priority is to classify in a consistent way.

England and Wales

- If you have data from multiple Local Authorities, check for any spatial overlaps between them. If these are found, make sure the overlap is removed by deleting the overlapping polygon from the least up-to-date / least accurate dataset.
- Make sure that all layers are projected using the British National Grid coordinate system.
- Add a Long integer field "GI_coder" to each layer. This code will represent the GI type. This is the main data field used by the toolkit. Ensure there are no inconsistencies in spelling or formatting.
- Optionally add a text field "Typology" to each layer, to assist with your data editing and classification (if this field name already exists, first rename the existing field). This field is for your information only and is not used directly by the mapping toolkit.

- Populate the “GI_coder” (and the Typology field if you wish) using the attribute information provided in each local authority dataset, comparing these to the terms listed in Table 17. This can be done using “Select by attributes” to select all features relevant to a particular typology (there may be more than one, e.g. “Cemetery” and “Churchyard” would both fall under the cemetery field name), followed by the field calculator to populate the fields. It is important to use exactly the same attribute codes as listed.
- Add and populate a Long integer field named "AccessGI". Populate this as detailed in the table below. 0 represents “No public access” and 1 represents “Publicly Accessible”.
- For advanced GIS users, if there are many records present an easy way to recode any existing categories is first to summarise the existing category data field. Open this new dataset and add the GI_coder field and the AccessGI fields. Use this to rename the old categories. Then join this field back to the original dataset using the common typology field.
- Any greenspace types mapped which do not fit into these Open Space / Greenspace or Access categories can be ignored and deleted – they will not be used by the model.
- Only a single typology type can be attributed to each polygon.
- Not all GI types may be mapped by Local Authority data – this is not a problem, but it is important to remember that the resulting map will be limited by the accuracy and detail of these inputs.
- Some categories are only used by the models to classify levels of accessibility and not to classify land use type. e.g. 10 (Accessible woodland) and 5 (Natural and semi-natural greenspace). For example a Local Authority mapping method may note that public access is a requirement of the Community Woodland, or Natural and Semi-natural Greenspace categories. The Green Corridor category used by some local authorities may also be useful in defining accessibility.
- When the datasets have been coded, delete any polygons that do not have either “GI_coder" or an “AccessGI” value. There should be no records or polygons that have blank or NULL values for BOTH these data fields, blank entries for one of the two fields is acceptable.
- Run the “Repair Geometry” tool to check for potential geometry problems – fix as necessary.
- Save datasets from each local authority to *ModelInputs/ES1BaseMap/Inputs.gdb* – make sure that each data layer is named with “_GI” at the end: <local authority>_GI e.g. “Durham_GI”, “Darlington_GI”, “Gateshead_GI”

Scotland

- In Scotland the Greenspace Scotland map data can be used as a national resource to identify areas of greenspace and to infer likely public use or lack of public access areas.
- Table 18 should be used to re-classify the polygons to code them with the appropriate EcoServ-GIS code. The data can be classified from the Primary land use field. Alternatively the Primary and Secondary Land use fields can be combined (concatenated) into a new field and this can be used as the basis on which to classify each category. This may allow a more accurate assessment of the greenspace and access levels present, but may require the use of additional data or aerial photograph comparison to verify each category.
- Wherever detailed, or more recent Open Space Survey or Green Infrastructure survey data is available it could be used in place, or alongside the Greenspace Scotland map to increase accuracy. This could be achieved by manually editing or by following the method suggested for England and Wales.

Classifying by whole categories, or by individual polygons

The dataset contains separate fields to identify GI type and public access levels. In most cases the known category of GI type can be used to assume or determine the likely level of public accessibility – as highlighted in the accompanying classification tables. However other locally available information or data may be available that allows individual polygons to be separately classified by Public Access type. For example information may be available to separately map areas of Amenity Greenspace that are Publicly accessible from areas around institutional grounds or business properties that have no Public Access.

Table 16. GI data attribute definitions (England and Wales)

Typology attribute names	GI_ Coder	Access GI	Definition	Assumed habitat type
Accessible woodland	10	1	Any areas of publicly accessible woodland. Note this may be community woodland etc and recently planted woodland, so it might not have been mapped in the Natural and Semi-Natural Greenspace category. If these areas are mapped as Natural and Semi-Natural Greenspace they need not be duplicated here.	N/A
Allotment or community farm	1	0	Land provided for cultivation and or community food growing activities.	Cultivated
Amenity greenspace	2	1	Village greens and greenspace in and around housing that is public and does not have a specific function. Typically this is short mown amenity grassland.	Amenity grassland
Cemetery	3	1	Churchyards, cemeteries & other burial grounds.	Amenity grassland
Civic space	9	1	All areas of pedestrian streets or urban sealed surfaces in towns and cities with public access	N/A
Coastal	4	1	Beaches and open access intertidal areas.	N/A
Natural and Semi-natural Greenspace	5	1	Various natural or semi-natural areas considered greenspace by local authority surveys. These may include meadows, riversides, woodlands etc. These should be publicly accessible. If no information is available, or it is unclear if a polygon is publicly accessible then these sites should not be included.	N/A
Park or public garden	6	1	Formal and informal urban parks, country parks, and formal gardens. These should be publicly accessible, not charge for access.	Amenity grassland
Play facilities	7	1	Areas equipped for children and teenagers to play and socialise (e.g. youth shelters and playgrounds).	N/A

Typology attribute names	GI_ Coder	Access GI	Definition	Assumed habitat type
Sports facilities	8	0	Tennis courts, bowling greens, sports pitches, golf courses, athletics tracks, school and other institutional playing fields, and other outdoor sports areas with natural or artificial surfaces. These may be either publicly or privately owned. These are assumed NOT to be publicly accessible but are retained to be used to classify land use type.	Amenity grassland
Mixed / Other	9	1	Mixed categories or where it is unclear which is the main greenspace type. Use this code if these areas have definitely been identified as publicly accessible open space. If it is not possible to assess any categories from the GI / Open Space data set, but it is clear that all areas are publicly accessible, then all the data can be coded as “Mixed / other - 9” to ensure the accessibility information is available to the toolkit, even though the lands cover /land use / habitat information is not.	N/A

Table 17. Greenspace Scotland Map attributes

Greenspace Scotland categories	EcoServ-GIS typology categories	GI_Coder	AccessGI	Assumed Accessibility	Assumed habitat types
Allotment & Community Growing area	Allotment or community farm	1	0	No public access	Cultivated
Amenity – business	Amenity greenspace	2	0	No public access	Amenity grassland
Amenity – residential	Amenity greenspace	2	1	Accessible	Amenity grassland
Bowling greens	Sports facilities	8	1	Accessible	Amenity grassland
Cemetery	Cemetery	3	1	Accessible	Amenity grassland
Churchyard	Cemetery	3	1	Accessible	Amenity grassland
Civic space	Mixed / Other	9	1	Accessible	-
Golf courses	Sports facilities	8	1	Accessible	Amenity grassland
Green Access routes	Mixed / Other	9	1	Accessible	-
Institutional grounds		Not used	0	No public access	Amenity grassland
Other sports		Not used	0	No public access	-
Playing fields	Sports facilities	8	1	Accessible	Amenity grassland
Playspace	Play facilities	7	1	Accessible	-
Public park and gardens	Park or public garden	6	1	Accessible	Amenity grassland
Riparian routes	Mixed / Other	9	1	Accessible	-
School grounds		Not used	0	No public access	-
Tennis courts		Not used	0	No public access	-

Note: Remaining broad categories are not used by the toolkit and should be deleted from the dataset, unless further data or analysis allows classification into one of the categories above.

BAP (Biodiversity Action Plan)	Required for toolboxes: ES1BaseMap

This data is optional. The UK Biodiversity Action Plan aimed to restore the UK's threatened habitats and species. Some of these habitats were mapped and EcoServ-GIS uses this data (where available) to update the BaseMap habitat attributes. Any available habitat mapping could be converted to this format to be included in the toolkit.

This is a brief summary of the data preparation steps. Further details are noted in the Data Preparation checklist in the Annex.

- There are different options for the use of BAP and semi-natural habitat data, depending on what data sources are available.
- BAP or semi-natural habitat type data may be present in National BAP data (e.g. Natural England Priority Habitat Layer), in local BAP habitat mapping or in available digital Phase 1 Habitat Mapping.
- Detailed data consideration steps are noted in the data preparation checklist (See Annex).
- The default option is to use the national BAP data provided in the toolkit (England coverage only).
- If local data is used this will require additional editing and data preparation.
- Initially the user and project partnership should consult the Annex that details which services are impacted by different levels of data used to create the BaseMap.
- Decide if just National data, just local data, or a combination of the two will be used to add habitat information to the BaseMap.
- The National or local BAP data should then be edited as follows.
- In any situation where particular habitat types or datasets are not used or are deleted because they are considered inaccurate or unreliable then this should be noted and included with the metadata on the toolkit map results (See Annex).
- LOCAL BAP - If various BAP survey datasets are available locally which have been collected by Wildlife Trusts (or others) and are not integrated into the Natural England datasets, these should be merged or unioned to form one layer. Check that there is no spatial overlap between separate datasets – if there is make sure that this is removed by deleting one of the overlapping polygons. Fields with long text strings may have to be removed during the merge. Add a short text field called "BAPcode" and a text field called "BAPhabitat" and use habitat information provided to populate with the associated codes listed in Table 19 using "Select by Attributes" and the Field Calculator.
- NATIONAL BAP - Check if a formatted copy of the data is included within this version of the toolkit. If not then download and extract Natural England BAP habitat data within 1, 3, 5 or 10km of the Study Area. Check for those polygons with attribute notes indicating that the identification or mapping of the habitat may be unreliable and remove these. Add the "BAPcode" and "BAPhabitat" fields and populate using the names listed in Table 19.
- COMBINING LOCAL AND NATIONAL BAP - The separate national and the local data need to be merged into one layer. A method is used that allocates the LOCAL BAP habitat information to a polygon in preference to the NATIONAL BAP for any areas that have coverage of both datasets. For all areas with no LOCAL BAP data, the NATIONAL BAP data is used. A set of Data Preparation models are provided that advanced GIS users may consider using for this task. Alternatively use Table 19 to populate the data fields.
    - Add fields to each dataset to be combined; "BAPcode" (text field), "BAPhabitat" (text field), BAPPriority (long integer)
    - Use habitat information provided to populate with the associated codes listed in Table 19 using "Select by Attributes" and the Field Calculator

- Make sure both the LOCAL BAP and NATIONAL BAP have all the required data fields and data
    - Merge the two vector datasets together
    - Convert the data to a raster, at 2 m cells, based on BAPCode, with the BAPPrioirty as the priority field.
    - Convert the raster back to a vector (check that the correct attribute code fields are used for values)
- Export the chosen data layer (either single LOCAL BAP, NATIONAL BAP or the combined BAP data layer) to *ModelInputs/ES1BaseMap/Inputs.gdb* using the name "BAP".

Table 18. Formatting and coding BAP data

BAPCode	BAPTxt	BAPPriority(local)*	BAPPriority(national)*	BAPhabitat (EcoServ-GIS)	Phase 1 Type***
B0	Grass_p	105	51	Species rich grass grassland	Bu1
B1	Lagn_p	100	50	Saline lagoons	G16
B2	Calc_p	99	49	Calcareous grassland	B31
B3	Dune_p	98	48	Coastal sand dunes	H6u
B4	Shingle_p	97	47	Coastal vegetated shingle	H3/H5
B5	Reed_p	96	46	Reedbeds	F1
B6	Mud_p	95	45	Mudflats	H11
B7	BlBog_p	94	44	Blanket bog	E1u
B8	RBog_p	93	43	Lowland raised bogs	E162
B9	Pave_p	92	42	Limestone pavement	I13
B10	SNWds_p	91	41	Semi-natural broadleaved woodland (not used)**	A111
B11	DecWds_p	89	40	Deciduous woods	A11
B12	Fens_p	88	39	Fens	E3/F1
B14	Acid_p	86	38	Lowland dry acid grassland	B11
B15	Heath_p	85	36	Heathland	Du
B17	Mosaic_p	83	34	Heathland / grassland mosaics	D5/D6
B18	Meadow_p	82	33	Meadows	B21
B19	Purple_p	81	32	Purple moor grass and rush pastures	B5
B21	Cliff_p	79	30	Maritime cliff and slope	H8u
B22	Flood_p	78	29	Coastal floodplain grazing marsh	B4
B23	Orch_p	77	28	Traditional orchards	A112
B24	Park_p	76	27	Wood pasture and parkland	A3p
B25	Brown_p	75	26	Brown field	J13
B26	Undt_p	74	10	Undetermined grassland (semi or unimproved)	Bu
B27	Satl_p	110	24	Saltmarsh	H2
B32	Grass_m_p	59	23	Grass_moor	B11
B33	GQSI_p	58	22	Good quality SI grassland	Bu2
B34	Up_p	57	21	Upland flushes, fens and swamps	E2/E3/F1
B35	MScrub_p	56	20	Mountain heath and willow scrub	A2m

Note: *The “BAPPrioirty” field is only required if both NATIONAL BAP and LOCAL BAP are being combined. It is listed twice in the table to illustrate the different values given to either LOCAL BAP or NATIONAL BAP polygons, of the same habitat type. **The semi-natural broadleaved woodland category is currently not implemented in the toolkit. Deciduous / broadleaved woodland is used instead. *** Phase1 type lists the simplified Phase 1 habitat equivalent that is used to code the polygons into the BaseMap.

LCM2007 (Land Cover Map 2007)	Required for toolboxes: ES1BaseMap
This data is optional. The Land Cover Map 2007 Vector data may be available to partnerships. The data is sourced via CEH and has additional licence restrictions and requirements on resulting map products. Verify these with your supplier.	
• Source the LCM 2007 Vector data product. • Refer to the accompanying Table 20. • The following process can be conducted either by selecting records and using calculate field on the resulting selection, or alternatively by using Summarise based on the LCM2007 class and adding the following attribute fields to the resulting summarised table, then joining this back to the main attribute table. • Add the text field "LCMCode". • Fill these fields based on the Table below. • Export to *ModelInputs/ES1BaseMap/ Inputs.gdb* using the name "LCM".	

Table 19. Formatting and coding Land Cover Map 2007 data (LCM 2007)

LCMCode	LCM 2007	Phase 1 Type*
LCM1	Acid grassland	B11
LCM2	Rough grassland	Bu1/Bu2
LCM3	Neutral grassland	Bu1/Bu2
LCM4	Calcareous Grassland	Bu1/Bu2
LCM5	Improved Grassland	B4
LCM6	Fen Marsh and Swamp	B5/E3/F
LCM7	Heather	Du1
LCM8	Heather Grassland	D5
LCM9	Bog	E1u
LCM10	Littoral sediment	H1u
LCM11	Littoral rock	H13
LCM12	Saltmarsh	H26
LCM13	Arable and horticulture	J11

* Phase1 type lists the simplified Phase 1 habitat equivalent that is used to code the polygons into the BaseMap.

LCA (Landscape Character Area)	Required for toolboxes: ES1BaseMap
This data is optional, and is generally not recommended. Landscape Character Assessments can be used to provide information on land use and character. Contact your Local Authority and conservation agency to assess availability. The availability of detailed character description unit data is very variable between different counties. If good quality data are available to map any of the range of habitats noted below then this data should be used. Alternatively key selected land use types could be extracted from alternative data sources and used in the place of the LCA data. Examples could be the extraction of "Arable" areas from the Corrine European Habitat data (Raster, 2006, 100m cells). From Version 2.2 of the toolkit onwards a copy of the Corrine European Raster 100 m data is included with the toolkit. This has already been processed and coded and converted to a polygon dataset. It can be used in place of a local LCA data. This data set is not used to add accessibility information.	

Initial notes on data preparation are provided, further details are in the "Data preparation checklist" in the Annex , which goes into more detail (Annex 11, Annex 12).

- Consult Annex 9 to determine the impact of including this optional dataset.
- Consider the relative merits of using the supplied European Corine data versus local data. Use of this coarse data may introduce classification errors into the habitat data, that should be checked later when the final BaseMap classifications are viewed.
- Consider the time available for editing or verifying this data.
- If using the supplied European Corine data then copy this data into *ModelInputs/ES1BaseMap/ Inputs.gdb* using the name "LCA".
- If using locally available LCA data then if necessary, merge separate local datasets into one layer (check for and remove spatial overlap).
- If the data covers a larger area than your Study Area then overlay the data to your buffered boundary and select the overlapping polygons. This reduces the polygons needed to be processed, as not all Landscape Types may be present and thus need coding in your area.
- Check for any spatial overlaps with conflicting attributes in any separate datasets – change as necessary.
- Add a <u>Long Integer</u> field "LCA_coder" This is the main field used to classify LCA types.
- Optionally a text field "LCA_habitat" can be added to track conversion of the LCA types. This is <u>not</u> used by any of the models but can be used to track any data preparation stages and to check the following code fields have been accurately classified. Populate this field by categorising polygons into one of the habitat classes listed in Table 21 using information already provided in the LCA attribute table.
- Populate the "LCA_coder" field by categorising each polygon into one of the habitat classes listed in Table 21 using information already provided in the LCA attribute table.
- Any LCA types mapped which do not fit into these categories can be ignored – they will not be used by the model.
- Reclassification can be achieved using "Select by attributes" followed by the field calculator to populate the fields. For example selecting all features relevant to a particular habitat (there may be more than one, e.g. "Park" and "Formal gardens" would both fall under the "Parks and gardens" category and would be coded as "12").
- Export to *ModelInputs/ES1BaseMap/ Inputs.gdb* using the name "LCA".

Table 20. Formatting and coding LCA data

LCA_habitat	LCA_Coder	Description
Allotments	1	Land provided for cultivation and voluntary activities
Amenity grassland	2	Short, improved grassland used which may be used for recreation or to fill space between housing and grey infrastructure (e.g. road verges). May also include sports facilities.
Arable	3	Areas used for growing crops
Cemetery	4	Churchyards, cemeteries & other burial grounds
Pasture	5	Areas used for grazing animals
Golf course	6	Areas dedicated to playing golf
Heath/Moors	7	Found mainly on acidic soils, characterized by open, low growing vegetation
Industry	8	Any areas dedicated to industry or other factories or works
Quarry/Mineral	9	Active or disused quarries and other mineral workings
Landfill	10	Active landfill sites
Mixed farmland	11	Areas containing both pasture and crops
Parks and gardens	12	Formal and informal urban parks, country parks, and formal gardens
Caravan	13	Caravan sites or travellers sites
Rough grassland	14	Grassland in the uplands or lowlands that tends not to be highly improved. In the lowlands these may not be regularly managed. In the uplands these are often larger acid grassland that are often unenclosed.

LWS (Local Wildlife Sites)	Required for toolboxes: ES1BaseMap, Multi-functionality

This data is optional. The data was used in earlier versions of the Toolkit during the creation of the BaseMap, but this element is no longer used. If sourced it can be used during multi-functionality analysis of sites. Local Wildlife Sites (LWS) are identified and selected for their local nature conservation value. They protect threatened species and habitats acting as buffers, stepping stones and corridors between nationally-designated wildlife sites. Maps of LWS should be held by the Local Authority, Local Wildlife Trust or Local Records Centre.

- Local Wildlife Sites mapped by Wildlife Trusts must be merged and saved as one vector layer in *ModelInputs/ES1BaseMap/Inputs.gdb.*
- *Habitat information is not used from these data, but if this information is available this layer can be merged to form part of the "BAP" layer.*

DTM (Digital Terrain Model)	Required for toolboxes: ES1BaseMap; ES2WaterPurification

Background
This data is optional. Elevation and topography of the landscape.

- Obtain a fine resolution DTM for your study area plus a buffer. A 10 m raster is preferable.
- Note that a 50 m DTM is provided with the toolkit. This can be replaced by a more accurate version.

• If your DTM is 5 m then aggregate this to a 10 m DTM. (Spatial Analyst Tools> Generalization > Aggregate) • Export the raster to the Geodatabase, using the name “DTM”: *ModelInputs/ES0CommonFiles*

FC_NWSS (Scottish native woodland survey)	Required for toolboxes: ES1BaseMap
This data is optional. Details the location and composition of native woodlands throughout Scotland.	
• Check if a current version of the data is supplied within the toolkit. • Source the data from the Forestry Commission. • Verify the attribute field “semint_pct” is present within the data. • Export the raster to the file Geodatabase, using the name “FC_NWSS”: *ModelInputs/ES1BaseMap/Inputs.gdb*	

7.2.2 Ecosystem Service inputs

See also the tables in Annex 11, 12

<table>
<tr><td>PRoW and Core Paths
(Public Rights of Way)</td><td>Required for toolboxes:
ES3AccessibleNature; ES3EducationKnowledge</td></tr>
<tr><td colspan="2">Rights of way that are legally open to the public, or those footpaths most likely to be used (footpaths, bridleways etc.).</td></tr>
<tr><td colspan="2">Obtain PRoW or Core Paths data for your area from each Local Authority
If additional line data is available on PATHS that aren't mapped by your Local Authority, merge these together
Merge data together. Check and if necessary repair geometry. (Data Management Tools > Check Geometry / Repair Geometry)
Export these vector line data as a feature class, using the name "PROW_CORE_PATHS" to the Geodatabase:
ModelInputs\ES0CommonFiles\Inputs.gdb</td></tr>
</table>

<table>
<tr><td>Soils
(European soil dataset)</td><td>Required for toolboxes:
ES2WaterPurification</td></tr>
<tr><td colspan="2">This data is optional. The default is not to use this data. These data are a representation of the diversity and spatial variability of the soil coverage across Europe ("The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004")</td></tr>
<tr><td colspan="2">The default is not to use soils data due to poor resolution of mapped boundaries.
Obtain the vector data from the Joint Research Centre's European Soil Data Centre
Use the version – SGDB_PTR.shp
Project this dataset using the "British National Grid" coordinate system (Data management tools / Projections and transformations / Feature / Project)
Export these data using the name "Soils" to this file Geodatabase:
ModelInputs\ES0CommonFiles\Inputs.gdb</td></tr>
</table>

8. RUNNING THE TOOLKIT MODELS

8.1 Summary of running the models from the Toolbox

Once all the data inputs for the BaseMap and ecosystem service toolkits of interest have been sourced, formatted and saved as instructed, the models can be run. The **ES1BaseMap toolkit needs to be run before any of the other toolkits**. The first ES1BaseMap model is used here to help explain how to use this section of the guide to set up and run the models correctly.

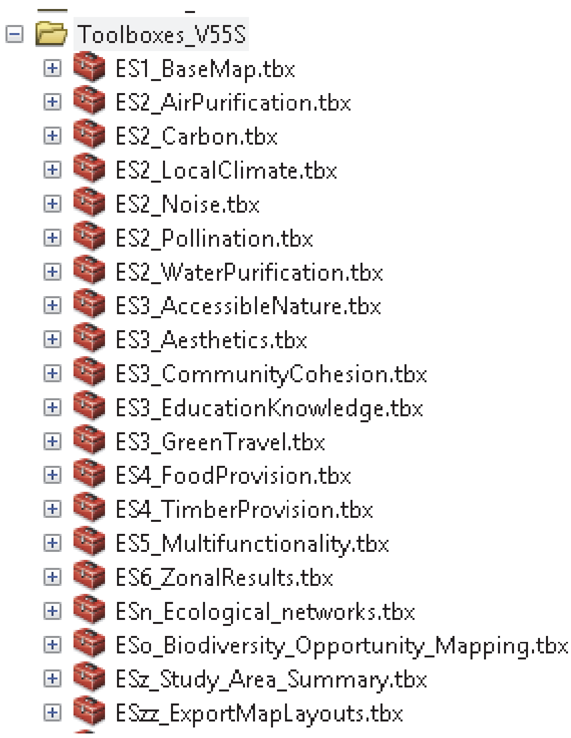


Figure 14. Viewing the Toolboxes in ArcCatalog

1) Begin a new session in ArcCatalog (close and reopen) and navigate to the toolkit. Click on the plus sign to the left of the toolkit to reveal the models inside. These should be run in numerical order.

A separate Toolbox (Figure 9) (Red Toolbox icon) is named for each main Service, or BaseMap. Each toolbox stores all the separate model tools (blue, green, yellow icon) for the BaseMap and each Service. Expand the toolbox by clicking on the plus sign to its left. This will reveal the models that it contains. Each model contains a series of connected Geoprocessing steps, which instruct ArcGIS how to analyse the data inputs in order to generate the desired output.

2) Review the list of "known issues" for this version of the toolkit (Annex 19).

3) Double click on the first model “ES1aStudyAreaWithSea”. Note the model inputs, parameters, and outputs. Please be patient, some models may be very slow to open. (If a model is very slow, close and reopen ArcCatalog).

4) Once you have clicked on the model, a dialog box will appear which gives a brief description of the model and provides boxes where the file pathways to model inputs can be specified and parameters can be set. These boxes will already contain information – the

pathways to the model inputs and outputs will already be filled in and these will be correct if model input data have been stored correctly. If a red error sign appears next to a model input it may be because the inputs have not been stored or named correctly. If this is the case, navigate to the inputs folder or Geodatabase and check the data. For further information on this error, consult the Troubleshooting Section 7.8.

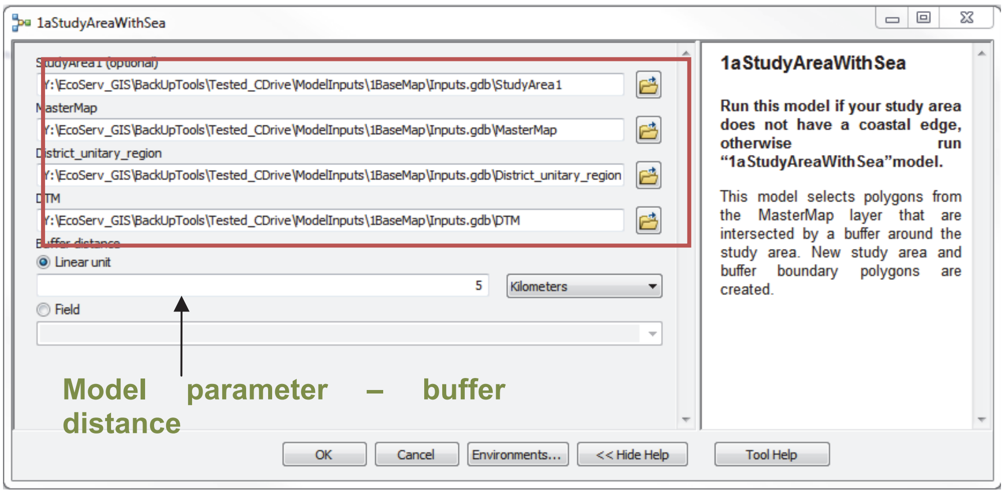


Figure 15. Example model window

The user guide provides a table explaining each of the model inputs (name, description and data type) and where they should have been saved (see example Figure 17). Some data that is already supplied with the toolkit may not be shown.

Input data	Description	Data type	Save to
BaseMap_Final	Final Base Map (detailed habitat & land use map)	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

Figure 16. Example Model input table

5) Model parameters are settings that the users can alter in order to change aspects of the analysis. A default value will be provided, but the user can change this (read the advice given in the explanation of the parameter). Parameters are listed in a table in each model's guide section. Not all models will have parameters. In this example the model requires users to specify a buffer which will determine the distance around which the analysis will be carried out (see example Figure 18).

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m
Maximum distance of air purification benefits from areas of capacity	20 m	A buffer distance beyond patches of greenspace within which the benefits of the service may occur

Figure 17. Example model parameters table

6) The model outputs table lists where the *main* model outputs will be saved. (see example table below). These will be saved in the "Outputs.gdb" for each model or service.

Output data	Description	Data type
AirPurification _Capacity	Estimated ability to trap or ameliorate air pollution. 1 (low) to 100 (high) scale (relative to all cells in study area)	Raster

Figure 18. Example model outputs table

7) The model indicators table lists where the main model indicators will be saved. (see example table below). These will be saved in the "Indicators.gdb" relevant to each model or service.

Indicator data	Description	Data type
AP_site_IndC	Site cell based air purification score, prior to focal analysis	Raster

Figure 19. Example model indicators table

8) Review any model specific information in Section 7.

9) Once you have checked the inputs and specified your parameter settings press OK to start the model.

Some models can take a considerable amount of time to run. Example analysis times taken to run the models at a 10 m resolution have been recorded in the guide for reference (Annex 1). Close down other programs while the model is running as this will reduce model run time. It may be worthwhile setting the models to run overnight *in some cases*.

10) As the model runs it will show each active analysis step. Once it is finished, navigate to the Outputs Geodatabase and inspect the data. If these are as expected (extent, content, format), the next model can be run.

11) Refer to the troubleshooting guide (Section 8.9) if the models fail to run or an error message appears. Note that Green *Warning* messages can be ignored, only Red *Error* messages are important.

12). After each model has run, close and then re-open ArcCatalog and ArcMap before starting the next model.

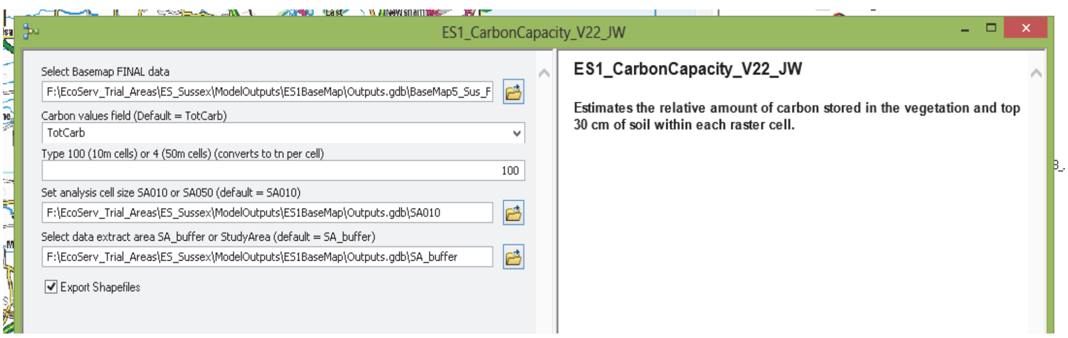


Figure 20. Model window example

13) Do not:

- **Move or rename folders or files**
  The EcoServ-GIS tools automatically find data and write the outputs to specific locations within the toolkit folder, which is split into subfolders (Box 2). For this reason, it is important not to change the structure of the folder and subfolders, or their contents. This includes re-naming items.

- **Run the sub models**
  Within some toolboxes there may be a toolsets called “Sub models" and "Indicators". You do not need to run these sub models, they will be automatically run by the main models.

- **Run more than one model at once**
  Separate models rely on some of the same datasets and a model will not be able to run if these data are already in use.

8.2 Creating the BaseMap (Habitat Map)

Tool Development: Chloe Bellamy (20%), Jonathan Winn (80%)

To be able to model ecosystem services we need information on land use and habitat type across the Study Area. Unfortunately, no single dataset that describes the landscape in enough detail and at a fine enough resolution is currently available for a service-based modelling approach at a county scale. This toolkit uses other datasets to update the attributes of a fine scale vector dataset, OS MasterMap. The other models included in the toolkit use OS VectorMap data to map specific landscape elements and to map socioeconomic properties, such as population density and Indices of Multiple Deprivation.

The ES1BaseMap models must be run before the ecosystem service models.

Table 21. BaseMap stages: input and output data

Model	Main input file	Output filename
ES 01a or ES01b	MasterMap	BaseMap_01
ES 02 Collate	Various	Various
ES 03 Add Open Space Typology to BaseMap	BaseMap01	BaseMap03_GI
ES 04 Add LCA Typology to BaseMap	*Selected BaseMap*	BaseMap04_LCA
ES 05 Add BAP Habitat to BaseMap	*Selected BaseMap*	BaseMap05_BAP
ES 06 Add Slopes to BaseMap	*Selected BaseMap*	BaseMap06_Slopes
ES 07 Add Elevation to BaseMap	*Selected BaseMap*	BaseMap07_Elevation
ES 08 Add Woodland Survey to BaseMap	*Selected BaseMap*	BaseMap08_SNW
ES 09 Add LCM2007 to BaseMap	*Selected BaseMap*	BaseMap09_LCM
ES 10 Add Urban AWI to BaseMap	*Selected BaseMap*	BaseMap10_Urban
ES 11 Classify all BaseMap habitats	BaseMap10_Urban	BaseMap11_Habitats
ES 12 Add Ecosystem Service Attribute Links	BaseMap11_Habitats	BaseMap_FINAL

ES 01a Study Area With Sea

Run this model if your Study Area is within your selected buffer distance of the coast (e.g. 5, 3 or 1 km), otherwise run "ES_1b_StudyAreaNoSea" model.

This model creates an updated Study Area boundary that matches MasterMap polygon edges and incorporates an area of sea along the coastline up to the user specific buffer distance. It draws a buffer around this boundary from which MasterMap data are extracted for later analysis. These data will form the basis of the BaseMap. A set of fields are added which are required for later models. The sea polygon's habitat and MasterMap fields are given the value "Sea". Several rasters with constant values of zero are created for the Study Area plus buffer (05, 10, 50, 100 m). The default is then to use the 10 m file to define the resolution of the analysis and to provide a mask and snap grid to ensure consistency of the analysis extent.

Instructions:

- Prepare the input data: StudyArea1, MasterMap (Area, Line, Points) and DTM
- Right click the model name and click "edit"
- From the "Model" menu click "Validate the entire model"
- From the "Model" menu click "Save" then close the model
- Right click the model name and click "Open"
- A "RunCode" field can be set so that you can label you output data by your Study Area
- You can add your OS MasterMap licence code so that it appears on output maps
- View the results by opening the relevant map in "ArcMaps0AnalysisProgress"

ES 01a Study Area With Sea model inputs

Input data	Description	Data type	Save to
StudyArea1	Boundary of study area	Vector (polygon)	ModelInputs/ES1BaseMap /Inputs.gdb
MasterMap_Area	MasterMap Topography layer	Vector (polygon)	ModelInputs/ES1BaseMap /Inputs.gdb
MasterMap_Line	MasterMap Topography layer	Vector (polyline)	ModelInputs/ES1BaseMap /Inputs.gdb
MasterMap_Point	MasterMap Topography layer	Vector (point)	ModelInputs/ES1BaseMap /Inputs.gdb
DTM	Digital Terrain Model	Raster	ModelInputs/ES0Common /Inputs.gdb

ES 01a Study Area With Sea model parameters

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run
OS MM licence	N/A	Enter the licence code relating to your OS MasterMap data
Buffer distance	3 km	A buffer around the study area is used because the wider landscape surrounding each point is involved in the computing ecosystem service demand and capacity. If information is not available outside the boundary of the study area then the resulting maps will be inaccurate close to this border. Set at 1, 3 or 5 km. NOTE: increasing the buffer size will increase model run time.
Use OS MM points and lines data?	Y	Some models, e.g. water purification use line data from OS MasterMap. Points data are not currently used in this Version of the toolkit.
Remove small polygons and landforms	Shape_Area > 5 AND DescGroup NOT LIKE '%Landform%' AND NOT PhysLev = 51	This removes small polygons and areas of overlapping landform data from the analysis. In very large Study Areas a higher threshold could be set to remove more small polygons, in order to reduce the number of polygons for analysis.

ES 01a Study Area With Sea model outputs ModelOutputs/ES1BaseMap/Outputs.gdb

Output data	Description	Data type
BaseMap1	MasterMap that is intersected by the buffer around the study area boundary (StudyArea1). Sea is added to the coastal boundary.	Vector (polygon)
StudyArea	MasterMap (plus sea) that is intersected by the study area boundary (StudyArea1).	Vector (polygon)
SA_buffer	BaseMap outline (study area with 15km sea and a 5 km land buffer).	Vector (polygon)
SA_buffer_grid	BaseMap outline (study area with 15km sea and a 5 km land buffer). Polygon split into several grid patches.	Vector (polygon)
SA010	10 m resolution study area buffer mask with a value of zero	Raster (10 m)
SA050	50 m resolution study area buffer mask with a value of zero	Raster (50 m)
SA100	100 m resolution study area buffer mask with a value of zero	Raster (100 m)

ES 01b Study Area No Sea

Run this model if your Study Area is not within your selected buffer distance of the coast (e.g. 5, 3 or 1 km), otherwise run "ES_1a_StudyAreaWithSea" model.

This model creates an updated Study Area boundary that matches MasterMap polygon edges. It draws a buffer around this boundary from which MasterMap data are extracted for later analysis. These data will form the basis of the BaseMap. Fields are added to these data which are required for later models. Several rasters with constant values of zero are created for the Study Area plus buffer (05, 10, 50, 100 m). The default is then to use the 10 m file to define the resolution of the analysis and to provide a mask and snap grid to ensure continuity of the analysis extent.

Instructions:

- Prepare the input data: StudyArea1, MasterMap (Area, Line, Points) and DTM
- Right click the model name and click "edit"
- From the "Model" menu click "Validate the entire model"
- From the "Model" menu click "Save" then close the model
- Right click the model name and click "Open"
- A "RunCode" field can be set so that you can label you output data by your Study Area
- You can add your OS MasterMap licence code so that it appears on output maps
- View the results by opening the relevant map in "ArcMaps0AnalysisProgress"

ES 01b Study Area No Sea model inputs

Input data	Description	Data type	Save to
StudyArea1	Boundary of study area	Vector (polygon)	ModelInputs/ES1BaseMap/Inputs.gdb
MasterMap_Area	MasterMap Topography layer	Vector (polygon)	ModelInputs/ES1BaseMap/Inputs.gdb
MasterMap_Line	MasterMap Topography layer	Vector (polyline)	ModelInputs/ES1BaseMap/Inputs.gdb
MasterMap_Point	MasterMap Topography layer	Vector (point)	ModelInputs/ES1BaseMap/Inputs.gdb
DTM	Digital Terrain Model	Raster	ModelInputs/ES0Common/Inputs.gdb

ES 01b Study Area No Sea model parameter

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run
OS MM licence	N/A	Enter the licence code relating to your OS MasterMap data
Buffer distance	3 km	A buffer around the study area is used because the wider landscape surrounding each point is involved in the computing ecosystem service demand and capacity. If information is not available outside the boundary of the study area then the resulting maps will be inaccurate close to this border. Set at 1, 3 or 5km. Increasing the buffer size will increase model run time.
Use OS MM points and lines data?	Y	Some models, e.g. water purification use line data from OS MasterMap. Points data are not currently used in this Version of the toolkit
Remove small polygons and landforms	Shape_Area > 5 AND DescGroup NOT LIKE '%Landform%' AND NOT PhysLev = 51	This removes small polygons and areas of overlapping landform data from the analysis. In very large Study Areas a higher threshold could be set to remove more small polygons, in order to reduce the number of polygons for analysis.

ES 01b Study Area No Sea model outputs ModelOutputs/ES1BaseMap/Outputs.gdb

Outputs	Description	Data type
BaseMap1	MasterMap that is intersected by the buffer around the study area boundary (StudyArea1).	Vector (polygon)
StudyArea	MasterMap that is intersected by the study area boundary (StudyArea1).	Vector (polygon)
SA_buffer	BaseMap outline.	Vector (polygon)
SA_buffer_grid	BaseMap outline. Polygon split into several grid patches.	Vector (polygon)
SA010	10 m resolution study area buffer mask with a value of zero	Raster (10 m)
SA050	50 m resolution study area buffer mask with a value of zero	Raster (50 m)
SA100	100 m resolution study area buffer mask with a value of zero	Raster (100 m)

ES 02 Collate VectorMap

This model extracts features from OS VectorMap District data. The model searches for data in the OSVectorMap folder belonging to a particular theme and merges the data from separate 10 km tiles. The outputs will be used for mapping particular ecosystem services.

Instructions
- Prepare the OSVector data
- Right click the model name and click "Open"
- View the results by opening the relevant map in "ArcMaps0AnalysisProgress"

ES 02 Collate VectorMap - model inputs

Input data	Description	Data type	Save to
OSVectorMap folder	The folder where the OSVectorMap data are stored	OSVectorMap = Vector (polygon)	ModelInputs/ES1BaseMap /OSVectorMap/*<Tile_name_folders>*

ES 02 Collate VectorMap - model outputs   ModelOutputs/ES1BaseMap/Outputs.gdb

Output data	Description (based on OS VectorMap technical guidelines)	Data type
OSAirports	Airport point data.	Vector (point)
OSBuildings	Buildings are any roofed structure greater than 175 square metres, and are represented as a generalised polygon.	Vector (point)
OSElectricityLines	Electricity transmission line alignments are represented as lines.	Vector (line)
OSForeshore	Foreshore lies between mean high water, or the NTL of rivers and mean low water. Foreshore is represented as a polygon, that is, there is no differentiation between sand, mud, shingle and so on.	Vector (line)
OSHeritage	A selection of heritage sites is represented as point data. These include World Heritage sites and sites managed by English Heritage.	Vector (point)
OSSportsCentres	Sports centres point data.	Vector (point)
OSPlacesof Worship	Places of worship point data.	Vector (point)
OSEducationFacil ities	Education facilities point data.	Vector (point)
OSRailstation	Railway stations are represented as points. The attribute 'classification' defines the type of station.	Vector (point)
OSRailways	All railways are represented as lines and are broken where they pass under bridges, buildings or other obstructing detail.	Vector (line)
OSRoads	These approximate to the road centre lines. Certain types of road have a road name and/or a road number held as attributes of the road alignment.	Vector (line)
OSWaterArea	Lakes, ponds and rivers or streams wider than 5 m are represented as polygons with their perimeters held as lines.	Vector (polygon)

Output data	Description (based on OS VectorMap technical guidelines)	Data type
OSWaterLines	Rivers and streams narrower than 5 m are represented as a single line.	Vector (line)
OSTidal	Mean high water and mean low water are defined as lines and differentiated by the attribute 'classification'. The tidal limits are shown for their full extents, including from the mouths of rivers to the normal tidal limit (NTL).	Vector (line)
OSWood	Areas of trees are represented as polygons. Small areas of woodland are omitted and small clearings in woodland are filled.	Vector (polygon)

Warning messages may occur if certain land use types do not occur in the Study Area. These can be ignored.

ES 03 Add Open Space Typology to BaseMap (OPTIONAL)

This model updates the BaseMap (MasterMap data extracted by the previous model) with information on the function and use of greenspace (GS), Green Infrastructure (GI) or Open Space (OpS). Local Authority greenspace vector data (or equivalent) are converted to fine-scale (2 m) rasters, coded by primary greenspace function. A typology field is classified in the BaseMap, “GI_type”, and if a park, public garden, cemetery, allotment, playground, sports field or general amenity greenspace raster covers the majority of a natural surface polygon (using zonal statistics), this polygon’s GI_type information is updated. All greenspace polygons which do not have a high overlap with these rasters are classed as “Undetermined greenspace”, and manmade features and surfaces are classed as “Not greenspace”. This initial classification does not take into account the types of OS MasterMap polygon. A further classification of these categories including quality control stages is conducted in a later model. Therefore the data produced by this model is intermediate.

Optional status
- This model requires the analysis and verification of Open Space / Green Infrastructure data.
- Review Annex 10 to note the impact of including or excluding this optional model
- This model will have most impact on Study Areas that include urban and urban fringe areas

Instructions
- Prepare the data supplied by Local Authorities (“<Local authority name>_GI”)
- Make sure the Tutorial “Durham_GI” data has been deleted from the Inputs
- Right click the model name and click “edit”
- From the “Model” menu click “Validate the entire model”
- From the “Model” menu click “Save” then close the model
- Right click the model name and click “Open”
- A “RunCode” field can be set so that you can label your data by Study Area
- View the results by opening the relevant map in “ArcMaps0AnalysisProgress”

ES 03 Add Open Space Typology to BaseMap model inputs

Input data	Description	Data type	Save to
BaseMap01	MasterMap within study area buffer	Vector (polygon)	No action needed. Previous model output already saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
Open Space Survey Data are "_GI" for each local authority)	The location of the Open Space Survey Data (GI data)	File Geodatabase	Save to ModelInputs/ES1BaseMap /Inputs.gdb

ES 03 Add Open Space Typology to BaseMap model parameters

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run
Cell size for zonal stats	2 m	Cell size used during conversion of polygons to raster data. In extremely large Study Areas setting this to 5 or 10 m may result in improved analysis times.

ES 03 Add Open Space Typology to BaseMap model outputs
ModelOutputs/ES1BaseMap/Outputs.gdb

Outputs	Description	Data type
BaseMap03_GI	BaseMap01 updated to include GI / Open Space data. Saved as a new data file.	Vector (polygon)

After the model has run:
- View the BaseMap03_GI data field in ArcMap and view and compare the classifications and extent against the source GI data layers.
- Note Warning messages (displayed on screen and in the results window).
- Note how many GI_Type and AccessGI polygons have NULL values
- Note how many larger GI_Type polygons (>0.5 ha) have NULL values
- Typically many small polygons (e.g. up to the low thousands) will have NULL values for AccessGI due to the way that zonal statistics is used in the calculations. This is not a problem for small polygons. If many large polygons are not coded (e.g. more than 500) then it may be necessary to double check the source GI layers.
- It may be useful to check any NULL coded polygons for the GI_Type field. There may be polygons that have an "unclassified" type for DescTerm or DescGroup. These are areas of recent change, or where OS has been unable to determine the current land use category. These will not necessarily cause problems with later models but if required these polygon could be amended in this dataset by editing the DescTerm, DescGroup, Make, GI_coder and GI_Type attribute fields.

Model limitations:
- Only those GI / Open Space areas that have been identified and mapped by Local Authorities will be included. This may not be comprehensive and may vary in coverage, extent and consistency between Local Authorities.
- Greenspace may have more than one function (e.g. a park and play facilities), but this model only identifies one primary function for each mapped polygon. Therefore if a Local Authority has separately mapped such areas in different polygons then they will be included. If they are simply noted as different data fields within one mapped polygon then only the main use will be considered within this toolkit. Unfortunately, this level of mapping accuracy may differ between Local Authority areas.
- Local Authority Open Space Survey data may be of poor quality or may not be available.
- The mapped greenspace polygons may not fit well or match the underlying OS MM polygons.

Modifications and actions to improve the model
- Where multiple Typology types have been classified per greenspace these could each be reviewed and the most appropriate Typology could be selected and used for Ecosystem Services mapping.
- Greenspace types or functions may be mapped using aerial photographs and local knowledge.
- The accuracy of the greenspace boundaries can be reviewed and where appropriate modified to more closely match the underlying OS MasterMap data.
- However, editing to remove features such as buildings, roads or other infrastructure is not necessary as such analysis (cross-validating against underlying OS MasterMap features) is carried out automatically by later models.

ES 04 Add LCA Typology to BaseMap (OPTIONAL)

This model makes fine resolution (5 m) rasters illustrating the distribution of Landscape Character Areas and uses the information to further classify the BaseMap. The percentage area of each MasterMap polygon that is covered by each particular LCA type raster is calculated (using zonal statistics) and these data are added to new BaseMap habitat fields. No final outputs are created by this model; the updated BaseMap04_LCA is used by later models.

Optional status

- This model is optional. Often sufficiently detailed LCA data will not be available.
- If LCM 2007 data is available, or a good coverage of BAP or habitat cover data is available then this model is unnecessary.
- Review sections in the User Guide to note the impact of including or excluding this optional data and model.
- If other habitat data sources are not available then Landscape Character data can be very useful to help classify areas of agricultural land within the Study Area.
- If BAP habitat data, LCM 2007 data or local Landscape Character Assessment data are not available then data could be extracted and saved from the Corine European Habitat Raster data (2006, 100 m cells) and used instead of the LCA data. A copy of this dataset, converted to vector format, is supplied with the toolkit.
- In summary the toolkit will still work if this model is not run, however in some situations certain land use types may be much reduced, or missing, in the resulting BaseMap (e.g. arable land).

Instructions

- Prepare the input data: LCA, and replace the version supplied in the toolkit
- Select which is the most recent version of the BaseMap that will be updated:
- Right click the model name and click “edit”
- From the “Model” menu click “Validate the entire model”
- From the “Model” menu click “Save” then close the model
- Right click the model name and click “Open”
- A “RunCode” field can be set so that you can label your data by your Study Area
- View the results by opening the relevant map in “ArcMaps0AnalysisProgress”

ES 04 Add LCA Typology to BaseMap model inputs

Input data	Description	Data type	Save to
BaseMap03_GI (BaseMap01)	BaseMap to be updated	Vector (polygon)	Normally no action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
LCA	Landscape Character Area data	Vector (polygon)	ModelInputs/ES1BaseMap/Inputs.gdb

ES 04 Add LCA Typology to BaseMap model parameters

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run
Conversion Cell size	5 m	Cell size used during conversion of polygons to raster data. In extremely large Study Areas setting this to 10 m may result in improved analysis times.

ES 04 Add LCA Typology to BaseMap model outputs
ModelOutputs/ES1BaseMap/Outputs.gdb

Outputs	Description	Data type
BaseMap04_LCA	BaseMap03_GI updated to include LCA data	Vector (polygon)

After the model has run:

- View the BaseMap04_LCA data fields in ArcMap and view and compare the classifications and extent against the underlying LCA data layers.
- Note any Warnings messages that occur after the model runs (displayed on screen and in the results window).
- Note how many polygons have NULL values (LCA_code). Warnings messages will indicate these, if present.

Model limitations

- This model only uses certain LCA habitat types to update the BaseMap. These have been chosen because of their usefulness for mapping particular ecosystem services.
- Any uncertainty or inaccuracies in the input data will be reflected in the resulting BaseMap.
- In most Landscape Character Assessments each polygon covers relatively large areas, for example an area mapped as "arable" will indicate this is the dominant land use in the area, however pockets of other land uses will also occur. These limitations are partly dealt with in later models where a quality control stage only uses the LCA information where it matches the potential land use indicated by the underlying OS MasterMap classifications.
- The LCA data is most useful in classifying areas of land that are not classified by either the underlying OS MasterMap data or by BAP habitats. If the LCA data is patchy, has incomplete coverage, or is not used then many typical agricultural fields will be left classified as the intermediate classification of "Arable/Improved grassland" as there will be no data to determine which of these two land uses they fall into.

Modifications and actions to improve the model

- If other data sources are not available, and if time is available, then the source LCA data can be edited, and potentially compared against other data, or aerial photography information to improve the classification accuracy and to create smaller, more well defined, polygons.

ES 05a Add BAP Habitat to BaseMap (OPTIONAL)
ES 05b Add BAP Habitat and LWS to BaseMap (OPTIONAL)

This model makes fine resolution (5m) rasters illustrating the distribution of habitat types identified by the BAP (or other digital habitat data). The percentage area of each MasterMap polygon that is covered by each habitat type raster is calculated (using zonal statistics) and these data are added to new BaseMap habitat fields. No final outputs are created by this model; the updated BaseMap is used by later models. The two models differ in that ES 05b also adds information on LWS sites to the BaseMap. **The LWS data is not currently required in Version 3.3 of the toolkit.**

Optional status

- This model is optional. Sufficiently detailed BAP data may not be available.
- Review Annex 10 to note the impact of including or excluding this optional data.

Instructions

- Prepare the input data: BAP
- Select which is the most recent version of the BaseMap that will be updated
- Right click the model name and click “edit”
- From the “Model” menu click “Validate the entire model”
- From the “Model” menu click “Save” then close the model
- Right click the model name and click “Open”
- Note that a “RunCode” field can be set so that you can label you output data by your Study Area
- View the results by opening the relevant map in “ArcMaps0AnalysisProgress”

ES 05 Add BAP Habitat to BaseMap model inputs

Input data	Description	Data type	Save to
BaseMap01, or BaseMap03_GI, or BaseMa04_LCA	BaseMap produced by earlier models. Use BaseMap4a_LCA if its exists, if not then use BaseMap3_GI	Vector (polygon)	Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
Select BAP data	Biodiversity Action Plan habitat data (or other habitat data)	Vector (polygon)	ModelInputs/ES1BaseMap /Inputs.gdb

ES 05 Add BAP Habitat to BaseMap model parameters

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run
Data conversion cell size	2 m	Cell size used during conversion of polygons to raster data. In extremely large Study Areas setting this to 5 or 10 m may result in improved analysis times.

ES 05 Add BAP Habitat to BaseMap model outputs

ModelOutputs/ES1BaseMap/Outputs.gdb

Outputs	Description	Data type
BaseMap05_BAP	BaseMap updated to include BAP habitat data and saved to a new file	Vector (polygon)

After the model has run:

- View the BaseMap05_BAP data fields in ArcMap and view and compare the classifications and extent against the underlying input BAP data layers.

Model limitations

- The main assumption and limitation of this model is that if an area of land within the Study Area is of BAP quality (of semi-natural habitat status and / or of conservation interest) then it will have been mapped and recorded in the BAP dataset.
- When a county or country based BAP data layer is available then it may be assumed that most larger expanses of semi-natural and BAP quality habitat will have been mapped and recorded but unfortunately this will not be true of small, fragmented, or isolated areas of habitat which are unlikely to have been surveyed or mapped. The model methods used in the toolkit uses absence of this BAP data to help classify polygons into particular habitat and land use types, therefore any omission or inaccuracies in the BAP data will carry through to the Final BaseMap habitat categories. This is a limitation of the GIS method used. The extent to which this will impact different Ecosystem Service maps varies between the different services.
- This model only takes certain BAP habitat types to update the BaseMap. These habitats have been chosen because of their usefulness for mapping particular ecosystem services.
- Overlaps between BAP habitats will result in only one habitat being mapped (habitats have been prioritized).
- Any uncertainty or inaccuracies in the input data may be reflected in the resulting BaseMap.
- The source BAP data may be out of date and habitats may have changed since they were digitised or surveyed. This can partly be addressed by quality control editing of the data before it is used in the toolkit.

Modifications and actions to improve the model

- This model could be improved by adding additional data quality control and verification stages to double check the BAP input data before it is used to update the BaseMap.
- Selections can be made so that only certain polygons from a BAP dataset are used within the model, such as those with higher "certainty" in the classification of the main habitat type.

ES 06 Add Slopes to BaseMap (OPTIONAL)

This model uses the DTM to update the BaseMap vector polygons to add slope (steepness) information. This is used within later models to classify habitat type.

Optional status

- This model is optional.
- Review Annex 9 to note the impact of including or excluding this optional data and model.
- This model is only appropriate if a 5 m or 10 m DTM is available and it is believed that steep slopes are present within the Study Area that are likely to influence land use. This judgement should be made by the toolkit user. The main impact of this model is that areas of unknown habitat types (areas of uncertain status, e.g. lacking in BAP habitat classification) are reclassified if they occur on areas of steep slopes (e.g. grassland is classified as unimproved or semi-improved in areas where ploughing and agricultural improvement is unlikely).
- The toolkit will still work if this model is not run.

Instructions

- Prepare the input data: DTM
- The input BaseMap depends on which of the BaseMap models have previously been run
- Select which is the most recent version of the BaseMap that will be updated
- Right click the model name and click “edit”
- From the “Model” menu click “Validate the entire model”
- From the “Model” menu click “Save” then close the model
- Right click the model name and click “Open”
- A “RunCode” field can be set so that you can label you output data by your Study Area
- View the results by opening the relevant map in “ArcMaps0AnalysisProgress”

ES 06 Add Slopes to BaseMap model inputs

Input data	Description	Data type	Save to
BaseMap01 or BaseMap03_GI or BaseMap04_LCA or BaseMap05_BAP	BaseMap produced by earlier models.	Vector (polygon)	Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
DTM	5 or 10 m input DTM	Vector (polygon)	ModelInputs/ES1BaseMap /Inputs.gdb

ES 05 Add Slopes to BaseMap model parameters

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run

ES 06 Add Slopes to BaseMap model outputs   ModelOutputs/ES1BaseMap/Outputs.gdb

Outputs	Description	Data type
BaseMap06_Slopes	BaseMap updated to include slopes data	Vector (polygon)

After the model has run:

- View BaseMap06_Slopes in ArcMap, with symbology labelled by Slope_mean and compare against a colour-classified copy of the DTM to confirm that polygons were coded correctly.
- Note any Warning messages that record how many polygons have NULL values. Numbers up to the low thousands are within expected levels.
- Note any Warning messages that record how many large polygons (> 0.5 ha) have NULL values. Numbers up to the low hundreds are within expected levels.

Model limitations

- In contrast to the use of BAP data which classifies areas based on typically known or surveyed data this use of slopes relies on predicted or modelled relationships and is not based on site surveys or knowledge.
- The model calculations are limited by DTM cell size resolution and accuracy.
- 50 m DTM is unsuitable for use because it does not capture slope angle well in smaller polygons due to the cell size.
- Due to the method used some output BaseMap polygons will not receive a slope value. This typically occurs for thin "sliver" polygon with complex shapes. These omission polygons are typically relatively few compared to the total number of polygons in the study area, and these will not overly impact subsequent model calculations.

ES 07 Add Elevation to BaseMap (OPTIONAL)

This model uses the DTM to update the BaseMap vector polygons to hold elevation information. The information is used within later models to classify habitat type.

Optional status
- This model is optional.
- Review Annex 9 to note the impact of including or excluding this optional data and model.
- The main use of elevation data is to reclassify "High elevation" or "upland" areas if they are present within the Study Area (Areas > 600 m)
- This currently only influences the “naturalness” scores, and services that use this such as Accessible Nature and Aesthetics.
- If no montane areas are present in the Study Area, the model does not need to be run.
- The toolkit will still work if this model is not run.

Instructions
- Prepare the input data: DTM
- Select which is the most recent version of the BaseMap that will be updated
- BaseMap06_SlopesRight click the model name and click “edit”
- From the “Model” menu click “Validate the entire model”
- From the “Model” menu click “Save” then close the model
- Right click the model name and click “Open”
- A “RunCode” field can be set so that you can label you output data by your Study Area
- View the results by opening the relevant map in “ArcMaps0AnalysisProgress”

ES 07 Add Elevation to BaseMap model inputs

Input data	Description	Data type	Save to
BaseMap01, or BaseMap03_GI, or BaseMap04_LCA, or BaseMap05_BAP, or BaseMap06_Slopes	The previous BaseMap results produced by earlier models.	Vector (polygon)	Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
DTM	5 m or 10 m input DTM or Open Data 50m DTM	Raster	ModelInputs/ES1BaseMap /Inputs.gdb

ES 07 Add Elevation to BaseMap model parameters

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run

ES 07 Add Elevation to BaseMap model outputs ModelOutputs/ES1BaseMap/Outputs.gdb

Outputs	Description	Data type
BaseMap07_Elevation	BaseMap updated to include Elevation (height) data per polygon	Vector (polygon)

After the model has run:

- View BaseMap07_Elevation in ArcMap, with symbology labelled by Elev_mean and compare against a colour classified copy of the DTM to confirm that polygons have been coded correctly.
- Note any Warning messages that record how many polygons have NULL values. Number up to the low thousands are within expected levels.
- Note any Warning messages that record how many large polygons (> 0.5 ha) have NULL values. Numbers up to the low hundreds are within expected levels.

Model limitations

- The model aims to add elevation data to each mapped polygon but can be limited by the DTM data used.
- If coarser DTM are used, e.g. 50 m DTM then small polygons may not receive an elevation value from this model. This typically occurs for thin "sliver" polygon with complex shapes. These omission polygons are typically relatively few compared to the total number of polygons in the study area, and these will not overly impact on subsequent model calculations.
- Such cell size limitations may lead to small areas being given the wrong naturalness values in a later model. Because typically there will be many larger polygons mapping upland landscape this is unlikely to cause significant errors in the models that use this data.

Modifications and actions to improve the model

- This model could be altered so that the input DTM is first re-sampled to a smaller cell size. This would help to avoid smaller polygons not receiving an elevation value.

ES 08 Add Woodland Survey to BaseMap (Scotland) (OPTIONAL)

This model only applies in Scotland, and uses the Forestry Commission Native Woodland Survey (NWSS). Native, semi-natural woodlands are extracted and used to code polygons in the BaseMap.

Optional status
- This model is optional, and only applies in Scotland.
- Including this model will allow the differentiation of semi-natural versus plantation woodland. This can be important for planning the ecological networks and biodiversity opportunity areas.
- The model is not required for most ecosystem service models as often service values are linked to broad woodland type, rather than to semi-natural or plantation types.
- The toolkit will still work if this model is not run.

Instructions
- Prepare the input data: FC_NWSS
- Select which is the most recent version of the BaseMap that will be updated
- Right click the model name and click “Open”
- Right click the model name and click “edit”
- From the “Model” menu click “Validate the entire model”
- From the “Model” menu click “Save” then close the model
- A “RunCode” field can be set so that you can label your output data by your Study Area
- View the results by opening the relevant map in “ArcMaps0AnalysisProgress”

ES 08 Add Woodland survey to BaseMap - model inputs

Input data	Description	Data type	Save to
BaseMap01 BaseMap03_GI, or BaseMap04_LCA, or BaseMap05_BAP, or BaseMap06_Slopes, or BaseMap07_Elevation	The previous BaseMap results produced by earlier models.	Vector (polygon)	Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
FC_NWSS	FC NWSS survey dataset	Vector (polygon)	ModelInputs/ES1BaseMap /Inputs.gdb

ES 08 Add Woodland Survey to BaseMap model parameters

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run
Semi natural cover	50	Level of semi natural tree cover used to define semi-natural compartments (not plantations)

ES 08 Add Woodland Survey to BaseMap   ModelOutputs/ES1BaseMap/Outputs.gdb

Outputs	Description	Data type
BaseMap08_SNW	BaseMap updated to include woodland survey data per polygon	Vector (polygon)

After the model has run:

- View BaseMap08_SNW in ArcMap, with symbology labelled by FC_woods_SN and compare against a colour classified copy of the original FC NWSS data to confirm that polygons have been coded correctly.

Model limitations

- The model uses selected cut-offs and thresholds with which to select appropriate semi-natural woods.

ES 09 Add LCM data to BaseMap (OPTIONAL)

This model uses the CEH LCM 2007 data to add habitat information to the polygons within the BaseMap.

Instructions
- Prepare the LCM data as indicated.
- Select which is the most recent version of the BaseMap that will be updated
- Right click the model name and click “edit”
- From the “Model” menu click “Validate the entire model”
- From the “Model” menu click “Save” then close the model
- Right click the model name and click “Open”
- A “RunCode” field can be set so that you can label your output data by your Study Area
- View the results by opening the relevant map in “ArcMaps0AnalysisProgress”

ES09 Add LCM2007 model inputs

Input data	Description	Data type	Save to
BaseMap01, or BaseMap03_GI, or BaseMap04_LCA, or BaseMap05_BAP, or BaseMap06_Slopes, or BaseMap07_Elevation, or BaseMap08_SNW	BaseMap produced by earlier models	Vector (polygon)	Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
LCM	LCM 2007 data	Vector (polygon)	Save to: ModelInputs/ ES1BaseMap/ Inputs.gdb

ES09 Add LCM2007 model parameters

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run
Processing cell size	5	Cell size used during raster conversion

ES08 Add LCM2007 model outputs ModelOutputs/ES1BaseMap/Outputs.gdb

Outputs	Description	Data type
BaseMap09_LCM	BaseMap updated to include LCM polygon data	Vector (polygon)

After the model has run:
- If required, the BaseMap09_LCM data can be viewed in ArcMap, with symbology labelled by LCM type and compared against a copy of the original LCM data.

Model limitations
- The model uses an overlap threshold to identify where data is passed to a BaseMap polygon.
- Patch overlap and polygon size thresholds have been used to aid the classification.

ES 10 Add Urban and AWI to BaseMap

This model uses the Urban input data, and Ancient Woodland Inventory (AWI) data to update the BaseMap vector polygons. The information is used within later models to classify habitat type (and within several service models).

Instructions
- No data to prepare (inputs are already present within the toolkit)
- If it is of particular interest that the toolkit includes accurate Ancient Woodland information then the AW data can be replaced with a locally available version. However this will not impact on much of the current model functionality.
- Select which is the most recent version of the BaseMap that will be updated
- Right click the model name and click "edit"
- From the "Model" menu click "Validate the entire model"
- From the "Model" menu click "Save" then close the model
- Right click the model name and click "Open"
- Note a "RunCode" field can be set so that you can label your output data by your Study Area
- View the results by opening the relevant map in "ArcMaps0AnalysisProgress"

ES 10 Add Urban and AWI to BaseMap model inputs

Input data	Description	Data type	Save to
BaseMap01, or BaseMap03_GI, or BaseMap04_LCA, or BaseMap05_BAP, or BaseMap06_Slopes, or BaseMap07_Elevation, or BaseMap08_SNW, or BaseMap09_LCM	BaseMap produced by earlier models	Vector (polygon)	Previous model output saved to: ModelOutputs/ES1BaseMap / Outputs.gdb
Urban_GB	Urban locations	Vector (polygon)	Saved in: ModelInputs/ES0CommonFiles /Inputs.gdb
AWI_ASNW_GB	Ancient woodland inventory, semi-natural woods	Vector (polygon)	Saved in:ModelInputs/ES0CommonFiles /Inputs.gdb

ES010 Add Urban and AWI to BaseMap model parameters

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run

ES 10 Add Urban and AWI to BaseMap model outputs
ModelOutputs/ES1BaseMap/Outputs.gdb

Outputs	Description	Data type
BaseMap10_Urban	Updated to include Urban and AWI data	Vector (polygon)

After the model has run:

- If required, the BaseMap10_Urban data can be viewed in ArcMap, with symbology labelled by "Urb" and compared against a copy of the Urban layer in the BaseMap inputs folder to confirm that polygons have been coded correctly.

Model limitations

- The model adds Urban and AWI classification data to the BaseMap polygons.
- The model uses a threshold of overlap to identify where data should be passed to a BaseMap polygon.
- Where the urban boundary or AWI data boundary have been poorly digitised or they do not match well the OS MasterMap polygon boundaries then areas may be missed or misclassified.

Modifications and actions to improve the model

- A data preparation and analysis stage could be added to pre-process AWI and Urban data against certain buffered land use features, e.g. roads or buildings in order to modify the mapped boundaries to help ensure that the data better matches underlying mapped OS polygon features.

ES 11 Classify all BaseMap habitats

This model uses all the available information complied into the BaseMap from the previously run models to sequentially classify BaseMap polygon habitat fields by using:

- Attribute information provided by OS MasterMap,
- The overlap with other habitat layers identified in the previous models,
- Rules on the structure, abiotic characteristics or spatial configuration of habitat patches

This model will produce different results depending on which of the optional models have previously been run.

The result of this model is a BaseMap dataset with each polygon holding a main classified habitat type code. Rules have also been incorporated to update information on the function of Open Space / GI. These steps are listed in the BaseMap Technical Report along with a list of the final habitat fields that are created.

This model uses the identified habitat type of each polygon to add a range of data values used by later Ecosystem Services models. These relate to properties of the habitat type, for example naturalness, surface roughness, etc. The full list of such fields are listed in the Technical Report and are referred to in turn within each service model description in the sections below.

A range of settings are used during the habitat classification process. For example areas of semi-improved or improved grassland are re-classified as unimproved grassland if they occur in fields where the mean slope is greater than a threshold value. Many of these settings can be altered by the user, giving greater control of how the habitat map is produced locally. These optional settings are listed, with explanations, in the parameters table below.
The resulting BaseMap is used by the next model to link a number of attribute to each land use / habitat polygon. At this stage it is possible to edit the data or use other GIS techniques to update or amend the data in order to ensure that the attribute field “HabCode_B” holds the best classification of each polygon’s habitat.

Before running this model, verify that your input data has been built using the correct set of optional data inputs for your Study Area. This can be checked by examining the filenames of each successive BaseMap and the "Data Sources" fields within the attribute table. The number codes relate to the numbered BaseMap models and list which input data have been used to build up the BaseMap.

Instructions

- This model always uses BaseMap10_Urban as the input BaseMap
- Right click the model name and click “Open”
- A “RunCode” field can be set so that you can label your output data by your Study Area
- View the results by opening the relevant map in “ArcMaps0AnalysisProgress”

ES 11 Classify all BaseMap Habitats - model inputs

Input data	Description	Data type	Save to
BaseMap10_Urban	BaseMap with classified data	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb

ES 11 Classify all BaseMap Habitats - model parameters

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run
Garden_max	800	Maximum size (m^2) for domestic gardens to map code J56 (Other habitat, Private garden)
Garden_shape	10	Maximum shape index for domestic gardens to map code J56 (Other habitat, Private garden)
Houses_max	800	Size (m^2) above which buildings are classed as code J361 (Built up area, Buildings, Business or Industry)
Houses_min	30	Size (m^2) below which buildings are classed as code J362 (Built up area, Shed, Garage, Farm Building)
Gardens distance	5	Distance used to classify buildings as Domestic if they occur this close to code J56 (Other habitat, Private garden)
BAP min	0.6	Minimum proportion of the polygon that must be covered by BAP habitat classification data before the relevant BAP habitat category is used to code the underlying polygon. Higher values require a higher degree of overlap before re-classification occurs.
BAP max	0.4	Maximum overlap with a BAP habitat cover up to which the BAP habitat is ignored in classification using the main OS MasterMap codes or LCA or Open Space / GI data.
Arable min	5,000	Size (m^2) below which uncertain polygons of code B4/J11 are re-classified as code B4 (Improved grassland)
Improved max	250,000	Size (m^2) above which uncertain polygons of code B4/J11 are re-classified as code J11 (Arable)
Unimproved slopes	18	Minimum slope angle above which grassland habitats are re-classified as unimproved
Semi-improved slopes	11	Minimum slope angle above which grassland habitats are re-classified as semi-improved
Dry slopes	11	Minimum slope angle above which wetland habitats will be re-classified as non-wetland habitat
Urban overlap	0.8	Minimum proportion of the polygon that much overlap and be covered by urban land cover data before the habitats are re-classified as urban habitat versions
AWI overlap	0.8	Minimum proportion of the polygon that must be covered by AWI data before the underlying polygon is re-classified. Higher values require a higher degree of overlap before re-classification occurs.
Montane	600	Elevation above which polygons are re-classified as

		Montane.
LCM_min	0.6	Minimum proportion of the polygon that must be covered by LCM habitat classification data before the relevant habitat category is used to code the underlying polygon. Higher values require a higher degree of overlap before re-classification occurs.
Heath_min	10,000	Size (m^2) below which the heath category from OS mapping is considered unreliable unless verified by other sources.
Heath_grass_min	5,000	Size (m^2) below which the heath and grassland mosaic category from OS mapping is considered unreliable unless verified by other sources.

ES 11 Classify all BaseMap Habitats - model output
ModelOutputs/ES1BaseMap/Outputs.gdb

Output data	Description	Data type
BaseMap11_Habitats	Detailed BaseMap with information on the distribution of habitat types	Vector (polygon)

After the model has run:

- Once this model has been run, inspect the BaseMap. This is the BaseMap that will be used for ecosystem services analysis. If it is satisfactory (e.g. the extent and content match the Study Area and local knowledge) then the intermediate BaseMaps may be deleted from the Outputs.gdb to reduce the file size (or archived elsewhere).
- Selected polygons, catchment or sites can be examined to verify the level of accuracy of the polygon habitat classifications. An awareness of the general level of errors or limitations to the accuracy of habitat classifications can be used to help interpret the outcome of the Ecosystem Service mapping.
- At this stage the habitat map could be edited for quality via stakeholders, before the next model is run. Alternatively these two models could be run iteratively with stakeholder input.

Model limitations

- The model classification rules will not achieve 100% accurate habitat identification rate, but they provide us with a best available estimate on how the land is likely to be used and what habitats are present. These rules have been tuned and validated using expert examination of the output produced for a number of test sites. They are also based on previous work such as mapping rules developed by the Mersey Forest or underlying the creation of the modelled elements within the LCM 2007 habitat map (CEH).
- The BaseMap_Final habitat classification are best considered as a compilation of the available information on locally mapped and classified habitat and land use cover, verified and quality controlled against the underlying OS MasterMap polygon classification.
- If an area is small and has not been mapped within OS MasterMap then it will not appear in the BaseMap.
- Recent improvements to classification include:
    - Further classification of the broad category “Improved grassland/Arable” using rules based on a polygon’s location in relation to urban areas, as well as its size and shape.
    - Implementation off the Mersey Forest (2010) rule regarding the identification of gardens based on their distance to domestic buildings.
    - A rule to identify "linear habitats", such as strips of grassland, ditch side habitats, tree lines and hedgerows.

Modifications and actions to improve the model

- The range for parameters used in the model to classify e.g. domestic houses, gardens and arable land are taken from previous studies or are based on trial and error approaches to find suitable values. Ideally, these would be based on published or established sources. The values can be altered by the user if new recommended values become available.
- Further literature review in relation to field level abiotic conditions that are predictive of habitat category would help to improve this model.

ES 12 Add Ecosystem Service Attributes Link Table

This model takes the classified habitat BaseMap11_Habitats and joins an ecosystem service attribute table that adds a range of attributes to each land use polygon. For advanced GIS users the ecosystem service attribute table that is used to link the data could be updated if new values are published in the literature. (See BaseMap Technical Report).

Instructions
- This model always uses BaseMap11_Habitats as the input BaseMap
- Right click the model name and click “Open”
- A “RunCode” field can be set so that you can label your output data by your Study Area
- View the results by opening the relevant map in “ArcMaps0AnalysisProgress”

ES 12 Add Ecosystem Services Attribute Link table - model inputs

Input data	Description	Data type	Save to
BaseMap11_Habitats	BaseMap with all classified data	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb

ES 12 Add Ecosystem Services Attribute Link table model parameters

Parameter	Default	Explanation
RunCode	Tutorial	Enter a short text code to label your analysis run
Select ecosystem services attribute link	Main_V15	Table with ecosystem service attribute values for each habitat type. This also holds the landscape cost values used in the least-cost ecological network mapping.
Select naturalness coding	Naturalness_V3	Table with naturalness scores for each habitat type
Export BaseMap as a Layer Package	No	Optional export as a layer package file to allow sharing via ArcGIS Online File is created in ES1BaseMap/LayerPackage
Export BaseMap as a shapefile	No	Optional export as a shapefile to allow sharing to other GIS File is created in ES1BaseMap/Shapefiles

ES 12 Add Ecosystem Services Attribute Link table - ModelOutputs/ES1BaseMap/Outputs.gdb

Output data	Description	Data type
BaseMap_FINAL	Detailed BaseMap with information on the distribution of habitat types, land use and perceived naturalness etc used by the Ecosystem service models	Vector (polygon)

Modifications and actions to improve the model
- If further research information or published studies are available, the attribute scores or values of certain habitats can be altered.
- Alternatively different versions of this "Main_V%" table can be updated and saved and used to compare the impact of changing attribute scores on model outputs maps.

ES 13 Add Socioeconomic data to BaseMap

This model creates a point dataset of the predicted location of domestic houses or dwellings. The data contains a range of social and socio-economic data that represents data at the household, Output Area (OA), DataZone (DZ) or Lower Super Output Area (LSOA) geography levels. Data is largely from the 2011 census, however some data on the Index of Multiple Deprivation is mapped using the 2001 LSOA boundaries. The full list of data fields are listed in the Technical Report.

This dataset is used to map the location of people and to enable summary statistics to be produced describing the human population in distance zones around focal grid cells. The resulting population estimate at each mapped domestic building allows later models to use the data to estimate the number of people living within a certain radius of any point. The Index of Multiple Deprivation scores (which give an indication of the relative levels of deprivation) are also disaggregated to this fine scale by joining this information to the household locations. This method allows the toolkit to pinpoint where people are actually living within an area so that these socio-economic data can be mapped to these locations and the societal demand for ecosystem services can be measured at relatively small spatial scales (but see limitations).

The model uses optional alternative data sources to identify domestic houses. The default is to use the OS MasterMap located in the Inputs folder to predict where domestic houses occur, based on building size and proximity rules. Alternatively, other datasets that identify the location of domestic houses such as based on address databases could be used as input data (these must be in polygon format). (The OS MasterMap data can be used to map and locate dwellings and to create the socio-economic dataset even if the OS MasterMap is not used to create the Habitat BaseMap.)

Instructions

- Decide if using the default method of mapping domestic dwellings, or if alternative data is available
- Decide if using the default parameters to classify domestic dwellings, or locally set variables
- Right click the model name and click “Open”
- Select any country specific parameters (e.g. IMD data)
- View the results by opening the relevant map in “ArcMaps0AnalysisProgress”

ES 13 Socioeconomic data - inputs

Input data	Description	Data type	Save to
MasterMap_Area	OS MasterMap data	Vector (polygon)	Saved to: ModelInputs/ ES1BaseMap/ Inputs.gdb
OA_2011_GB	Polygon data holding population level data	Vector (polygon)	Saved to: ModelInputs/ ES1BaseMap/ Inputs.gdb

ES 13 Socioeconomic data - model parameters

Parameter	Default	Explanation
Select country IMD data	-	IMD data per country (Scotland, England, Wales versions)
Infer domestic property address location from	Yes	Selects that the analysis will use the rules below to predict domestic property locations

MasterMap Gardens distance	5	Distance used to classify buildings as Domestic if they occur this close to code J56 (Other habitat, Private garden)
Garden_max	800	Maximum size (m^2) for domestic gardens to map code J56 (Other habitat, Private garden)
Garden_shape	10	Maximum shape index for domestic gardens to map code J56 (Other habitat, Private garden)
Houses_max	800	Size (m^2) above which buildings are classed as code J361 (Built up area, Buildings, Business or Industry)
Houses_min	30	Size (m^2) below which buildings are classed as code J362 (Built up area, Shed, Garage, Farm Building)
Use alternative property address data	No	Provide a polygon feature class to map the location of domestic buildings
Alternative buildings location data	Replace With data	Dummy variable to be replaced with data if the optional analysis above is selected

ES 13 Socioeconomic data – model outputs ModelOutputs/ES1BaseMap/Outputs.gdb

Output data	Description	Data type
domestic_buildings	Domestic buildings	Vector (polygon)
Pop_socioec_points	IMD, socio economic and population data mapped to domestic buildings	Vector (point)

After the model has run:

- View the output data files in ArcMap and assess their accuracy. If necessary the model inputs or parameters can then be altered to result in more satisfactory mapping of dwelling house locations.
- Points that have very low or very high values for attribute field “House_pop” may identify problem classified locations for review.

Model limitations

- Although this model maps patterns of population density and deprivation to point based locations, and this is useful in increasing the spatial accuracy of these statistics, there are important limitations in the interpretation of the attribute fields.
- The majority of the census based information is collected at the Output Area / DataZone geography level. However the IMD data was collected at the LSOA scale, and therefore represent a broader geographic area.
- Fine scale variations in social characteristic are not shown by the data, it is not possible to fully characterise the human population on a street by street basis. Often the source file boundaries are apparent when the points are mapped and coded by data fields.
- Using summary statistics on the point file locations does help to characterise the human population of different areas, however the limitations must be realised. For example certain houses within a particular OA or DZ may not necessarily contain people that area accurately categorised by the population characteristics of the whole constituent OA or DZ. This is partly accounted for within later analysis by service model calculations by setting minimum thresholds of domestic dwellings to remove isolated hamlets or dwellings from the resulting maps of collated and averaged population or socio-economic data.
- The classification of buildings into domestic or industry/shed/farm building is not 100% accurate, but an approximation based on based available information, based on their size (The Mersey Forest, 2010) and distance from a road (See Technical Report).
- Due to different population densities in rural and urban areas the LSOA boundaries vary greatly in size, it may be that there will be larger spatial variations in the population characteristics in the larger mapped LSOAs.
- LSOAs are much smaller and closely packed in urban areas. The use of the socio-economic points data is considered to be much more accurate and to truly reflect socio-economic conditions in urban areas compared to very sparse rural areas. In many cases a threshold is suitable to apply to sparsely populated areas where both the representative nature of the IMD scores and the likely inaccuracies in the mapping of domestic buildings combine to make the use of the data in these areas unreliable. Where such thresholds are applied they are noted in each service model.

Modifications and actions to improve the model

- If time is available this model can be run several times with different optional parameter settings to more accurately map the location of domestic buildings, based on local knowledge or comparing against alternative data sources or aerial photograph information.

ES_14_Produce summary statistics: habitat cover

This model creates attribute tables and excel files listing the area (ha, km^2) and % cover of each habitat type, allowing the landscape composition of the Study Area to be quantified. Different versions are produced for each of the main habitat classifications. The tables also detail the relative levels of certainty that have been applied to the habitat classifications, allowing the reliability of the BaseMap to be assessed.

Instructions

- Right click the model name and click “Open”

ES 14 Produce summary statistics habitat cover - inputs

Input data	Description	Data type	Save to
BaseMap_FINAL	Habitat BaseMap	Vector (polygon)	Saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

ES 14 Produce summary statistics habitat cover - *model parameters*

Parameter	Default	Explanation
Area to produce cover statistics	StudyArea	The boundary of the Study Area for which habitat composition statistics will be produced
RunCode	Tutorial	Enter a short text code to label your analysis run
InputsCode	_	Optional additional code to define e.g. different use of Study Area or BaseMap data

ES 14 Produce summary statistics habitat cover – ModelOutputs/ES1BaseMap/Indicators.gdb

Output data	Description	Data type
various	Several files holding the habitat composition summary	Table

ES 14 Produce summary statistics habitat cover ModelOutputs/ES1BaseMap/Statistics

Output data	Description	Data type
various	Several files holding the habitat composition summary	Excel files

- Example table format (selected fields shown):

HabClass	Habitat classification
Frequency	Number of polygons / patches
SUM_ Shape_Area	Total area in meters
High_pcnt	% of this habitat category that has high classification certainty
Moderate_pcnt	% of this habitat category that has high classification certainty
Low_pcnt	% of this habitat category that has high classification certainty
Percent cover	% cover of the landscape for this habitat type
Ha	Area in hectares
Km2	Area in sq kilometres

8.3 Verifying and updating the BaseMap

At this stage the content of the BaseMap (Habitat Map) should be reviewed. The following stages can be used to check the content of the BaseMap, amend the map and re-run the models.

- Open ArcMap and view the BaseMap_FINAL, colour-coded by “Phase 1 types”, “Habitat NamePLUS” and by “Habitat Broad”
- Decide the time available for map verification and updates
- Work with colleagues who know the Study Area well
- Review the maps on screen or on printed paper copies to identify any areas where habitats have been coded as NULL, Unclassified or where local experts can identify areas that have coded as the wrong habitat type

If time is available and areas are found that can be re-classified, then the following steps can be followed:

- Open ArcMap and view the “BaseMap11_Habitats” data
- Add local data, such as the “imagery” layer that will help identify sites, boundaries and habitats
- Make the “BaseMap11_Habitats” data editable
- Edit the “Habcode_B” data field to correct any misclassifications by entering the correct Habitat Code from the list in data Table Main_V% (See also BaseMap Technical Report)
- Re-run the Model “ES12 Add Ecosystem Service attribute Links” to create a new BaseMap_FINAL

In situations where considerable time is available for data verification and updating, and to ensure maximum accuracy in the resulting BaseMap the following broad stages can also be considered:

- The BaseMap_FINAL habitat can be viewed against each optional input data type, e.g. LCA, BAP, GI data.
- New categories or amended boundaries can be edited or digitised in the LCA, GI, BAP data and then the BaseMap models can all be re-run to incorporate these updates.

If only OS MasterMap data was used to create the habitat BaseMap the following categories should be viewed and checked:

- Heaths (HabCode_B: D/E) may not be reliably mapped. Typically the smaller sites will not actually contain heathland, and may instead be acid grassland or rough grassland. Larger polygons can more reliably be considered to be heath or mire habitats.

8.4 Creating the Ecosystem Service maps

The following sections detail the individual Models that map each Ecosystem Service. All these models require the BaseMap_FINAL data that was created in the previous analysis. Each Service can be run and mapped separately. However it is recommended that they are run in order and that as many different services are run as possible. To facilitate planning, the run times for several different Study Areas are listed in Annex 1.

8.4.1 Air Purification Toolbox

Tool Development: Chloe Bellamy (20%), Jonathan Winn (60%), Tom Fisher (20%)

Vehicles and built-up areas are sources of, or are associated with, high levels of air pollution which can impact human health (Zhang & Batterman 2013; Kagawa 2002; Kampa & Castanas 2008; Hoek et al. 2002; Tzivian et al. 2015). People can be exposed to various pollutants whilst commuting to work (Karanasiou et al. 2014; Kaur et al. 2005). Modelling can be used to estimate or predict atmospheric pollution and air quality levels in relation to traffic rates or road densities (Fallah Shorshani et al. 2015). The positive impact of trees and urban woodlands on air pollution levels is now widely reported, and has been known for some time (Beckett et al. 1998; Nowak et al. 2006; Freer-Smith et al. 1997). City-wide studies have illustrated the range of current benefits of urban woods to health (Tallis et al. 2011; Jim & Chen 2008). Modelling of the potential benefits of different types of greenbelt indicate that effectiveness tails off at a width of approximately 700–800 m (Khan & Abbasi 2001), however many studies indicate that vegetation closest to the source of air pollution adsorbs or traps most of the pollutants at distances of tens of metres (Al-Dabbous & Kumar 2014; Obara et al. 2011). Urban parks can be effective in reducing local air pollution levels (Cohen et al. 2014).

Several insights from the following research were used to help construct the current GIS model:

- A study in Brisbane, Australia of charged particles emitted from vehicles on busy roads found that concentration dropped with distance from roads, rapidly up to 100 m, but was detectable up to around 400 m from roads. Potentially dangerous smaller particles travelled less distance from roads, up to 25 m (Jayaratne et al. 2014).
- A modelling system in the USA used a maximum 500 m buffer distance from roads, and considered this sufficient to capture most "near road" air pollution impacts on people (Barzyk et al. 2015).
- Measurements from over 700 recordings from roads in the USA indicate that almost all air pollutants reduce back to background levels between 115 and 590 m from the road edge (Karner et al. 2010).
- A study in Raleigh, USA showed that presence of structures and vegetation can significantly impact air pollution levels from roads, up to several hundred metres from a road. Highest concentrations occurred close to the roads e.g. <50 m but this was impacted by sound barriers or vegetation presence. Generally levels dropped by 200 or 300 m from roads, depending on the pollutant and site conditions (Bowker et al. 2007).
- Several UK studies have shown that trees can intercept a range of pollutants such as metals at close distance to roads, with such interception declining with distance from road (Obara et al. 2011; Al-Dabbous & Kumar 2014).
- Leaf surface of conifers can result in higher pollutant capture levels than broadleaved species (Beckett et al. 2000).
- Pollution from roads is best modelled by logarithmic decay function (Hendrik Merbitz et al. 2012).
- PM pollution levels have been shown to correlate with building density at 50 to 400 m scales (Hendrik Merbitz et al. 2012).

This service identifies likely areas of high demand (need) for air purification and compares this to the existence of habitats such as woodland and trees near roads that may be helping to reduce pollution levels.

ES1 Air Purification Capacity

Estimates the relative ability of vegetation to trap airborne pollutants or ameliorate air pollution

The capacity of an area of greenspace to deliver air purification is determined by the types of vegetation and habitats present and the size or width of these natural spaces. Certain vegetation types, such as woodland have high capacity to deliver air purification, due to the structure and surface area of the vegetation. Small patches of greenspace or natural spaces may not hold enough vegetation to deliver the service. Similarly there is likely to be a maximum size above which larger patches do not deliver additional benefits.

- Presence of vegetation, especially trees and woodland can reduce air pollution levels, most effectively at sites close to the pollution source, but also over longer distances.
- A score is assigned to each habitat type in the link table "AirPurScore" data field. This represents the relative capacity of each habitat to ameliorate air pollution. Analysis of the BaseMap (default 10 m cell resolution) calculates the cumulative score (sum of cell values) within a search radius around each cell (default 20 and 100 m radius).
- Coniferous trees are more effective at trapping pollution, due to a combination of leaf characteristics, density and seasonality of cover.
- The effectiveness of vegetation was calculated at a *short* scale and a *local* scale and these were combined to give patch scores using cumulative scores (sum of all cell values within focal search distance).
- A *short* scale distance of 40 m (20 m search radius) was selected as several studies reported sharp drops in certain pollutants with vegetation cover.
- A *local* scale maximum effective distance of 200 m (100 m search radius) was used, informed by measured pollution decline rates in open land areas and after vegetation. Beyond this distance presence of vegetation may not contribute additional benefits to reducing pollution levels.
- The benefits of pollution reduction by trees and greenspace may continue for a distance beyond the greenspace boundary itself, where complex air movement circulation may occur. Little research was available on which to base this distance, therefore an arbitrary default value of 20 m was used. This is particularly difficult to model as the zone would ideally be directional in response to the pollution source. The model does not currently account for air movement direction. The distance can be set to 0 if required in order to limit the benefits only to greenspace areas.

The following scores have been selected to create the capacity scores:

Table 22. Air purification capacity scores

Habitat type	Phase 1 code(s)	Capacity score
Woodland, coniferous	A12, A122, etc	100
Woodland, mixed	A13, A132, etc	90
Woodland, broadleaved	A11, A112, etc	80
Scrub	A2 (all types)	50
Scattered trees (all types)	A3 (all types)	50
All other greenspace	various	10

These scores are based on opinion, as inspired by the literature review. A range of selected intermediate scores have been applied to partially classified habitats to allow the models to run in data poor situations. The full range of scores can be seen in the "Main_V%" data lookup table within the toolkit (ModelInputs/ES1Basemap/Inputs).

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click "edit", from "Model" menu click "Validate the entire model", from "Model" menu click "Save". Close the model.
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES1 Capacity model inputs

Input data	Description	Data type	Save to
BaseMap_Final	Final Base Map (detailed habitat & land use map)	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

ES1 Capacity model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m
Maximum distance of air purification benefits from areas of capacity	20 m	A buffer distance beyond patches of greenspace within which the benefits of the service may occur
Focal neighbourhood distance - short	20 m	Analysis size for calculation of cumulative sum score of air purification capacity of nearby greenspace
Focal neighbourhood distance - short	100 m	Analysis size for calculation of cumulative sum score of air purification capacity of nearby greenspace
Minimum functional patch size	500 m	Minimum size of areas below which an area is not considered to have capacity to significantly deliver the service. Note this is based on mapped capacity, not mapped greenspace areas, and therefore each "patch" includes any buffering or distance analysis.
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Capacity is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)

ES1 Capacity model outputs ModelOutputs\ES2AirPurification \Outputs.gdb

Output data	Description	Data type
AirPurification _Capacity	Estimated ability to trap or ameliorate air pollution. 1 (low) to 100 (high) scale (relative to all cells in study area)	Raster

ES1 Capacity model indicators   ModelOutputs\ES2AirPurification \Indicators.gdb

Indicator data	Description	Data type
AP_site_IndC	Site cell based air purification score, prior to focal analysis	Raster

Notes & limitations (capacity)

- This models maps one summary of the ability of vegetation to trap or ameliorate pollution. In reality many local factors will determine the actual ability within greenspace and natural spaces. Such factors, which are not addressed by this model, may include: site management, vegetation structure, season, weather conditions and additional complex interactions with the local landscape: proximity and shape of nearby habitats, site elevation and slope conditions.
- Uncertainty will be introduced into the model by the BaseMap, which is not a completely accurate representation of habitat presence and land use, but is EcoServ-GIS's best approximation based on the data available.

Modifications and actions to improve the model (capacity)

- The benefits of vegetation to air quality are simply mapped, and do not incorporate directional affects in relation to the source of the air pollution. The analysis could be altered further to incorporate flow accumulation measures, further highlighting those sites where greenspace occur in the areas between sources of air pollution and those areas where people live and walk.
- The immediate benefits of air purification are likely to be determined by the distance from patch, however this distance effect may vary by patch size, such that larger patches may have a higher capacity to give benefits over a longer distance. This could be incorporated by making capacity scores relative to local greenspace patch size.

ES2 Air Purification Demand

Illustrates the relative predicted demand (need) within the Study Area for air purification based on pollution levels, modelled by distance to busy roads, local population density, and local health scores

Demand for air purification is assumed to be highest in areas where there are likely to be high air pollution levels and there are lots of people who could benefit from the air purification. The mapping aims to capture areas of demand in those locations where people live, and the immediate areas around their houses, where they are most likely to be exposed to air pollution.

- Vehicular air pollution declines rapidly with distance from roads; this can be modelled by a logarithmic function and may be detectable at levels above background values for some distance from roads. A relatively conservative maximum air pollution zone distance of 300 m (max search distance) was selected to model this.
- Health benefits via any reduction of pollution levels are difficult to quantify. These were approximated by modelling the local scale residential populations, using 300 m to indicate likely nearby use by residents or regular walking or cycling commuting use. Health scores were measured at the same scale.
- The % surface coverage by buildings is correlated with pollution levels, and can be represented by % cover within 400 m (200 m search radius).
- Four indicator scores were produced.
    - Distance to roads (1 to 100)
    - Population density (1 to 100)
    - Man-made surface cover (1 to 100)
    - Health deprivation (1 to 100)
- Each re-scaled indicator score (roads, population, man-made cover and health) is weighted via an optional user defined weight. Setting a weight of 0 allows one or more of the indicators to be removed from the analysis.
- Values for the weighted indicators are combined to give the final demand score.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model.
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES2 Demand model inputs

Input data	Description	Data type	Save to
StudyArea	Study area boundary	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/Outputs.gdb

ES2 Demand model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010
BaseMap_FINAL	BaseMap_FINAL	Habitat mapping to locate areas of greenspace
Pop socio points	Pop socio points	Socio-economic points data to locate population density and health scores
OS Roads	OS Roads	Used to locate roads causing air pollution. (This can be replaced with alternative line data representing pollution sources)
Select roads for air pollution source	SQL: Motorways, Dual carriageways "A" roads and Primary roads	Selection query to identify road categories most likely to be causing pollution.
Maximum distance from roads	300 m	A maximum distance from roads at which air pollution may occur
Neighbourhood distance for Man Made surface	400 m	Search distance used to calculate Man Made surface cover score
Local neighbourhood population threshold	> 50	Threshold used to identify areas of very sparse population, which are removed from the analysis as population density and health statistics would be inaccurate in such areas.
Local neighbourhood population	300 m	Search distance used to calculate local population density (sum)

density		
Local neighbourhood health scores	300 m	Search distance used to calculate local health scores (mean)
Set weight for Man Made surface scores	1	Weighting used to modify indicator scores prior to creation of the final combined score
Set weight for Roads distance scores	1	Weighting used to modify indicator scores prior to creation of the final combined score
Set weight for Population scores	1	Weighting used to modify indicator scores prior to creation of the final combined score
Set weight for Health scores	1	Weighting used to modify indicator scores prior to creation of the final combined score
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Demand is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended

ES2 Demand model outputs ModelOutputs\ES2AirPurification \Outputs.gdb

Output data	Description	Data type
AirPurification_Demand	The demand for air purification across the Study Area	Raster

ES2 Demand model indicators ModelOutputs\ES2AirPurification \Indicators.gdb

Output data	Description	Data type
ManMade_IndD	% cover of manmade surfaces within local search distance	Raster
Health2_IndD	Mean health scores within local search distance	Raster
Popn2_IndD	Sum population density within local search distance	Raster
Road Dist 2_IndD	Distance score to nearest road (high score = close distance)	Raster

Notes & limitations (demand)

- The current method does not map the benefiting areas to accessible spaces.
- This method only considers air pollution from road traffic.

Modifications and actions to improve the model (demand)

- Further information on road traffic levels could be incorporated, allowing an additional weighting of those busiest roads most likely to be causing high local pollution levels. The method could be adapted to show the demand for benefits as only occurring in accessible / likely high use spaces, or domestic gardens, to highlight those areas most likely to be frequently used by people.
- Local air pollution may be impacted from industry and this could be included in future model revisions.

ES3 Air Purification Service Flow Maps

This model overlays the Demand and Capacity maps to illustrate how well they align. The combined maps are then used to illustrate those areas where it is predicted people benefit from this ecosystem service (Benefiting Areas) or where interventions could be planned (Management Zones). The areas of Demand and Capacity are split into quintiles by value (or optionally by area) and these are used to identify categories from Highest to Lowest. Additionally those areas with capacity to deliver the service, within areas of demand, and which hold existing greenspace cover are identified as green infrastructure assets (GI_assets).

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog).
- Open ArcCatalog. Right click model name click "edit", from "Model" menu click "Validate the entire model" , from "Model" menu click "Save". Close the model.
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required. Click OK to run the tool

ES3 Service Flows model inputs ModelOutputs/ES2AirPurification /Outputs.gdb

Input data	Description	Data type
AirPurification Capacity	Estimated capacity for air purification, per cell	Raster
AirPurification Demand	Estimated demand for air purification, per cell	Raster

ES3 Service Flows model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010
Set extent of service maps	StudyArea	This sets the area for which the Flows are mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.
Use quintiles by value	Yes	Capacity and Demand scores are split into five equal interval classes
Use quintiles by area	No	Capacity and Demand scores are split into five classes of equal area
BaseMap_FINAL	BaseMap_FINAL	The available habitat map used to map the habitats in the Masks below.
Mask 1	NOT: Water, Sea, urban, Infrastructure	Identifies all areas with management potential for change (greenspace areas and semi-natural habitats)
Mask 2	Urban	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring within all areas of mapped demand
Mask 3	Infrastructure	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring only within areas of highest or high

		mapped demand
Run Mask 2	Yes	Select to run the mask analysis
Run Mask 3	Yes	Select to run the mask analysis
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)
Set minimum patch size for shapefiles	200	Set threshold to omit small polygons during shapefiles conversion

Model outputs are created in the "Outputs" geodatabase for:
- ESBA and Gaps, ESBA and Gaps Prioritised, ESBA Management Zones, GI assets
- See Section 3.1 and Table 9 for definitions of these outputs.

8.4.2 Carbon Storage Toolbox

Tool Development: Chloe Bellamy (80%), Jonathan Winn (20%)

The UK government has pledged to reduce greenhouse gas emissions by 80% by 2050, compared to 1990 levels, as part of the “Low Carbon Transition Plan” (HM Government 2011; HM Government 2009). The importance of managing land as a carbon store was recognised in this plan, which encourages woodland creation and sensitive land management to protect and increase this carbon store. Levels of carbon sequestration can be difficult to estimate, therefore, many studies have estimated and mapped the amount of carbon stored instead (Chan et al. 2006; CEP 2008; CEP 2007; CCW & Environment Systems 2012; Countryside Council for Wales 2010; Z. G. Davies et al. 2011). There is now a growing body of published research using similar methods to map carbon levels.

Several insights from the following research were used to help construct the current GIS model:

- Reviews of the literature can be used to extract typical carbon storage values, per habitat type that can be used to map carbon storage levels via linkage to habitat or ecosystem maps (Cantarello et al. 2011)
- A number of habitats / ecosystem have no or few recorded measures of carbon, e.g. manmade structures or surfaces, water courses, water bodies, the sea, sand dunes, intertidal areas, rock and unclassified habitats (Cantarello et al. 2011; Milne & Brown 1997).
- A national scale study in Wales used available information and expert opinion to create a 0 to 3 scoring system to rank habitats by importance for carbon storage in soils, vegetation and a combined assessment (Countryside Council for Wales 2010). Both vegetation mapping and soils mapping were used to create the combined maps.
- Research at the city scale has shown that urban areas should not be discounted and that urban habitats and soils can store significant levels of carbon, therefore they should be considered in analysis (Davies et al. 2013; Edmondson et al. 2014).
- Research has examined the social value of carbon storage and sequestration of GB woodlands, illustrating the complexity required when assessing areas of existing habitat together with scenarios of land use change (Brainard et al. 2009).
- Most mapping studies have not graded levels of carbon storage demand, assuming high or constant demand across the study area (Bagstad et al. 2014), or only mapping capacity (Countryside Council for Wales 2010; Hölzinger et al. 2013; Cantarello et al. 2011; Newton et al. 2012).

ES1 Carbon Capacity

Estimates the relative amount of carbon stored in vegetation and top 30 cm of soil within each raster cell.

The amount of carbon stored within the vegetation and top 30 cm of soil of each raster cell is mapped according to the land use and habitat type present). All man-made structures or surfaces, water courses, water bodies, the sea, sand dunes, intertidal areas, rock and unclassified habitats are considered to store zero carbon (Milne & Brown 1997; Cantarello et al. 2011).

- Carbon storage values are based on a UK-based systematic literature review which compared measurements of carbon storage within different land use classes recorded in the scientific literature (Cantarello et al. 2011). Cantarello *et al.* grouped land use types into 11 classes and calculated the mean amount of carbon storage (t ha^{-1}) for each of these using the measurements reported by the studies reviewed.
- Carbon storage levels can be linked to broad habitat types / ecosystems and used to map carbon storage levels, although mean values are used, storage levels vary greatly within each type.
- The carbon storage capacity of an ecosystem results from both storage in vegetation and within soils.
- The availability of fine scale resolution habitat mapping via OS MasterMap and local scale greenspace data allows habitats within urban areas to be included in carbon calculations, which are often lost in regional scale analysis, or by using data sources that do not account for urban vegetation cover.

To build the capacity model the carbon storage values from (Cantarello et al. 2011) were used to populate the values in the data link / lookup tables. Where applicable the values were approximated to other broader habitat types, or to intermediate habitat types based on logical rules, or a best-fit strategy. The full range of values can be seen in the data link tables within the toolkit.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model.
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES1 Capacity model inputs

Input data	Description	Data type	Save to
BaseMap_Final	Final Base Map (detailed habitat & land use map)	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

ES1 Capacity model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m
Type 100 (10 m resolution) or 4 (50 m resolution)	100	If the analysis is being run at 10 m (SA010 was selected), keep the value of 100. Otherwise, if the analysis is being run at a 50 m resolution (SA050 was selected), change 100 to 4.
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Capacity is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended

ES1 Capacity model outputs ModelOutputs\ES2Carbon_storage _regulation \Outputs.gdb

Output data	Description	Data type
Carbon_Capacity	Estimated amount of carbon stored per raster cell in vegetation and top 30 cm of soil (relative to all cells in study area)	Raster

ES1 Capacity model indicators
ModelOutputs\ES2Carbon_storage_regulation \Indicators.gdb

Indicator data	Description	Data type
Ton_C_Cell	Estimated tonnes of carbon stored per raster cell in vegetation and top 30 cm of soil	Raster

Notes & limitations (capacity)

- This is only an estimate of carbon storage capacity. In reality carbon storage by each habitat will vary locally according to factors that this model does not take into account.
- The link between land use / habitat and carbon values is simplistic and assumes a particular habitat state. It can be considered a potential maximum capacity value. Local

factors such as habitat age (e.g. time since planting of woodlands) or management (e.g. draining on moorland) will greatly impact and reduce the real world carbon storage levels. Topography will also influence both vegetation and soils carbon content.

- The carbon storage values assume a particular contribution from "typical" soils likely to be found under each habitat type. Several situations occur where these measures will be inaccurate. For example improved grassland present over deep peat soils will underestimate the carbon storage. Similarly different plantation woodland values over deep peatland soils, e.g. planted on blanket bog will give inaccurate carbon storage values.
- Uncertainty will be introduced into the model by the BaseMap, which is not a completely accurate representation of habitat presence and land use, but is EcoServ-GIS's best approximation based on the data available.
- Many of the factors that would aid more accurate mapping of the carbon values are simply not readily available as spatial data (e.g. management type, soils data, habitat age).
- It is debateable the improvements that would be gained by attempting to include further datasets. For example soils data is often coarsely mapped and the boundary for example of deep peat soils may in many cases be better represented by various BAP habitat mapping than by using soils maps (with the exception of the woodland habitats noted above).

Modifications and actions to improve the model (capacity)

- Further literature sources on carbon content could be included to allow measures to be matched against a finder resolution of habitat categories.
- Values for a further range of modified habitat types could also be included, such as woodland plantation over various habitats such as blanket bog.

ES2 Carbon Demand

Illustrates the (homogeneous) demand for carbon storage across the study area

A map showing equal, high demand for carbon storage across the study area is produced.

- The effects of carbon release on the climate and the resulting mal-effects on the environment and people occur over spatio-temporal scales too large to map at a county scale.

Instructions
- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model” , from “Model” menu click “Save". Close the model.
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES2 Demand model inputs

Input data	Description	Data type	Save to
StudyArea	Study area boundary	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb

ES2 Demand model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Demand is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended

ES2 Demand model outputs ModelOutputs\ES2Carbon_storage_regulation \Outputs.gdb

Output data	Description	Data type
Carbon_Demand	The (homogeneous) demand for carbon storage across the Study Area	Raster

Notes & limitations (demand)
- The method is not able to identify areas of Low vs. High Demand, all areas are therefore considered to be Highest Demand for Carbon storage.

ES3 Carbon Service Flow Maps

This model overlays the Demand and Capacity maps to illustrate how well they align. The combined maps are then used to illustrate those areas where it is predicted people benefit from this ecosystem service (Benefiting Areas) or where interventions could be planned (Management Zones). The areas of Demand and Capacity are split into quintiles by value (or optionally by area) and these are used to identify categories from Highest to Lowest. Additionally those areas with capacity to deliver the service, within areas of demand, and which hold existing greenspace cover are identified as green infrastructure assets (GI_assets).

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog).
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model.
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required. Click OK to run the tool

ES3 Service Flows model inputs
ModelOutputs/ES2Carbon_storage _regulation /Outputs.gdb

Input data	Description	Data type
Carbon_Capacity	Estimated amount of carbon stored per raster cell in vegetation and top 30 cm of	Raster
Carbon_Demand	The (homogeneous) demand for carbon storage	Raster

ES3 Service Flow model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010
Set extent of service maps	StudyArea	This sets the area for which the Flows are mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.
Use quintiles by value	Yes	Capacity and Demand scores are split into five equal interval classes
Use quintiles by area	No	Capacity and Demand scores are split into five classes of equal area
BaseMap_FINAL	BaseMap_FINAL	The available habitat map used to map the habitats in the Masks below.
Mask 1	NOT: Water, Sea, urban, Infrastructure	Identifies all areas with management potential for change (greenspace areas and semi-natural habitats)
Mask 2	Urban	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring within all areas of mapped demand

Mask 3	Infrastructure	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring only within areas of highest or high mapped demand
Run Mask 2	Yes	Select to run the mask analysis
Run Mask 3	No	Select to run the mask analysis
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)
Set minimum patch size for shapefiles	200	Set threshold to omit small polygons during shapefiles conversion

Model outputs are created in the "Outputs" geodatabase for:

- ESBA and Gaps, ESBA and Gaps Prioritised, ESBA Management Zones, GI assets
- See Section 3.1 and Table 9 for definitions of these outputs.

8.4.3 Local Climate Toolbox

Tool Development: Chloe Bellamy (40%), Jonathan Winn (60%)

Local climate regulation is a recognised ecosystem service in urban areas (Bolund & Hunhammar 1999). Land use has a large impact on local climate because surface types differ in their rates of net radiation absorption and their influence on the amount of water that is absorbed or enters into surface runoff or evapotranspiration (Kalnay & Cai 2003; Foley et al. 2005; Gill et al. 2007). A large proportion of people in the UK reside in urban areas (England: 81 %, Wales: 66 %, Scotland: 81%, based on census area urban / rural classifications) (Pateman 2010), and urban areas continue to expand at a faster rate than other types of land use (Antrop 2004). As opposed to the USA, where cities have tended to grow "outward", creating vast regions of urban sprawl, in the UK urbanisation has tended to involve increasing the density of buildings and people per unit area, often resulting in the loss of urban greenspace (Dallimer et al. 2011). These built-up areas experience different local climates compared to rural areas because of the relative amount of impervious, man-made surfaces compared to unsealed areas with vegetation (Gill et al. 2007). Temperatures within these urban areas are often one or two degrees warmer than surrounding countryside. Global climate change is likely to amplify these differences (Gill et al. 2007; Diana E. Bowler et al. 2010).

The positive impact of greening, urban vegetation or parks has been investigated in several cities around the world (Edward et al. 2011; Dugord et al. 2012; Doick et al. 2014; Chang et al. 2007; Gill et al. 2013; Shashua-bar & Hoffman 2000; Skelhorn et al. 2014; B. Zhang et al. 2014; Kong, Yin, Wang, et al. 2014). For example studies in the subtropics have also shown that parks can lead to cooler conditions in cities, and have suggested an interesting correlation to park size, noting that smaller parks may not consistently hold the same benefits as larger parks , e.g. sites less than 2 ha (Chang et al. 2007). Recent work has confirmed positive impacts of urban greenspace in a UK context (Hall et al. 2012; Armson et al. 2012; Doick et al. 2014).

The following literature insights informed model construction:

Capacity

- Research of the impact of climate change on typical English domestic buildings indicated that shading is the most appropriate strategy to help reduce future overheating via climate change (Gupta & Gregg 2012).
- Modelling work indicates that increased tree planting could partly help maintain lower temperatures as climate change occurs in a UK (Hall et al. 2012) and an American city (House-Peters & Chang 2011).
- Natural and semi-natural habitats can reduce urban temperature maxima over small scales (Shashua-bar & Hoffman 2000) and several studies show the positive impacts relate to both forest patch size and cumulative local area e.g. (Kong, Yin, James, et al. 2014) .
- The effectiveness of natural cooling by greenspace is improved by increased tree cover, and this is likely to be strongest at small scales, e.g. 200 to 400 m (H. Merbitz et al. 2012).
- Building and man-made surface densities are positively correlated with temperature maxima (H. Merbitz et al. 2012; Tratalos et al. 2007).
- Merbitz et al (2012) found that surface sealing was most strongly related to temperatures at the 200 m, rather than 400 m buffer scale.
- Tratalos *et al.* (2007) reported a positive relationship between urban density and increasing temperatures in UK cities, with roughly a 4 degree Celsius rise difference between areas with <10 addresses per hectare, compared to areas with about 20 addresses per hectare.

- A study in Manchester, UK showed that tree shading had an impact on air temperatures during summer days and that parks were cooler than nearby urban areas (Armson et al. 2012).
- Urban grassland and tree cover can help ameliorate the urban heat island effect and both together are preferable to either in isolation (Armson et al. 2012).
- A study in a London park has shown that urban heat island night time temperature can be reduced both within and adjacent to parks. The cooling effects can extend up to 100 m from the park (Doick et al. 2014).
- In Berlin, impacts were related to greenspace size and reduced temperatures to distances over 50 m from site boundaries (Dugord et al. 2012).

Demand

- Higher temperatures can cause thermal discomfort and heat waves pose a risk to human health (Forest Research 2008; Kleerekoper et al. 2011).
- Areas with high population densities are more at risk and older people are more vulnerable to health problems associated with heat waves (Department of Health 2010; Tomlinson et al. 2011).
- Research in Berlin used population density and age characteristics (elderly >= 65, young <= 6) to illustrate areas at risk of extreme heat events (Dugord et al. 2012). Degree of soil sealing was a good predictor of temperatures (Dugord et al. 2012).

ES1 Local Climate Capacity

Estimates the capacity of an ecosystem to cool the local environment and cause a reduction in urban heat maxima.

This model calculates the proportion of the landscape that is covered by greenspace within a 200 m radius window around each focal cell. Buffer distances, based on patch size thresholds indicate how far the capacity for the service extends beyond the site boundary.

- The proportion of the local landscape that is covered by woodland and trees can be used to indicate capacity for affecting the local climate (using a focal statistics window, default 200 m).
- The benefits of woodland and trees occur in the areas beneath the tree canopy and in nearby adjacent areas.
- There are likely to be density dependence and threshold effects of woodland patch size on the local climate regulation benefits.
- Wider benefit buffers are modelled around larger capacity sites.

In the absence of data to separately indicate the beneficial impact of different woodland types, all woodland scattered trees and scrub are considered to deliver the service. A focal sum calculation of all nearby cells within a set neighbourhood distance was used to capture the value of both patches and scattered smaller sites of woodland and trees. To reflect the wider transfer of benefits from larger sites the following buffer distances were applied, within which the focal sum scores are masked. Prior to the following analysis all woodland and trees sites are buffered by 4 m, then dissolved, in order to capture the true occurrence of contiguous sites that would otherwise be divided by narrow paths, tracks or streams.

Table 23. Buffer distances applied to greenspace sites - local climate regulation capacity

Patch size (m^2)	Patch size (ha)	Buffer distance (m)
<= 20000	2	20
> 20,000 <= 50,000	2 to 5	40
> 50,000 <=100,000	5 to 10	80
> 100,000	> 10	100

It is acknowledged that these buffer distances, although inspired by the available literature, are arbitrary. Ideally the model would also include analysis of the broader cover of greenspace in addition to woodland and trees, but this is not currently implemented.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click "edit", from "Model" menu click "Validate the entire model", from "Model" menu click "Save". Close the model.
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES1 Capacity model inputs

Input data	Description	Data type	Save to
BaseMap_Final	Final Base Map (detailed habitat & land use map)	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

ES1 Capacity model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution at which the analysis will be carried out on. Chose SA010 for 10 m
Habitats that cool the local climate	HabClass = "Woodland and Scrub"	Habitats used to calculate local capacity for climate cooling
Neighbourhood search distance	200	Search distance used to calculate the capacity score
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Capacity is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the Study Area. The default SA_buffer is recommended

ES1 Capacity model outputs ModelOutputs\ES2Local_climate_regulation\Outputs.gdb

Output data	Description	Data type
Local_Climate _Capacity	The relative level of cooling received from ecosystems with capacity at each cell	Raster

ES1 Capacity model indicators ModelOutputs\ES2Local_climate_regulation \Indicators.gdb

Output data	Description	Data type
Greencover_IndC	The amount of land covered by greenspace within 200 m	Raster

Notes & limitations (capacity)

- This service benefits the local area around each functioning ecosystem. Therefore, “Local_Climate_Capacity” illustrates this capacity for cooling to be delivered at each cell, even if the ecosystem providing the service is not present at that particular cell.
- More evidence is needed to establish the degree to which greenspace cools the surrounding area and how this is affected by habitat composition, structure and configuration at different scales.
- Landform, topography and building form all impact temperature maxima, but are not measured by the model.
- The influence of water on cooling capacity is complex. The impact is dependent on waterbody type (standing versus flowing) and the timescale over which cooling or urban heat islands occur. Current research suggests the benefits of vegetation are higher, that standing waterbodies can retain heat and negatively impact night-time temperatures and therefore water is not currently included in the model.
- Uncertainty will be introduced into the model by the BaseMap, which is not a completely accurate representation of habitat presence and land use, but is EcoServ-GIS’s best approximation based on the data available.

Modifications and actions to improve the model (capacity)

- The model would benefit from further literature justification of the focal search distances over which the natural environment has cooling effects.
- The model would benefit from further literature justification of the relevant benefits particular habitat types on the level of potential cooling achieved. However such attempts at "improvements" to this model must acknowledge that for such a strategic tool as this that full information on habitat structure, management or composition will never be fully available at a fine resolution and there is a limited scope to fully include fine scale habitat information on potential cooling.

ES2 Local Climate Demand

Estimates societal demand and regulatory need across space for ecosystems that can reduce temperature maxima

- Urban area boundaries are used to locate the areas where the service may occur.
- Census statistics are used to map population occurrence, and the relative proportion of the population in old or very young population bands.

Regulatory need: Urban areas are used to locate the areas where the urban heat island effect may occur. Users can select a size threshold, the default is all urban areas > 1,000 ha. Within these areas the proportion of land covered by man-made surfaces is calculated and re-scaled from high to low, at the 200 m scale.

Societal need: Population densities and the proportion of residents ≤10 or ≥65 years of age are calculated at the 200 m scale within the urban area buffers (using 2011 Census data):

Total demand: The standardised scores for regulatory and societal demand are summed with an equal weighting to illustrate total demand for this service. Users can alter the weight given to each factor.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model.
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES2 Demand model inputs

Input data	Description	Data type	Save to
BaseMap_Final	Final Base Map (detailed habitat & land use map)	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs /ES1BaseMap /Outputs.gdb
Pop_socioec _points	IMD and population data mapped to domestic buildings	Vector (point)	No action needed. Previous model output saved to: ModelOutputs /ES1BaseMap/Outputs.gdb

ES2 Demand model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution at which the analysis will be carried out. Choose SA010 for 10 m
Risk group (proportion)	Risk group	Data field within "Pop_socioec_points data. The proportion of people within an LSOA falling within the age groups deemed most at risk to the health problems related to high temperatures (≥65 and ≤10 years of age)
Local neighbourhood for manmade surface	200 m	Search distance (radius) used to calculate score (sum)
Local population neighbourhood	200 m	Search distance used to calculate score (sum)
Local age risk neighbourhood	200 m	Search distance used to calculate score (mean)
Urban locations	Urban_GB	Layer representing urban land cover areas
Minimum urban area (ha)	1,000	Smallest size of urban area likely to experience urban heat island impacts (higher values will target demand only to larger urban areas)
Domestic building layer	Domestic buildings (BaseMap)	Location of domestic buildings, used to locate areas of need
Weight for population age risk score	1	Optional weight used to alter the score, prior to creating total demand score
Weight for manmade	1	Optional weight used to alter the score, prior to creating total demand score

surfaces score		
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Demand is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended

ES2 Demand model outputs ModelOutputs/ES2Local_climate_regulation/Outputs.gdb

Output data	Description	Data type
Local_Climate_ Demand	Overall regulatory need and societal demand for local climate regulation	Raster

ES2 Demand model indicators
ModelOutputs/ES2Local_climate_regulation/Indicators.gdb

Output data	Description	Data type
LocClimSocDemand _IndD	Societal demand Indicator group: The density of people within 200 m plus the proportion of these people that fall within age groups with the highest susceptibility to heat-related health problems	Raster
LocClimRegNeed _IndD	Regulatory need Indicator group: The relative risk of high temperature maxima based on manmade surface density within 200 m in urban areas	Raster

Notes & Limitations (demand)

- Population and age risk data are upscaled from Lower Super Output Areas to those buildings predicted to be domestic housing.
- Urban areas of different sizes are considered to require this service equally. In reality demand may be higher in larger cities.
- The use of proportion of man-made surfaces as a proxy for high temperature risk is simplistic.
- The indicators are currently combined with equal weighting.
- The model assesses population characteristics, but does not account for building height. Heat wave impacts are likely to be different in bungalows, houses or blocks of flats.

Modifications and actions to improve the model (demand)

- Future work could research the effects of man-made surface cover, city size or population density and may investigate incorporating thresholds under which temperature regulation are considered to be relevant. These may vary with latitude, the service may be considered more relevant in the southern UK.
- Further research on the relative impact of different methods to combine the separate demand indicators and the weight given to each could be examined.
- Building height should be incorporated in the analysis (relative risk in bungalows, houses or blocks of flats).

ES3 Local Climate Service Flow Maps

This model overlays the Demand and Capacity maps to illustrate how well they align. The combined maps are then used to illustrate those areas where it is predicted people benefit from this ecosystem service (Benefiting Areas) or where interventions could be planned (Management Zones). The areas of Demand and Capacity are split into quintiles by value (or optionally by area) and these are used to identify categories from Highest to Lowest. Additionally those areas with capacity to deliver the service, within areas of demand, and which hold existing greenspace cover are identified as green infrastructure assets (GI_assets).

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog).
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model.
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path).
- Change any other parameters, if required. Click OK to run the tool.

ES3 Service Flow Maps model inputs
ModelOutputs/ES2Local_climate_ regulation /Outputs.gdb

Input data	Description	Data type
Local_Climate_Capacity	Local climate regulation capacity	Raster
Local_Climate_Demand	Total regulatory and societal need for local climate regulation	Raster

ES3 Service Flow Maps model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010
Set extent of service maps	StudyArea	This sets the area for which the Flows are mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.
Use quintiles by value	Yes	Capacity and Demand scores are split into five equal interval classes
Use quintiles by area	No	Capacity and Demand scores are split into five classes of equal area
BaseMap_FINAL	BaseMap_FINAL	The available habitat map used to map the habitats in the Masks below.
Mask 1	NOT: Water, Sea, urban, Infrastructure	Identifies all areas with management potential for change (greenspace areas and semi-natural habitats)
Mask 2	Urban	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring within all areas of mapped demand
Mask 3	Infrastructure	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring only within areas of highest or high mapped demand
Run Mask 2	Yes	Select to run the mask analysis
Run Mask 3	Yes	Select to run the mask analysis
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)
Set minimum patch size for shapefiles	200	Set threshold to omit small polygons during shapefiles conversion

Model outputs are created in the "Outputs" geodatabase for:

- ESBA and Gaps, ESBA and Gaps Prioritised, ESBA Management Zones, GI assets
- See Section 3.1 and Table 9 for definitions of these outputs.

Notes & limitations (flows)

- Due to the methods used there is unlikely to be areas where High Capacity and High Demand overlap, this is due to the inclusion of manmade cover as a demand indicator, and the greenspace cover as a capacity indicator, with these two being inversely correlated.
- Typically there will not be any mapped Gaps as most areas have some level of greenspace present within a 200 m radius.

8.4.4 Noise Regulation Toolbox

Tool Development: Chloe Bellamy (60%), Jonathan Winn (40%)

Noise regulation is a recognised ecosystem service of vegetation and greenspace (Bolund & Hunhammar 1999; Greenspace Scotland 2008). Noise pollution is a recognised public health issue and may be more important to vulnerable sub groups of the population (Berglund et al. 1999; HPA 2010). Significant proportions of the population may currently be impacted by noise pollution in European countries (Berglund & Lindvall 1995). In the UK about 10% of the population live in areas of excessive daytime sound levels, although up to 30% of the population express dissatisfaction in surveys of their local noise environment (HPA 2010). Noise pollution can lead to various health impacts and has been implicated in increased stress levels and is thought to be an influencing factor in a range of mental health problems (Tzivian et al. 2015; HPA 2010). These impacts are greatest closer to the source of noise. Examples include a recent study that showed negative impact of noise on blood pressure in children (Liu et al. 2014). Reviews indicate that noise may impact cardiovascular heart disease and raise blood pressure (HPA 2010). In addition to impacting health, noise can have economic impacts such as being associated with lower house prices (Łowicki & Piotrowska 2015).

Noise can be produced from various sources, such as road traffic, air traffic, construction work, building noise and domestic activities, with varying negative impacts on people (Berglund & Lindvall 1995). Several studies have examined and mapped noise levels in urban areas (Farcaş & Sivertun 2005; Fiedler & Zannin 2015; Foraster et al. 2011; Gan et al. 2012; Lin-hua et al. 2013). The importance of road noise is well known and various mitigation methods and strategies have been established (ARRB Group 2005; Cook & Haverbeke 1972). Advice suggests that government and planners adopt noise reduction strategies (Berglund et al. 1999), and mapping studies can be used to identify areas that may require noise action plans to deal with the resulting noise pollution levels (Ruiz-Padillo et al. 2014). Many modelling methods require the use of detailed data such as building height (Gulliver et al. 2015). Detailed guidance is available, for example estimating noise pollution impacts from roads (Department of Transport 1998).

Greenspace provides varying levels of noise mitigation. An area's effectiveness as a noise barrier is related to the structure, size and density of the vegetation (Fang & Ling 2005). Trees and shrubs are best at scattering noise, with coniferous trees functioning all year round. Noise levels can be reduced by 5 – 10 decibels for every 30 m of woodland (Cook & Haverbeke 1972). It is also known that absorbent vegetation cover on the ground can also impact on noise levels, e.g. where grass cover occurs versus sealed surfaces (Department of Transport 1998).

Vegetation can be used in the design of development or roads to help reduce road noise levels (Van Renterghem et al. 2015). Studies have shown the positive and additive impact of tree canopy, tree stems and shrubs on road noise levels in relatively narrow 15 m wide tree belts (Van Renterghem et al. 2012). Noise reduction ability is relative to tree belt width (Van Renterghem 2014), although even narrow hedges can cause reduction in noise levels (Van Renterghem et al. 2014). Vegetated walls, lines of trees and green roofs may also have positive impacts on noise reduction (Van Renterghem et al. 2015).

The creation and maintenance of greenspace features or buffers can help to screen undesirable noise levels along roads (Bentrup 2008). Guidance in the US recommends that for moderate road speeds (<40 mph) a barrier of 6 to 15 m width is appropriate, for high speed roads a barrier of 20 to 30 m is advised (Bentrup 2008). Buffers with evergreen species and with a mix of trees and shrubs are advised (Bentrup 2008). There will be a maximum distance beyond which additional cover of buffers, trees or woodland is no longer effective or necessary, this will depend on the level of noise pollution present but will be in the range of 300 to 500 m (Bentrup 2008).

Several insights from the following research were used to construct the GIS model:

Capacity

- Design guidance indicates that dense vegetation can reduce noise levels by 1dB(A) per 10 m depth, Nelson (1987) in (ARRB Group 2005).
- Advice in Australia summarises that noise reduction projects should aim for a minimum of >3 dB(A) and that levels of reduction of 3 to 5 dB(A) are attainable and likely to be noticeable by local communities (ARRB Group 2005).
- Studies have shown reduced noise levels in urban parks compared to nearby streets (Cohen et al. 2014)
- Greenspace provides varying level of noise mitigation. An area's effectiveness as a noise barrier is related to the structure, size and density of the vegetation (Van Renterghem et al. 2012; Fang & Ling 2005). Trees and shrubs are best at scattering noise, with coniferous trees functioning all year round.
- Measurement of tree belt buffer strips in Taiwan indicated that both tree height and belt width positively impacted on noise reduction ability (Fang & Ling 2005).

Demand

- The presence of urban noise pollution can be related to complex patterns of land use and urban form, rather than simple distance measures (Ariza-Villaverde et al. 2014; Abbaspour et al. 2015).
- Noise can be predicted and modelled from road flows, or via estimates from road type, road density, distance measures of levels of urbanisation (European Commission Working Group Assessment of Exposure to Noise (WG-AEN) 2006; Fiedler & Zannin 2015; Foraster et al. 2011; Gozalo et al. 2013).
- Combined noise impact is important to consider, e.g. from multiple sources (Berglund et al. 1999).
- A study in Greece examined and modelled noise and found that transport networks are a primary source of noise pollution. Votsi et al. (2012) assumed that areas within 800 m of a high-quality carriageway (motorway), 600 m of a dual carriageway, 550 m of other regional roads, 650 m from railways and 1,500 m from major airports and 900 m around other airports represented noise hazard areas (Votsi et al. 2012).
- Vulnerable population sub groups, badly affected by noise pollution may include: those in ill health, the elderly and very young and at spatial locations such as schools and hospitals (Berglund et al. 1999).
- Noise mapping has been conducted for city areas and allows the assessment of the proportions of the population affected by noise pollution levels (Farcaş & Sivertun 2005; Gulliver et al. 2015).
- High percentage cover of sealed surfaces are likely to exacerbate noise pollution (Department of Transport 1998).

Despite insights from the literature in linking noise levels to health, caution must be applied to simplistic measures and assessment as studies indicate that there may be complex correlations between detrimental noise measures and air pollution impacts on health (Allen et al. 2009; Foraster et al. 2011; Gan et al. 2012; Kim et al. 2012; Morelli et al. 2015; Sørensen et al. 2014; Tzivian et al. 2015; van Kempen et al. 2012; Vlachokostas et al. 2012; Weber et al. 2014). Additionally in reality many other sources of noise may contribute to perceived noise pollution levels, such as from commercial spaces or industry, including features such as wind turbines (Baker 2015). Finally, the exact detrimental health impacts of noise on particular diseases or conditions often requires further research to clarify short-term versus long-term impacts (HPA 2010).

This service occurs in areas where vegetation or semi-natural habitat helps to block noise. This may include "purpose built" woodland plantations along roads, but also the semi-natural woodlands present within river corridors or parks or gardens within towns and cities. The service flows from areas of structurally rich vegetation such as woodland or scrub to areas where people may suffer from the negative impacts of noise, within their house or workplaces. The flow of the service is assumed to be strongly linear directional between areas where the noise source occurs to areas where people occur.

ES1 Noise Regulation Capacity

Maps the capacity for the absorption and reflection of anthropogenic noise

- Vegetation cover can help to reduce noise levels.
- Complex vegetation cover such as woodland, trees and scrub is most effective, although general cover of vegetation compared to artificial sealed surfaces are still effective.
- Wider belts of vegetation are more effective than narrow belts.
- There is both a maximum width of vegetation and distance from a noise source, beyond which vegetation has no beneficial impact.

Land cover is scored according to the ability to act as a barrier to anthropogenic noise. All man-made structures and bodies of water are assigned a score of 0. The remaining results are classified according to expert judgement. Woodland is assigned the highest score, then scattered trees and scrub, and finally grassland. The following scores are applied (see also the data link table, within the toolkit).

Table 24. Noise absorption scores by habitat type

Habitat	Noise regulation value
Woodland, Coniferous	100
Woodland, unknown	90
Woodland, mixed	90
Woodland, broadleaved	80
Scrub (all)	40
Scattered trees (all)	40
All other greenspace	10
Hedges and Walls	5
All manmade	0

Note. Scores have been assigned via author judgement

In order to allocate higher scores to wider bands of vegetation a two-scale focal analysis is applied. A focal statistics analysis calculates a SUM score for the *short distance* neighbourhood (default 30 m). Another focal statistics analysis calculates a SUM score for the *local distance* neighbourhood (default 100 m). The scores are then summed to give a higher value to wider belts.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES1 Capacity model inputs

Input data	Description	Data type	Save to
BaseMap_Final	Final Base Map (detailed habitat & land use map)	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

ES1 Capacity model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the extent & resolution at which the analysis will be carried out. Choose SA010 for 10 m
Noise regulation value field	Noise	Field in the BaseMap holding the scores representing the capacity of each habitat type
Noise regulation neighbourhood influence - short	30 m	Search distance (radius) used to calculate short distance cumulative noise capacity (sum)
Noise regulation neighbourhood influence - local	100 m	Search distance (radius) used to calculate local distance cumulative noise capacity (sum)
Minimum functional patch size	500 m^2	Minimum size of areas below which an area is not considered to have capacity to significantly deliver the service. Note this is based on mapped capacity, not mapped greenspace areas, and therefore each "patch" includes any buffering or distance analysis.
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Capacity is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended

ES1 Capacity model outputs. ModelOutputs\ES2Noise_regulation\Outputs.gdb

Output data	Description	Data type
NoiseRegulation _Capacity	The relative level of noise mitigation received at each cell in the study area from ecosystems with the capacity to absorb and reflect noise	Raster

NB. No indicator maps are produced as separate outputs because only one indicator is used to create final capacity score.

Notes & limitations (capacity)

- Please note that this ecosystem service provides benefits to the local area around each functioning ecosystem. Therefore, “NoiseRegulation_Capacity” illustrates the potential reduction in noise delivered at each cell, even if the ecosystem providing the service is not present at that particular cell.
- Evidence on the absorptive and reflective properties of different habitat types in relation to anthropogenic noise varies greatly between studies (Mcpherson 1988; Land Use Consultants 2004 & Bentrup 2008). The noise absorption scores used are therefore not based on the results of a field study, but have been selected using authors judgement.
- Uncertainty will be introduced into the model by the BaseMap, which is not a completely accurate representation of habitat presence and land use, but is EcoServ-GIS’s best available representation based on the data available.

Modifications and actions to improve the model (capacity)

- Future work to identify literature that allows the relative scores attributed to each vegetation to be further justified or to be applied to finer resolution or more specific categories habitats would be useful.

ES2 Noise Regulation Demand

Estimates societal and regulatory need for ecosystems that can absorb and reflect anthropogenic noise

Analysis steps & rationale

- Noise levels can be estimated by modelling the location of noise from multiple sources.
- Proportion of sealed surface (man-made urban cover) can be correlated with noise levels.
- The population impacted by noise pollution can be modelled and measured by relating the location to modelled noise maps, and by segmenting the population by health or age categories.

These models first identify parts of the study area that are most likely to be affected by anthropogenic noise (areas with a regulatory need). These areas are then graded according to the likely level of noise experienced, the number of residents, and the level of health deprivation of the residents living within these noise buffers.

Regulatory need: The area within which noise pollution may be experienced is mapped. The inverse logarithm is calculated for the distance to roads, railways, and airports. Maximum search distances were used based on the expected range of the noise produced from these sources (airports = 1500 m, motorways = 800 m, railways = 650 m, major roads = 600 m, minor roads = 550 m). The individual distance scores are overlaid and summed because different noise sources are assumed to have additive effects on noise pollution levels at any one point. Distance bands are derived from a study in Greece by Votsi *et al.* (2012).

Societal demand: To illustrate the areas which would most benefit from the presence of natural features that absorb and reflect anthropogenic noise, the number of residents and their mean health scores are estimated within a local scale (default 300 m) circular window for each raster cell, using the average number of people per household reported in the 2011 census and the 2001 IMD health domain scores.

Total demand: Within those areas affected by anthropogenic noise the three separate scores for predicted noise, population density and health scores are summed. The separate scores can optionally be weighted during this stage. A default weighting of 1 is used. The combined score represents total demand for this service.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES2 Demand model inputs

Input data	Description	Data type	Save to
Pop_socioec_points	Index of Multiple Deprivation scores and population data mapped to domestic buildings	Vector (point)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb
OSAirports	Airports	Vector (point)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb
OSRailways	Railways	Vector (line)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb
OSRoads	Roads	Vector (line)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

ES2 Demand model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m.
Maximum distance to Motorways	800 m	Maximum value (m) used to calculate distance to nearest noise source
Maximum distance to A roads	600 m	Maximum value (m) used to calculate distance to nearest noise source
Maximum distance to B roads	550 m	Maximum value (m) used to calculate distance to nearest noise source
Maximum distance to Airports	1500 m	Maximum value (m) used to calculate distance to nearest noise source
Maximum distance to Railways	650 m	Maximum value (m) used to calculate distance to nearest noise source
Local health score search neighbourhood	300 m	Search distance (radius) used to calculate health scores (mean)
Local population score neighbourhood	300 m	Search distance (radius) used to calculate population density (sum)
Local population threshold	50	Threshold used to remove areas of sparse population from the analysis (where population density and

		health scores would be unreliable).
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Demand is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the Study Area. The default SA_buffer is recommended

ES2 Demand model outputs ModelOutputs/ ES2Noise_regulation/Ouputs.gdb

Output data	Description	Data type
NoiseRegulation _Demand	Demand for noise regulation in areas affected by anthropogenic noise	Raster

ES2 Demand model indicators ModelOutputs/ES2Noise_regulation/Indicators.gdb

Output data	Description	Data type
NoiseSoc Demand_IndD	Societal demand Indicator group: The density of people within 300 m plus the proportion mean health scores. (Only mapped for areas with Regulatory Need).	Raster
Popsum_IndD	Societal demand Indicator group: The density of people within 300 m (Only mapped for areas with Regulatory Need).	Raster
HealthScore _IndD	Societal demand Indicator group: The mean deprivation health score of people within 300 m (Only mapped for areas with Regulatory Need).	Raster
NoiseRegNee d_IndD	Regulatory need Indicator group: The predicted noise levels from several categories of noise generating land uses (e.g. roads, rail).	Raster

Notes & limitations (demand)

- This is a simple model of noise regulation. Other factors will have effects on the level of noise that is emitted and absorbed, which EcoServ-GIS does not incorporate (e.g., traffic volume, building form, landform, and topography).
- Uncertainty will be introduced into the model by the BaseMap, which is not a completely accurate representation of habitat presence and land use, but is EcoServ-GIS's best approximation of habitat cover and land use based on the data available.
- Although the presence of separately mapped potential noise sources uses a cumulative calculation of noise, within each category only the nearest noise feature is scored (e.g., the nearest A road). Therefore this will underestimate noise levels in situations where an area is close to several potential noise sources of the same category type.
- Topography is not included in the model and this could potentially significantly alter noise levels, e.g. where noise is blocked by steep topography / banks.
- The noise amelioration caused by the presence of existing vegetation and buildings is not calculated. This may for example cause the potential noise threat to be overestimated in areas of existing high woodland cover.

Modifications and actions to improve the model (demand)

- Future work to justify the relative weighting of population density, health scores and predicted noise levels on the overall demand for the service.
- Include analysis to reduce predicted noise levels due to existing vegetation cover and topography.
- A range of noise mapping across the UK is available and could be used to compare, calibrate or replace the demand layer in the EcoServ-GIS analysis. Where local expertise is available the distance bands could be set to reflect local conditions (or to more closely match available mapping).
- Feedback from EcoServ-GIs users suggests that in a UK context the maximum distance bands for busy roads (Motorways etc) could be increased and the distance bands for minor roads reduced.

ES3 Noise Regulation Service Flow Maps

This model overlays the Demand and Capacity maps to illustrate how well they align. The combined maps are then used to illustrate those areas where it is predicted people benefit from this ecosystem service (Benefiting Areas) or where interventions could be planned (Management Zones). The areas of Demand and Capacity are split into quintiles by value (or optionally by area) and these are used to identify categories from Highest to Lowest. Additionally those areas with capacity to deliver the service, within areas of demand, and which hold existing greenspace cover are identified as green infrastructure assets (GI_assets).

Instructions
- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model” , from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required. Click OK to run the tool

ES3 Service Flows model inputs ModelOutputs/ES2Noise _regulation/Outputs.gdb

Input data	Description	Data type
Noise_Regulation_Capacity	Noise regulation capacity across the study area	Raster
Noise_Regulation_Demand	Total regulatory and societal need for noise regulation across the study area	Raster

ES3 Service Flows model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010
Set extent of service maps	StudyArea	This sets the area for which the Flows are mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.
Use quintiles by value	Yes	Capacity and Demand scores are split into five equal interval classes
Use quintiles by area	No	Capacity and Demand scores are split into five classes of equal area
BaseMap _FINAL	BaseMap _FINAL	The available habitat map used to map the habitats in the Masks below.
Mask 1	NOT: Water, Sea, urban, Infrastructure	Identifies all areas with management potential for change (greenspace areas and semi-natural habitats)
Mask 2	Urban	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring within all areas of mapped demand
Mask 3	Infrastructure	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring only within areas of highest or high

Parameter	Default	Explanation
		mapped demand
Run Mask 2	Yes	Select to run the mask analysis
Run Mask 3	Yes	Select to run the mask analysis
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)
Set minimum patch size for shapefiles	200	Set threshold to omit small polygons during shapefiles conversion

Model outputs are created in the "Outputs" geodatabase for:

- ESBA and Gaps, ESBA and Gaps Prioritised, ESBA Management Zones, GI assets
- See Section 3.1 and Table 9 for definitions of these outputs.

8.4.5 Pollination Toolbox

Tool Development: Chloe Bellamy (60%), Jonathan Winn (30%), Tom Fisher (10%)

Arable land, orchards and allotments all contain plants that require pollination in order to produce crops for sale or sustenance. Wild pollinators such as bees are vital to sustaining the production of these crops. UK pollination services have a high economic value (Breeze et al. 2015), and insect pollinated crops are important in UK agriculture (Breeze et al. 2011; Vanbergen et al. 2014). In the UK insect pollinators have been shown to be important to the apple crop industry by affecting both crop yield and quality (Garratt et al. 2014). A recent review in England highlighted the importance of the pollination ecosystem service (Defra 2013). The review highlighted that land use can be an important determinant of pollinator occurrence (Defra 2013). There is now a strategy focussed on sustaining pollinators in England (DEFRA 2014). The natural and semi-natural environment helps to sustain populations of bees and other pollinators, providing a free source of pollination. By protecting natural and semi-natural environments close to areas of arable agriculture the continued pollination of plants can be ensured. Although reviews have indicated that bee abundance or diversity is higher in areas where semi-natural habitats are more frequent or closer (Ricketts et al. 2008), detailed reviews of evidence on the conservation of bee species have shown that often detailed data or evidence is lacking on species-environment or management relationships (Dicks et al. 2010). However certain factors can promote bee conservation such as the beneficial impact of flower-rich field margins on pollinator abundance (Dicks et al. 2010).

Managed honeybees are not necessarily critical to crop pollination in the UK as during the period of honey bee decline the insect pollinated crop yields have increased (Breeze et al. 2011). Studies have indicated that wild pollinators are required, in addition to honey bees to help pollinate crops (Button & Elle 2014).

Detailed methods to map pollination supply would ideally use information on the occurrence, diversity, abundance and foraging ability of local pollinators. Some mapping work aims to model to this level of detail, such as the InVEST analysis (Natural Capital Project). However typically data on the location and population size of all local pollinating species is unavailable.

Although some research examined small scale detailed pollinator behaviour and found that bees were sensitive to wildflower patch area and richness even at small scales (Blaauw & Isaacs 2014), most research has been at broader field or landscape scales. This has often examined landscape composition in relation to pollinator occurrence. It has recently been noted that the use of positive conservation features in the landscape e.g. sown wildflowers may complicate the picture of landscape use by pollinators (Korpela et al. 2013). Nevertheless models have been produced relating abundance of pollinators in nesting habitats and on farms to landscape variables (Lonsdorf et al. 2009). It has been shown that mapping of the pollination service is very dependent on land cover map data sources (Schulp & Alkemade 2011).

Recent mapping work in Europe instead uses generalised relationships to estimate pollinator occurrence and visitation likelihood (Schulp et al. 2014). This method assumes that the location and number of wild bees are representative of pollinators as a whole. Following this method, with the exception of agricultural land, all open natural and semi-natural sites, and areas of woodland 100 m from open areas act as habitat for bees. It is assumed that all areas of habitat identified this way act as equally good habitat for bees. 688 m was taken as the distance bees will travel from habitat to each cell. This figure was taken from Ricketts et al. 2008, who present a meta-study evidence which suggests that there is only a 50% chance that pollinators will travel 668 m from habitat areas. The likelihood of a pollinator travelling to a focal cell from its habitat is used as a proxy for the amount of pollination within each cell. Further information on this method can be found in Schlup et al. 2013. This method does not take into account the additive effect of multiple patches of bee habitat within travelling distance from a cell. For example, two sites will receive the same capacity if they are the same distance from bee habitat regardless of any difference in the amount of bee habitat within 668 m.

Several insights from the following research were used to construct the GIS model:

- A study in France showed that bee abundance and taxa richness declined with distance from forest edge in oilseed rape fields (Bailey et al. 2014). A maximum distance of 230 m from forest edge were measured, as forest edges were likely to be important nesting or mating sites.
- Research in USA illustrated landscape composition had a significant impact on bee abundance and diversity (Bennett & Isaacs 2014), being correlated with perennial grassland cover. The strongest response to landscape variables occurred at the 1500 m scale. Relationships were positive for bee abundance (grassland cover) and bee diversity (forest cover).
- Research on honeybees and wild pollinators in Canada measured distance from field edges to assess pollination at 0, 50 and 100 m scales (Button & Elle 2014).
- European scale analysis showed complex relationships between landcover in a 3 km radius around focal areas on bee abundance and diversity (Carré et al. 2009). Forest and shrub cover were found to be positively associated with wild bee diversity (Carré et al. 2009).
- Californian research has shown a method of assessing pollination services by assessing the nearby area of habitat suitable for pollinators (Chaplin-Kramer et al. 2011). The authors examined vegetation types within 2.4 km of focal patches and extrapolated from studies of pollinator habitat use.
- Research on a single plant species found that seed viability was related to landscape variables, being higher in farms close to semi-natural habitat, but actually lower in landscapes with a high cover of semi-natural habitats (Chateil & Porcher 2015). Distances in the study were up to 698 m to nearby habitat with area proportions measured in 250, 500, 750 and 1000 m buffers. The interesting effect of area may be due to pollinators staying in high quality natural habitat rather than venturing into fields in high nature cover areas. The study noted and used short distances for some foraging distances, e.g. bumblebees, 300 m.
- Work in Germany indicated that thresholds occurred, in landscapes with more scarce grassland cover then species richness of wild bees declined with distance from main nearby habitat type, but did not have the same relationship in landscapes with higher cover (Jauker et al. 2009) (although this could potentially be due to unrecorded or measured site features). Abundance however declined with distance in all landscape matrix types. Hoverflies relationships were more complex and contradictory. This work shows that ideally all taxa need to be considered for pollination. The study measured transects up to 2000 m from main habitats.
- Canadian research in orchards found pollination (fruit set) increased with functional pollinator diversity, and decreased with distance from nearby meadows. Bee functional diversity was positively correlated with area of nearby meadow and forest (Martins et al. 2015). The authors used an average foraging range of local pollinator species of 680 m. This was used to set the areal extent of analyses.
- In Sweden bee abundance and richness was found to be positively associated with distance to gardens in intensive agricultural landscapes (Samnegård et al. 2011). In the study distant sites were considered to be 140 m from garden habitats.

- Research examining pollinator-landscape relationships over multiple scales found pollinator numbers could be explained only at small scales (up to 1000 m) (Steffan-Dewenter et al. 2001).
- In urban areas in Belgium research illustrated that pollination of certain species is not negatively associated with urban cover (Verboven et al. 2014).
- Research in California indicated that pollination was better predicted by habitat characteristics rather than landscape composition (Williams & Winfree 2013).
- Work in Europe has mapped both the supply and demand of the pollination service (Schulp et al. 2014). The method located crops needing pollination per 1 km cell and then modelled potential wild bee habitat and visitation probability, based on distance from nesting habitats. Bee habit comprised land cover map elements of habitat and green linear elements . Edges were <=100 m from open habitat, but the area was calculated as each cell provided 150 m length but 10 m width of "edge". Visitation probability was calculated twice and the maximum used per cell, e.g. for edges and for bee habitat area. Calculated from visitation probability = e(-0.00104 x distance to habitat).
- Another study in Europe modelled potential for pollination by using habitat and landscape characteristics (Zulian et al. 2013). The method used expert assessment of links to habitat type for pollinators, floral availability, foraging ranges and sites and effective pollinator activity, all applied to Corine landcover maps. Habitat types included: forest cover, roadsides, riparian, forest edge zones (25 m buffers were used around riparian areas, and roadsides). Pollinator foraging distance was based on 200 m. This research used locally accurate mapping data, where available, but in its absence used Corine data (Zulian et al. 2013).

Relationships between pollinators and landscape are complex and variable between taxa groups and landscape types (Winfree et al. 2011). Any broad relationship will be a crude simplification due to the complexity of relationships among taxonomic types and landscape composition and structure. However in summary, a variety of studies have related habitat cover, isolation or other landscape variables to wild pollinator diversity or abundance at scales from 100 to 3,000 m, around focal sites (Bennett & Isaacs 2014; Carré et al. 2009; Chaplin-Kramer et al. 2011; Chateil & Porcher 2015; Jauker et al. 2009; Martins et al. 2015; Steffan-Dewenter et al. 2001). Many studies use short distances to indicate the likely foraging distance of wild pollinators (e.g. 300 to 700 m). Most previous work suggests that "edge habitat" is an important resource for pollinators in the landscape in addition to key areas of habitat (Bailey et al. 2014; Button & Elle 2014; Schulp et al. 2014). Several studies indicate that pollinators are not negatively impacted by urban cover (Williams & Winfree 2013; Verboven et al. 2014). A range of research suggests that species - environment relationships should be modelled separately in landscapes with differing proportions of natural habitat or linear features, however there is no generalised information currently available to allow this.

ES1 Pollination Capacity

This model makes predictions on an area's capacity to provide pollination services by likelihood that pollinators will travel from habitat to an area of arable land, allotment or orchard.

- Visitation likelihood / probability by wild pollinator was selected as an indicator to represent the capacity of the natural environment of pollination.
- This was modelled based on the formula published in Schlup et al 2013 to convert distance from habitat to visitation probability.

The maximum foraging distance pollinators are willing to travel from habitats is disputed although there is a general consensus that this distance is greater than 1 km. Although pollinators may forage over very large distances, 50% of the population may travel no further than a short distance. Ricketts et al (2008) provide evidence which suggests that as distance from pollinator habitat increases, the likelihood of a pollinator visiting a site decreases non-linearly. This finding was used by Schlup et al. (2013) to map the pollination ecosystem service across Europe. EcoServ-GIS adapts this method to map pollination service capacity:

- Edge and Full pollinator habitats are identified within the BaseMap. Edge habitats are woodlands
- where pollinators are unlikely to utilise the full area of habitat, preferring to nest along the edges of each patch. Full habitats are those such as grasslands where pollinators are likely to use the whole patch to nest.
- Inverse logarithmic distance to full and edge habitats is calculated using a max search distance of 668 m. Beyond 668 m there is a less than 50% chance that a pollinator will visit a site (Ricketts et al. 2008). This was chosen as an arbitrary cut-off to highlight the best areas for pollination.
- Likelihood to visit a site is calculated based on the equation used by Schlup et al. (2013): $e^{(beta \times Distance\ to\ habitat)}$ where beta = -0.00104.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES1 Capacity model inputs

Input data	Description	Data type	Save to
BaseMap_Final	Base Map (detailed habitat & land use map)	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb

ES1 Capacity model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m
Select pollinator habitats	Multiple habitats	List of habitats that may act as core source habitat for wild pollinators
Select edge habitats	Multiple habitats	Habitats comprising edge habitat for wild pollinators
Max distance from habitats	668 m	Max distance from habitats used to input to calculation to convert distance to visitation probability
Select Edge distance	< 21 m	Edge depth into non pollinator source habitats, which is considered suitable for pollinator use/ nesting.
Calculation Power	2.718281828	Power used in the pollinator visitation calculation
Calculation constant	-0.00104	Constant used in the pollinator visitation calculation
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Capacity is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended

ES1 Capacity model outputs ModelOutputs\ ES2Pollination_regulation\Outputs.gdb

Output data	Description	Data type
Pollination_Capacity	Likelihood of site visitation by pollinators	Raster

ES1 Capacity model indicators ModelOutputs\ES2Pollination_regulation\Indicators.gdb

Output data	Description	Data type
EdgeHabitats_IndC	All Edge habitats	Vector (Polygon)
FullHabitats_IndC	All full habitats	Vector (Polygon)
PollinatorHab_IndC	All pollinator habitats	Vector (Polygon)
DisFromHabitat_IndC	Euclidean distance from pollinator habitat	Raster
VisitationProbability_IndC	Percentage chance that a pollinator will visit each cell	Raster

Notes & limitations (capacity)

- Likelihood of visitation is only one correlate of pollen production and crop yield. Evidence suggests that pollinator abundance and pollinator species richness may also be important factors in pollen production and crop yield (Kareiva *et al.* 2011, Steffan-Dewenter *et al.* 2001).
- This method does not consider very fine scale habitat attributes (e.g., presence of hedgerows and floral composition).
- Uncertainty will be introduced into the model by the BaseMap, particularly when identifying pollinator habitats. The BaseMap is a combination of all best available habitat and land use data.

Modifications and actions to improve the model (capacity)

- The linear features habitat data within the BaseMap should be included (e.g. by priority conversion at a fine raster cells size).
- Edge habitats and distances should be further clarified via the literature.

ES2 Pollination Demand

This model highlights the relative demand for pollination by mapping the need for populations of pollinators to occur in the landscape, based on distance from crop growing areas.

- All habitats and land use types that may potentially require the pollination service are selected from the BaseMap.
- This includes all agricultural land, allotments, orchards
- Users can optionally use an alternative dataset to locate land requiring pollination, e.g. if a map of crops types are available.
- A distance analysis is used to identify demand for pollination service. This is based on the occurrence of habitat that is likely to hold pollinators. High demand occurs in areas of habitat that require pollinators to be present, whilst demand reduces with distance from such habitats.
- A maximum distance can be set by the user (default 668 m).

This model identifies allotments, orchards and areas of arable agriculture. These areas may contain food crops which rely (at least partly) on animals for pollination. For pollination to occur wild pollinators must exist within the landscape. This model takes the simple assumption that the demand for wild pollinators is highest in, or directly adjacent to, crop growing areas, and declines with distance. There is assumed to be no demand for pollinators in the landscape at an arbitrary maximum distance from crops, set by reference to likely pollinator travel distances. The default is 668 m. Beyond 668 m there is a less than 50% chance that a pollinator will visit a site (Ricketts et al. 2008). This maximum distance can be altered by the user.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES2 Demand model inputs

Input data	Description	Data type	Save to
BaseMap _Final	Base Map (detailed habitat & land use map).	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

ES2 Demand model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m
Habitat types representing agricultural use and crops	Multiple habitats	A selection of habitat types, from the BaseMap_FINAL layer at which pollination is expected to be required.
Maximum distance to pollinator populations	668 m	The maximum distance beyond which, if pollinator populations occur, they will not be of significance to the pollination of crop growing areas.
Use alternative agricultural layer	Boolean	Tick this box if an alternative dataset is available to locate all areas requiring pollination. If ticked this data will be used in preference to the BaseMap data.
Alternative data source - land requiring pollination	Dummy variable	Replace the dummy variable with a feature class if data is available to map areas requiring pollination.
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Capacity is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended

ES 2 Demand model outputs ModelOutputs\ES2Pollination_regulation \Outputs.gdb

Output data	Description	Data type
Pollination _Demand	Areas that are most likely to contain food crops that (partly) rely on animal pollination	Raster

ES2 Demand model indicators ModelOutputs\ES2Pollination_regulation\Indicators.gdb

Output data	Description	Data type
AgriculturalFeat _IndD	All land classified as Arable, Orchard or Allotment	Vector (Polygon)

Notes & Limitations (demand)

- The main limitation of this model is that the location of arable areas is only approximately mapped, as there is no information freely available on the location of arable land and particular crop types.
- Many areas that are mapped as "Arable" are predicted to hold arable land use due to field size and slope information. However large flat fields that are not arable may be misclassified, leading to errors in the mapping of areas of pollination demand.
- For this model it is particularly important that the Habitat BaseMap has been checked and verified wherever possible.
- If available an alternative dataset showing the locations of crop growing areas can be used as a data input.
- The yield of different types of crops and agricultural regimes will vary in their dependence on wild pollination (some do not require animal pollination).

- Uncertainty will be introduced into the model by the BaseMap, particularly when identifying agricultural areas. The BaseMap is a combination of all best available data and is not perfect.
- The model does not account for the pollinating service provided to plants providing "wild food" or that are grown in domestic gardens, nor does it illustrate the cultural benefits provided by plants that are pollinated by animals.

Modifications and actions to improve the model (demand)

- Use of data to more accurately locate arable land, ideally to crop type would greatly improve the models.
- Literature and methods to support the grading of areas by relative demand would be useful, but would be a secondary model improvement, after the location accuracy of mapped demand areas was improved.

ES3 Pollination Service Flow Maps

This model overlays the Demand and Capacity maps to illustrate how well they align. The combined maps are then used to illustrate those areas where it is predicted people benefit from this ecosystem service (Benefiting Areas) or where interventions could be planned (Management Zones). The areas of Demand and Capacity are split into quintiles by value (or optionally by area) and these are used to identify categories from Highest to Lowest. Additionally those areas with capacity to deliver the service, within areas of demand, and which hold existing greenspace cover are identified as green infrastructure assets (GI_assets).

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model” , from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required. Click OK to run the tool

ES3 Service Flows model inputs ModelOutputs/ES2Pollination _regulation /Outputs.gdb

Input data	Description	Data type
Pollination_Capacity	Pollination capacity map - estimated pollinator abundance (relative to all cells in study area)	Raster
Pollination_Demand	Pollination demand map - demand for pollination across the study area.	Raster

ES3 Service Flow model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010
Set extent of service maps	StudyArea	This sets the area for which the Flows are mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.
Use quintiles by value	Yes	Capacity and Demand scores are split into five equal interval classes
Use quintiles by area	No	Capacity and Demand scores are split into five classes of equal area
BaseMap _FINAL	BaseMap _FINAL	The available habitat map used to map the habitats in the Masks below.
Mask 1	NOT: Water, Sea, urban, Infrastructure	Identifies all areas with management potential for change (greenspace areas and semi-natural habitats)
Mask 2	Urban	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring within all areas of mapped demand
Mask 3	Infrastructure	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring only within

Parameter	Default	Explanation
		areas of highest or high mapped demand
Run Mask 2	No	Select to run the mask analysis
Run Mask 3	No	Select to run the mask analysis
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)
Set minimum patch size for shapefiles	200	Set threshold to omit small polygons during shapefiles conversion

Model outputs are created in the "Outputs" geodatabase for:

- ESBA and Gaps, ESBA and Gaps Prioritised, ESBA Management Zones, GI assets
- See Section 3.1 and Table 9 for definitions of these outputs.

8.4.6 *Water Purification Toolbox*

Tool Development: Chloe Bellamy (50%), Jonathan Winn (50%)

Water purification (water quality regulation) is a key ecosystem service (Brauman et al. 2007), however there are a number of interpretations of how broad or specific the service is, with regard to particular pollutants or water quality risks. This toolkit address water purification within the context of diffuse agricultural and urban pollution.

Several methods and toolkits exist to predict the threat of agricultural pollution, and to examine the risk of such pollutants reaching a watercourse (e.g. Scimap) (Reaney et al. 2011; Milledge et al. 2012). Studies have linked land use categories or crop types to the local risk of aquatic pollution and many studies have used GIS techniques and the Universal Soil Loss Equation (USLE) to assess the local risk of water or sediment mobilisation (Brabec 2002; Wang et al. 1997; Prasuhn et al. 2013; Sivertun & Prange 2003; Borselli et al. 2008). Modelling suggests that changing land use practices to account for known hydrological risks of pollution, such as installing grass strips near watercourses can be effective in reducing pollution loads before they reach watercourses (Liu et al. 2015).

The detrimental impact of soil erosion on farms is well known (Defra 2005). A reduction in water quality can be caused by excess fine sediment and soluble pollutants (such as pesticides, nitrogen and phosphorus). This can result in increased turbidity, reduced visibility, smothering of the channel bed, the death of fish and other water life and an increase in cyanobacteria blooms. Nitrate levels remain high in UK surface water bodies, often exceeding the EC limit of 50 mg/l, and it is has been suggested that there may be a link with this pollutant and human health problems such as stomach cancer (Koo & O'Connell 2006). Low water quality can impact humans by additional costs for water treatment or through effects on recreation use in, or along, watercourses (walking, swimming, fishing).

Fertilisers from agricultural land, which have been leached from soils or in water runoff, cause a decrease in water quality. Intensive agriculture increases erosion and sediment load whilst urbanisation can decrease the quality of water runoff (Foley et al. 2005). However, agriculture has been reported to have less of a damaging effect on water quality compared to urban cover (Brabec 2002). Wang et al. (1997) found that 10 – 20% of urban cover was enough to cause water quality scores to be classified as "poor", compared to 40% for agricultural areas. Impervious cover models have been used to show the negative impact of urban areas on watershed water quality (Wang et al. 1997; Schueler 1994), the exact mechanism varies including "missed connections" where household waste water directly enters streams, or the cumulative impact of small pollution events on urban roads, streets and pavements.

Areas of agricultural land that are prone to erosion will contribute highly to the sediment and pollutant load of surface runoff water. Therefore, these areas and those downslope have a high need for ecosystems that can slow this run off, helping to reduce water pollutant load before it enters a watercourse. The USLE and various modifications of this model have been used to estimate rates of soil loss based on rainfall patterns, soil properties, land cover and topography (Wischmeier & Smith. 1978; Sivertun et al. 1988; Sivertun & Prange 2003; Wu & Wang 2011; Prasuhn et al. 2013). Sivertun & Prange (2003) specially adapted this model for GIS, simplifying the original model by reducing the data required to four factors which can be mapped using GIS (soil, slope length, land use and distance to watercourse); this modified method cannot estimate actual sediment load at any point, but they found it useful for mapping relative erosion risk quickly across large areas in Sweden (Sivertun & Prange 2003; Sivertun et al. 1988). Manning's roughness coefficient can be calculated to describe the surface resistance of a habitat to water flow e.g. (Liu & Smedt 2004). Additional research has shown how slope and roughness are good indicators of an area's capacity to purify surface runoff (He et al. 2010). In addition a wide variety of other hydrological models have been developed and are well reviewed in the literature (Golden et al. 2014; Jackson-Blake et al. 2015; Pullar & Springer 2000).

Connectivity of areas of erosion or of agricultural fields to watercourses has been variably mapped in (Srinivasan & McDowell 2009; Milledge et al. 2012). The original USLE model estimate soil loss due to erosion at rates per unit area (tons/ha). The full model includes climate factors, soil, land use, slope, and management factors. Authors have noted many limitations of the original USLE formula (Sivertun & Prange 2003) and its origin from measurements in sub-field sized plots has been discussed in the literature (Foster et al. 1981; García Rodríguez & Giménez Suárez 2010). A key factor is the slope length or "LS" factor. Different methods to calculate LS exist, e.g. (Moore & Burch 1986). Several researchers use a modified USLE or revised RUSLE (Renard et al. 1997) with flow accumulation instead of slope length in order to account for the influence of converging water flow, e.g. (Sivertun & Prange 2003; MITASOVA et al. 1996; Helena Mitasova et al. 1998; Desmet & Govers 1996).

Some research has applied methods to deal with the high flow accumulation figures that can be created in big landscapes. Sivertun and Prange (2003) dealt with the issue by removing all areas of rivers, lakes and streams from the landscape. Similarly associated work has masked out areas of roads or streams where drains or sink areas for sediment or pollution are expected to occur (Borselli et al. 2008). Caps to the flow accumulation values were applied in Mattheus & Norton (2013). Studies have confirmed that linear features such as roads or tracks can influence water movement and pollution risk in farmed landscapes (Heathwaite et al. 2005).

In an alternative method catchment features were used to derive a connectivity index. This method considered the relationships between a set of upstream factors, to a set of downstream factors at each focal cell to give an index of connectivity (Borselli et al. 2008). This study was notable in its ease of calculation from the method notes presented. Many similar studies could not be so readily reproduced from published sources.

Another method "Scimap" takes a data driven approach to the issue of pollution modelling and reveals a number of important considerations (Milledge et al. 2012). This model estimates the risk of generation of pollution, based on land use weightings and topography, a connection risk, which indicates the likelihood of runoff reaching a stream and then analysis to collate the impacts of pollution moving through the river network, relative to total flow levels. Generation risk is determined through analysis of measured pollution levels and relates catchment cover characteristics. Connection risk is modelled using the network index. This is "the lowest value of the topographic wetness index along the dominant flow path between a location in the catchment and the river network" (Milledge et al. 2012). The method relies on the EA water quality measurements being representative of the catchments in which they were collected.

A method developed by Sivertun and Prange (2003) used an adaptation of the USLE and was found to allow rapid consideration of large areas within GIS for planning. This method is discussed in further detail later in this section.

Several insights from the following research were used to construct the GIS model:

Capacity

- Guidance on the use of conservation buffers illustrates that they can help slow water runoff and enhance infiltration, and trap pollutants in surface runoff (Bentrup 2008).

Targeting buffer creation in areas of highest risk of pollution may be most effective (Bentrup 2008).

- Slope and roughness are good indicators of an area's capacity to purify surface runoff (He et al. 2010) .
- Manning's coefficient has been applied to different land use types in GIS models to represent vegetation or habitat "roughness" to water movement (Liu & Smedt 2004) .
- Research in China illustrate forest cover was negatively associated with aquatic pollution levels in catchments, especially in urban catchments (Huang et al. 2015).
- Government guidance considers slope type to impact on the risk of agricultural runoff (depending on soil type) using slope degree classes of: steep (>7), moderate (3-7), gentle (2-3), low (<2). These were noted to correlate with runoff levels (Defra 2005).
- Studies indicate that strategies to reduce pollution risk to aquatic habitats should concentrate on areas of land use very close to streams, such as by buffering streams with planted woodland or fencing to prevent access by livestock (Monaghan et al. 2009).
- Riparian wetland has been shown to absorb agricultural pollution (Zhao et al. 2009).
- Urban greenspace can contribute to the water purification service (Yang et al. 2015).

Demand

- Intensive agriculture increases erosion and sediment load and urbanisation can decrease the quality of water runoff (Foley et al. 2005).
- Agriculture has been reported to have less of a damaging effect on water quality compared to urban cover (Brabec 2002).
- Impervious cover models have shown the negative impact of urban areas on watershed water quality (Wang et al. 1997; Schueler 1994).
- Studies have estimated risk of erosion using adaptations of the USLE equation to predict the release of sediment and pollutants (Wischmeier & Smith. 1978; Sivertun, Reinelta, & Castenssona 1988; Sivertun & Prange 2003; Wu & Wang 2011; Prasuhn *et al.* 2013).
- Increasing cover of urban land use or sealed surfaces has been shown to be associated with degraded stream ecosystems (Brabec 2002).
- Urban areas can be sources of pollution to watercourses via pollution on roads and highways reaching streams via street drains (Van Bohemen & Van De Laak 2003).
- Studies have shown that proportion or cover of both agricultural land and urban areas (cover or population density) is associated with degraded aquatic ecosystems as measured by nutrient levels or suspended solids (Ahearn et al. 2005) .
- Pollution impacts can be related to intensity levels of agricultural use in UK catchments (Crowther et al. 2002).
- Research in China showed that area of crop land has a positive association with aquatic pollution levels in agricultural catchments, and that built up area was consistently associated with pollution in catchments (Huang et al. 2015).
- In America work has highlighted that much phosphorous and suspended sediment loads into streams occur from features such as gateways, water troughs and areas where livestock access streamsides, at relatively small scales during localised events (McDowell & Srinivasan 2009).
- American catchments have been shown to have a link between extent of agricultural area, e.g. dairying and pollution loads in aquatic systems (McDowell et al. 2011).
- In North West England examination of catchment characteristics found nutrient pollution was linked to agricultural land cover and urban cover (Rothwell et al. 2010). Suspended sediments were seen to be most strongly related to urban cover rather than agricultural cover (Rothwell et al. 2010).
- In Spain measurements in a catchment highlighted the importance of assessing connectivity between areas of likely erosion and streams, observing that much erosion events did not research watercourses, especially where vegetation was present at the bottom of cropped fields (Rodríguez-Blanco et al. 2013).

- Work in Germany showed that to accurately predict pollution levels in waterbodies that separate model systems in urban and rural areas should be used, ideally at high spatial and temporal resolutions (Bach & Ostrowski 2013).
- Research recognises that often at the landscape scale that models to asses both field scale pollution risk, and also catchment scale pollution risk are both required and have their uses (Vigiak et al. 2012).
- Research suggests that modelling of hydrology process can be an effective way to estimate pollution risk compared to the need for detailed water quality measurements (Chang et al. 2015).

A review of the literature illustrates significant research linking pollution impacts to land use features and potential land management mitigation strategies. Conservation land management and use of e.g. buffer strips (Bentrup 2008) offer significant opportunities to reduce pollution events. However the impact of such actions must be placed into context, where urban land use has often been shown to be a key cause of reduced water quality, and in many cases there are limited opportunities for land to deliver the water purification ecosystem service within towns and cities. Nevertheless in support of the uptake of this ecosystem service, land use strategies to reduce pollution by implementing restoration, e.g. of wetlands, have been shown to be financially viable (Trepel 2010). The current focus of this service model is on land management and the use of buffers, however several studies have noted the importance of point-based pollution incidents, such as from farmyards or livestock crossing points (Crowther et al. 2002), and these are not included within this current model. Therefore whilst the ecosystem service of existing or future buffer vegetation may be very important in high-risk catchments, in reality management of selected point based sources may have most impact on reducing pollution events in streams within the catchment. Additionally there are many farm management measures that can help reduce erosion and thus runoff pollution events without needing vegetation change, such as altered timing and method of cultivation (Defra 2005; Monaghan et al. 2007). Similarly in-stream waterbodies or constructed wetlands can significantly help with water purification (Tournebize et al. 2014), although these are not included within the current service models.

Whilst GIS models can allow rapid assessment of large areas, the limitation of pollution models must be accepted and the many error factors that can occur in modelling work should ideally be compared against measured factors in catchments to assess how well such models reflect reality (Jackson-Blake et al. 2015; Letcher et al. 2002; Srinivasan & McDowell 2009). Although the present focus is on sediments and nutrients, other pollutants such as herbicides may also be washed into watercourses during storm events (Tediosi et al. 2012).

Illustrates the capacity for an area of land to slow water runoff, trapping pollutants and sediments before they enter watercourses

- Ecosystems and vegetation types can modify the speed of flow of water and can be broadly represented by Manning's roughness coefficient.
- The slope value of ecosystems will impact on speed of water flow.
- The combination of ecosystem vegetation type and slope can be used to represent capacity to intercept and slow run-off.
- Gentle slopes covered by vegetation with high roughness, density or complexity are likely to be most effective at water purification.

The Water Purification Capacity maps grade the landscape by its capacity to slow water and trap or ameliorate pollution. Higher scoring areas are those where structurally complex habitats such as broadleaved woodland, marsh or wetlands occur on flat or gently sloping land. Lower scoring areas are those with structurally more simple habitats or areas of steeper slopes. Manning's roughness coefficient is calculated to describe the surface resistance of the habitat to water flow (Table 26). These values are then multiplied by the steepness of the slope on which the habitat lies (Table 27). Flat areas with high roughness values are assigned the highest scores. All areas of land with 0 roughness value, and all areas of land that could generate run-off pollution (rather than ameliorate it) are removed from the map before the final capacity score is calculated. This parameter can be altered by the user.

Table 25. Manning's coefficients (hydraulic roughness) for land use types

Habitat	Manning's coefficient	Equivalent land use classes (Liu & Smedt 2004)
Broadleaved woodland	0.60	Deciduous needleleaf forest; deciduous broadleaf forest
Mixed woodland	0.55	Mixed forest
Coniferous woodland	0.50	Evergreen needleleaf forest; evergreen broadleaf forest
Bog/Heath/Wet grassland	0.50	Permanent wetlands
Scrub, scattered trees & mixed scrub/trees/grassland	0.40	Closed shrubland; Open shrubland
Other mixed habitats	0.35	Cropland/Natural vegetation
Farmland	0.35	Croplands
Rough & improved grassland	0.30	Grasslands
Rock & water	0.00*	Water bodies
Manmade surfaces & structures	0.00*	Urban and built-up

Adapted from Liu & Smedt (2004). The greater the value the higher an area's capacity to slow water runoff and trap pollutants & sediments. *Reduced from 0.05 to 0.00

Table 26. Slope reclassification values to represent pollution interception ability

Slope degree	Slope category	Value
0 – 5	Flat	100
5 – 8	Gentle	85
8 – 15	Sloping	70
15 - 25	Moderate	60
25 – 35	Steep	30
35 - 45	Very steep	20
45 - 90	Extreme	10

Note: this reclassification has been based on the authors opinion as informed by the literature.

Instructions
- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click "edit", from "Model" menu click "Validate the entire model", from "Model" menu click "Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click  icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES1 Capacity model inputs

Input data	Description	Data type	Save to
BaseMap _Final	Base Map (detailed habitat & land use map).	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb
DTM	Digital Terrain Model	Raster	Saved in: ModelInputs/ ES10CommonFiles/ Intputs.gdb

ES1 Capacity model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m.
Exclude areas with no capacity, that may generate run-off	Agricultural land, improved grassland	Areas can be removed from the capacity maps where the field may potentially be generating pollutants in run-off. This setting allows a focus on semi-natural habitats.
Minimum patch size (m)	500 m^2	Minimum size of areas below which an area is not considered to have capacity to significantly deliver the service. Note this is based on mapped capacity, not mapped greenspace areas, and therefore each "patch" includes any buffering or distance analysis.
Data extract area SA_buffer or StudyArea	StudyArea	This sets the area for which the Flows are mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.

ES1 Capacity model outputs ModelOutputs\ES2Water_purification_regulation\Outputs.gdb

Output data	Description	Data type
WaterPurification_Capacity	Estimated water purification capacity	Raster

ES1 Capacity model indicators
ModelOutputs\ES2Water_purification_regulation\Indicators.gdb

Output data	Description	Data type
Slope_cap _IndC	The capacity based on slope for deposition or interception of pollution based on slope steepness (high slopes, low capacity)	Raster
RoughnessScore _IndC	Manning's roughness coefficients – hydraulic resistance values for different land use types	Raster

Notes & Limitations (capacity)

- Uncertainty will be introduced by the BaseMap, which is not a completely accurate representation of habitat presence and land use, but is EcoServ-GIS's compilation of best available habitat mapping.
- The level of habitat mapping accuracy within the BaseMap will influence the models outputs.
- The Manning's roughness scores are attributed to broad classes of habitat, in reality there will be variation between different sub habitats types.
- Water flows along its pathway from one cell to another and is not partitioned between multiple downstream cells (Liu & Smedt 2004).
- The water purification services carried out by habitat features that are too fine sale to be captured by MasterMap, such as hedgerows and treelines, are not captured by this model.
- The slope class categories used to indicate habitat potential to deposit or trap pollutant are currently broad and simplistic.

Modifications and actions to improve the model (capacity)

- Literature and methods to support the grading of slope steepness, and the application of roughness values to finer resolution habitat sub classifications would be useful.
- Using a majority filter to alter the map outputs to map broader zones (rather than mixed classification cells) could aid the clarity and use of the service maps.
- The model could be further developed to account for the width of the habitat patch influencing capacity.

ES2 Water Purification Demand

Models the risk of surface runoff water becoming contaminated with high pollutant and sediment loads before entering a watercourse.

- Water quality can be reduced due to the pollution from agricultural run-off or urban street pollution reaching watercourses.
- Both dissolved pollutants and fine sediments can cause such pollution.
- Polluted watercourses may impact the direct or indirect use of water and watercourses by people.
- The risk of pollution can be assessed at the cell scale, or at the catchment scale.
- Catchment scale risk of pollution can be broadly assessed based on % cover of land use types (urban cover and agricultural cover).
- Catchments can be modelled using GIS-based hydrology tools.
- Cell or site based pollution risk can be modelled using a modified universal soil loss equation (USLE).
- The USLE can be further modified for use in GIS models and mapping.

The Water Purification Demand maps grade the landscape by the predicted relative levels of pollution that could be washed into watercourses. Areas of higher demand are where agriculture occurs on steep slopes close to streams, where there is a risk of erosion events washing the soil and potential pollutants into a stream and also where catchments as a whole have higher percentage cover of urban or agricultural land use. Areas of lower demand are those parts of the landscape where there is less agricultural or urban land use and where there is less risk of pollution events or erosion reaching a watercourse.

Regulatory need
This model first estimates the risk of water contamination at the watershed scale by focusing on catchment land use characteristics. At a much finer scale, the “Universal Soil Loss Equation” (USLE) is then used to estimate rates of soil loss at each particular cell. These two factors are then multiplied together.

1) Watershed scale land use: Each watershed is graded according to the proportion of its area that is covered by farmland (arable land cover) or urban (sealed surfaces). These scores are combined to give a final land use risk score between 0 - 100, giving the urban cover raster a higher weighting (Table 28). Those areas with higher covers are assumed to have a higher risk of water contamination. Although inspired by the literature it is acknowledged that these categories are arbitrary and they would ideally be validated by UK specific research. As the focus of the service is the ability of land to help minimise the additional contribution of agricultural pollution to watercourses, those catchments that are mainly urban or that have low covers or farmland are excluded with a demand score of 0.

Table 27. Watershed pollution risk based on cover of urban and farmland land use

Urban (%)	Farmland (%)					
	Very low (0 to 5)	Low (5 to 10)	Moderate (10 to 20)	High (20 - 30)	Very high (30 - 40)	Dominant (40 - 100)
Very low (0 to 5)	0	20	40	60	80	100
Low (5 to 10)	0	40	40	60	80	100
Moderate (10 to 20)	0	40	60	80	100	100
High (20 to 30)	0	60	80	100	100	100
Very high (30 +)	0	60	80	100	100	100

Farmland is mapped from arable land cover, the accuracy of mapping of which varies by BaseMap data source. Urban is mapped from cover of sealed surfaces and excludes urban greenspace cover. These can be altered by the user.

Hydrology tools are used to create flow accumulation grids, stream networks and watersheds. A threshold of flow accumulation of 20,000 is used for stream delineation and watershed boundary generation. A default is set, but this can be varied by the user. Selection of a higher threshold would result in larger watersheds. Due to the methods used there may be areas at the periphery of the study area, or along lowland coastlines that are not accurately mapped by the watershed analysis. These areas will not receive a demand score and will be mapped as zero. This will not significantly impact the models as this is normally resolved by the use of the buffer zone around the Study Area. Additionally small coastal watersheds may be mapped, these will tend to output directly to the sea, and within the context of the current mapping methods these areas would not impact on any land areas, and there would be no beneficiaries of water purification in these areas. (Beneficiaries would be related to the marine ecosystem, but these are not covered by this toolkit).

2) Cell based risk of pollutants reaching a watercourse: Each cell is graded by its estimated risk of erosion using an adaptation of the USLE equation (Sivertun & Prange 2003), resulting in the release of sediment and pollutants. Sivertun and Prange (2003) developed a method that was verified against field studies in Sweden. This was based on four factors:

A) Land use
B) Soil type
C) Distance to watercourse
$f(x) = (0.6/(\exp^{0.002x} - 0.4))$
D) Slope length (LS from the USLE)
Power(flow accumulation * cell area / 22.1, 0.6) * Power(Sin(slope in degrees * 0.01745) / 0.09, 1.3) * 1.6

The method of Sivertun and Prange (2003) has been adapted for EcoServ-GIS by simply indicating that each feature may contribute to the risk of erosion products reaching a watercourse. Each indicator is standardised (1 – 100 scale) and summed to indicate this, rather than multiplied together to create the final score. A user-defined optional weighting is applied. Defaults are set as follows, typically omitting the soils data, because freely available soils data is of very low resolution.

The aim of this method is to identify those areas that have a combination of characteristics that may result in erosion, and the transfer of the erosion, sediment, or dissolved pollutants to a watercourse. Certain land uses (**A**) and soil types (**B**) have a higher susceptibility to erosion. The model concentrates on overland flow and storm wash events. The inclusion of a factor to represent distance to watercourses (**C**) acts as measure of the likelihood of erosion or pollution reaching a watercourse, acknowledging that erosion events are unlikely to travel long distances. Erosion events and the transfer of pollutants can occur in any location, but the assumption is that if they are a long way from watercourses that the material will be deposited or intercepted by vegetation or will drain into soils. Subsurface flow or transfer in groundwater is not considered by this model. A slope length factor (**D**) is used to assess the potential erosion power of water movement at each point, potentially contributing to pollution or sediment loads in any overland flow event.

Land Use (A) and Soil type (B) values are applied as in Sivertun and Prange (2003), however the default is to exclude the soil score, due to data quality and scale issues.

Distance to watercourse (C) The original Sivertun and Prange (2003) formula using Euclidean distance to watercourse is not an accurate representation of potential flow distance or connectivity to watercourses because the distance may stretch to a separate watershed or the distance may span areas of steep topography or ridges. Therefore, Euclidean distance to the nearest stream has been constrained by applying a mask to the analysis using least cost distance, where areas of ridges or locally high elevation were given a high cost score to ensure across ridge distances are not included in these calculations. This was calculated using a local Topographic Position Index (TPI) (De Reu et al. 2013), search distance set at 150 m, ridges were extracted as all areas TPI > 5, these were set a cost value of 50, and landscape areas with TPI >2 <5 were set a cost value of 20, compared to other landscape areas. All areas of least cost <= 500 were then used as a mask to the Euclidean distance from streams.

The main analysis of the formula selected by Sivertun and Prange (2003) is then applied, again with a maximum limit, which can be altered by the user. Ideally, the distance zone of highest pollution risk from the nearest stream would be identified from the literature, however figures were not available. A conservative default of 250 m is applied within the toolkit, this can be altered by the user.

Slope length factor (D) The slope length factor is taken from studies using the USLE equation. There are several important limitations in the use of USLE derived indices. The USLE was developed from measured field values, concentrating on erosion within agricultural areas on moderate slopes within the USA. The “LS” factor illustrates expected erosion levels, based on a combination of slope steepness and slope length. Steeper slopes and longer slope lengths result in higher erosion levels due to their influence on the velocity and power of resulting overland flow events. Several studies have substituted flow accumulation for slope length when calculated within a GIS. The following formula was used:

> Power(flow accumulation * cell area / 22.1, 0.6) * Power(Sin(slope in degrees * 0.01745) / 0.09, 1.3) * 1.6

There can be issues with this modification of the original calculation (see Technical Report). Recent use of flow accumulation in place of slope length acknowledges the importance of the convergence power of water flow and gives a better reflection of the upslope contributing area over which water accumulation can influence erosion, compared to linear measures of slope length. However this use of flow accumulation requires consideration of a suitable threshold. In this analysis a maximum flow accumulation threshold of 500 cells was used, with all values above this being reclassified to 500. Additionally all areas of mapped rivers, streams, roads and houses were used as masks to the analysis. This assumes that flow accumulation will cease and the flow will be directed into channels and land drains. These mask areas were analysed by first converting to rasters at 5 m resolution, then forcing this to a higher cell size as used within the main analysis, so that these areas are mapped with priority. A final amendment applied a threshold value of 2, only flow accumulation values greater than the threshold were used in the calculation to remove small insignificant areas of potential water movement.

Another alteration was made to formula in the use of the slope values. As the focus is on identifying need for erosion and pollution reduction in agricultural and urban areas extreme slope values associated with cliffs or non-farmland areas were excluded (> 40 degrees). Similarly, areas of zero slope, but within modelled flow accumulation areas, were considered to be relevant to this service. These areas may not actively involve erosion of sediment but they can contribute to landscape level transport of sediment, overland flow or storm wash events. They should not be considered a barrier to flow movement, especially where they only occur for short distances. Therefore to create the "slope in degrees" value in the equation above, all areas of zero degrees slope were re-classified to 0.1 to ensure such areas appear in the ecosystem service maps, for areas where flow accumulation is predicted.

A final modification relates to the calculation of the flow accumulation grid. In order to highlight areas of higher potential pollution a weight grid was applied to the flow accumulation analysis with values of 1 applied to urban (HabClass = “Infrastructure” OR HabClass = “Urban”) and agricultural (HabNmPLUS = “Cultivated/disturbed land/arable” OR HabNmPLUS = “Grassland, Improved” OR HabNmPLUS = “Grassland, Improved / arable (probable)”) and a value of zero applied to all other land uses. This is the default setting and can be modified by the user if desired.

This model does not include precipitation or climate data and any variation in these across a Study Area will influence the predictions of the model. However, within most Local Authority areas this is not considered to be a significant issue, but would be more relevant where there was a very large range in elevation or topography within a Study Area.

Table 28. Land use and soil factors used to estimate potential soil loss per cell

Indicator	GIS data categories	USLE factor	Categories from the literature*
Land use	Water	0.000	Water
	Woodland, scrub, scattered trees & mixed scrub/trees/grassland	0.005	Forests
	Bog/Heath/Wet grassland	0.010	Wetland **
	Rough grassland, & other mixed habitats (no trees)	0.010	Grassland
	Improved grassland	0.020	Improved grassland **
	Manmade surfaces & structures	0.030	Urban areas
	Rock	0.200	Bare rocks**
	Bare ground / bare peat	0.100	Bare peat / ground**
	Farmland	0.100	Average of: Agriculture (exposed/harvested/ perennial/covered)
Soil	Texture class: 4 (fine: 35 % < clay < 60 %) or 5 (very fine: clay > 60 %)	0.45	Clay
	Texture class: 3 (medium fine: clay < 35 % and sand < 15 %)	0.38	Silts
	Texture class: 2 (medium: 18% < clay < 35% and sand > 15%, or clay < 18% and 15% < sand < 65%) or 1 (coarse: clay < 18 % and sand > 65 %)	0.33	Sands
	Texture class: 8 (no texture because of organic layer)	0.30	Organic matter
	Texture class: 7 (no texture (because of rock outcrop)) or 6 (no texture (other cases)) or 0 (No information – generally lakes or urban areas)	0.20	Gravels/hard rock

*Based on results from (Schein & Sivertun 2001) or ** (Sivertun & Prange 2003)

Societal demand: This model does not map the societal demand for water purification because drinking water is typically transported long distances., e.g., via pipelines, and this could not meaningfully be mapped in order to indicate the human benefit of water purification.

Total demand: The final demand score is created by summing the separate scores with any user defined weightings (Table 30). Any areas of No Data are carried through in the final sum score, only areas with risk for each mapped factor will be given a full Demand score.

Table 29. Water purification demand - indicator weighting

Indicator	Default weighting
1. Watershed (catchment) risk	1
2. A Land use	1
2. B Soil type	0
2. C Distance to watercourse	1
2. D Slope length	1

Instructions

1) Prepare “Soils” data (OPTIONAL) 2) Run the model “ES2_WaterPurificationDemand”

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES2 Demand model inputs

Input data	Description	Data type	Save to
BaseMap _Final	Base Map (detailed habitat & land use map).	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap /Outputs.gdb
DTM	Digital Terrain Model	Raster	No action needed. Previous model output saved to: ModelInputs /ES2Water_purification_regulation / Inputs.gdb
Soils	Soil map of Europe	Vector (polygon)	Save to: ModelInputs/ ES2Water_purification _regulation / Inputs.gdb

ES2 Demand model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m.
Farmland cover habitats	HabNmPlus = Grassland, Improved,/arable (probable) OR Cultivated / disturbed land, Arable, OR Land principally occupied by agriculture	Habitats used to calculate % cover of "farmland" per watershed
Urban cover habitats	HabClass = Urban OR Infrastructure	Habitats used to calculate % cover of "urban" per watershed
Select potentially polluting land uses	Multiple Habitats	Habitats and land use types that may contribute pollution to runoff events
Flow accumulation threshold for streams	20,000	Value used to define streams from the flow accumulation grids

Parameter	Default	Explanation
Maximum distance to watercourse	250 m	Maximum distance from streams, beyond which pollution events or runoffs is considered unlikely to reach watercourses
Minimum site area (m)	500	Threshold used to identify small areas where may be less reliable
Weight for distance to Watercourse score	1	Weight (optional) used to modify the score, prior to scores being combined into the final demand score
Weight for soil type score	0	Weight (optional) used to modify the score, prior to scores being combined into the final demand score
Weight for slope erosion score	1	Weight (optional) used to modify the score, prior to scores being combined into the final demand score
Weight for land use score	1	Weight (optional) used to modify the score, prior to scores being combined into the final demand score
Weight for watershed risk score	1	Weight (optional) used to modify the score, prior to scores being combined into the final demand score
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Demand is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended

ES2 Demand model outputs
ModelOutputs\ES2Water_purification_regulation\Outputs.gdb

Output data	Description	Data type
WaterPurification_Demand	The relative risk of surface water runoff containing high sediment and pollutant loads across the study area	Raster

ES2 Demand model indicators
ModelOutputs\ES2Water_purification_regulation\Outputs.gdb

Output data	Description	Data type
WaterShedRisk_IndD	The proportion of each watershed that is covered by manmade surfaces or farmland. Used to indicate total watershed based risk of pollution (via runoff or diffuse pollution events)	Raster
Urban_p_IndD	% of watershed covered by urban and infrastructure (0 - 100) (absolute)	Raster
Farm_p_IndD	% of watershed covered by cultivated agricultural land (0 - 100) (absolute)	Raster
WaterD_Ind	Index representing distance to watercourse (0 - ~1) (absolute)	Raster
Soils_scr_IndD	Soil type erosion factor (0 - 0.45) (absolute)	Raster
Land_Erosion_risk_IndD	Land use type erosion factor (0 - 0.1) (absolute)	Raster
Slope_IndD	Slope length factor (absolute)	Raster

Log10Slope _IndD	Log10 of Slope length factor (absolute)	Raster

Notes & limitations (demand)

- The freely available European scale soil data are at a very coarse resolution (1:1,000,000) and therefore does not reflect the local changes in soil properties at the county scale. However, this is currently the only soil dataset that covers the UK and is available for use at no cost.
- Soil and land use characteristics are assumed to be homogeneous for each single raster cell.
- Water flows along its pathway from one cell to another and is not partitioned between multiple downstream cells (Liu & Smedt 2004).
- The water purification services carried out by habitat features that are too fine sale to be captured by MasterMap, such as hedgerows and treelines, are not captured by this model.
- Uncertainty will be introduced by the BaseMap, which is not a completely accurate representation of habitat presence and land use, but is EcoServ-GIS's compilation of best available information.
- Due to the use of slope steepness, flow length / flow accumulation in the modelling the service will not be mapped well in larger areas of flat, lowland agricultural land. In such area aquatic habitats or large expanses of e.g. reedbed may deliver this service, but there are not highlighted well by this current mapping method.

Modifications and actions to improve the model (demand)

- Forestry operations on steep slopes may generate large sediment loads, these impacts could be included in future model versions in order to highlight woodland stream buffers.
- Societal demand indicators could be developed, for example using location of beneficiaries of drinking water extraction, or local population density per catchment.

ES3 Water Purification Service Flow Maps

This model overlays the Demand and Capacity maps to illustrate how well they align. The combined maps are then used to illustrate those areas where it is predicted people benefit from this ecosystem service (Benefiting Areas) or where interventions could be planned (Management Zones). The areas of Demand and Capacity are split into quintiles by value (or optionally by area) and these are used to identify categories from Highest to Lowest. Additionally those areas with capacity to deliver the service, within areas of demand, and which hold existing greenspace cover are identified as green infrastructure assets (GI_assets).

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required. Click OK to run the tool

ES3 Service Flows model inputs
ModelOutputs\ES2Water_purification_regulation \Outputs.gdb

Input data	Description	Data type
WaterPurification_Capacity	Estimated water purification capacity (relative to all cells in study area.	Raster
WaterPurification_Demand	The demand for water purification across the study area.	Raster

ES3 Service Flows model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010
Set extent of service maps	StudyArea	This sets the area for which the Flows are mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.
Use quintiles by value	Yes	Capacity and Demand scores are split into five equal interval classes
Use quintiles by area	No	Capacity and Demand scores are split into five classes of equal area
BaseMap _FINAL	BaseMap _FINAL	The available habitat map used to map the habitats in the Masks below.
Mask 1	NOT: Water, Sea, urban, Infrastructure	Identifies all areas with management potential for change (greenspace areas and semi-natural habitats)
Mask 2	Urban	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring within all areas of mapped demand
Mask 3	Infrastructure	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring only within areas of highest or high mapped demand
Run Mask 2	No	Select to run the mask analysis
Run Mask 3	No	Select to run the mask analysis
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)
Set minimum patch size for shapefiles	200	Set threshold to omit small polygons during shapefiles conversion

Model outputs are created in the "Outputs" geodatabase for:

- ESBA and Gaps, ESBA and Gaps Prioritised, ESBA Management Zones, GI assets
- See Section 3.1 and Table 9 for definitions of these outputs.

8.4.7 Accessible Nature Toolbox

Tool Development: Chloe Bellamy (40%), Jonathan Winn (60%)

Greenspace and semi-natural areas within or near urban localities provide ecosystem services that are important to local residents' quality of life, such as recreation and cultural values (Bolund & Hunhammar 1999). Well-designed urban areas, achieved through active planning can lead to a greater quality of life, including mental and physical health of the residents (Barton 2009). There is now substantial support in the academic (Jorgensen & Gobster 2010; Haines-Young & Potschin 2010; Clark et al. 2014), policy (Balfour & Allen 2014; Faculty of Public Health 2010; Aked et al. 2008), and agency (CABE 2010; Greenspace 2011; Forest Research 2010; Greenspace Scotland 2008; Dempsey et al. 2007; LUC 2004), literature for the benefits to human health of greenspace provision, access and use, although the exact benefits, and beneficiaries, may differ between populations and localities, and causal mechanisms can be complex (Miller & Morrice 2014).

Several reviews note particular benefits of access to greenspace (Croucher et al. 2008; Faculty of Public Health 2010; Forest Research 2010). These reviews note:

- Improvements in levels of physical activity, life expectancy and reduced health inequality
- Promotion of psychological health and mental well-being.
- Sites must be of sufficient size, be accessible and well connected to residential areas to be of most benefit and support use by high volumes of people.
- People who use greenspace the most usually live nearby.
- Local authorities should provide more accessible green spaces and open-air leisure facilities in which children, families, adults and older people can safely play and exercise.
- Local strategic partnerships, especially those in urban areas, should maximise the use of available greenspace for health-promoting activities.
- GPs should consider providing advice about physical activity in greenspace as an alternative or adjunct to medication for patients with milder forms of depression or anxiety.
- Exercise prescription schemes in general practice could usefully be extended to cover supervised physical activity in greenspaces.
- Programmes, such as *Walking for Health*, which encourage physical activity in greenspaces and natural environments should be fully supported.

Guidance in Scotland indicates a number of features of greenspace that are considered to promote physical activity (and thus health) (Greenspace Scotland 2008): Distance from residence, ease of access, size, connectivity, attractiveness, and multi-use features.
A wide range of additional research in the area of greenspace accessibility, health, spatial analysis and planning exist. The following insights were used to help construct the current GIS service model:

Site attractiveness, naturalness and accessibility

- "Naturalness" features are important to urban park users, such as richness of bird and plant species, biological diversity and natural design (Bertram & Rehdanz 2014).
- Site features including aesthetics promote use by people, but support is less clear, for example, than the impact of accessibility in promoting use (Bauman & Bull 2007).

Site attractiveness, naturalness, biodiversity and human benefits

- There are positive effects of activity in natural environment settings on well-being compared to similar levels of activity in "synthetic" environments (Diana E Bowler et al. 2010). Such benefits are separate from the additional pull factors of natural greenspace on length or frequency of use.

- Surveys in Finland found a positive association between reported well-being and participation in nature-based recreation (Korpela et al. 2014).
- Research in urban parks indicated measures of well-being were positively associated with perceived biodiversity levels in parks (mainly species richness), and that for plants perceived richness was related to measured richness levels (Fuller et al. 2007).
- In Italy results from a self reported study found that higher natural settings (higher biodiversity level) was associated with a higher perceived restorativeness of visits to greenspace (Carrus et al. 2015).
- Perceived naturalness scores have been used to study *wildness* in Scotland, averaged across 250 m cells to account for how local landscape pattern impacts on how individuals may experience their landscape (Carver et al. 2011).
- Studies have examined links between public well-being and measured species richness in riparian greenspace sites and found no correlation, illustrating the complexity of linking site features of naturalness, species richness or broader biodiversity measures to well-being (Dallimer et al. 2012). Interestingly however, the study found a positive correlation between public perceived species richness and resulting well-being at greenspace sites.
- In Holland examination of street "greenery" found positive relationships at the street and neighbourhood level with self reported mental and physical health levels (particularly for stress) (De Vries et al. 2013).
- The "Mappiness" study in the UK examined the association between self-reported well-being and location, and found higher well-being levels in green and natural habitats compared to urban environments (MacKerron & Mourato 2013).
- The public may hold different levels of perception of site naturalness or biodiversity compared to professional groups or specialists (Hofmann et al. 2012). Woodland habitats, and degree of canopy closure at sites are noted by the public as characteristic "natural" features of greenspace (Hofmann et al. 2012; Dallimer et al. 2012).
- Research of public parks in Scandinavia showed that observers felt that parks were more restorative if they were more generally green, had a cover of trees and shrubs, and were larger (Nordh et al. 2009). This study of small pockets parks, less than 3,000 m^2 (0.3 ha) highlights the importance of small urban greenspace sites.
- Reviews have highlighted the difficulty of summarising the influence of biodiversity *per se* on human health, as compared to the general benefits of greenspace or the outdoors (Clark et al. 2014).

Greenspace use is affected by site accessibility and desirability

- Different user groups exist for greenspaces, and visits may be motivated by different reasons (Conedera et al. 2015).
- Neighbourhood greenspace availability “was positively associated with likelihood of reporting full physical, occupational, and social participation” in a study of the influence of local land use characteristics and features on activity levels in disabled adults using two scales of analysis (neighbourhood 800 m, community 8 km) (Botticello et al. 2014).
- Reviews indicate that physical activity levels are linked to accessibility, proximity and ease of walkability (Bauman & Bull 2007).
- Many studies have indicated that use and access of sites for recreation reduces with travel distance (Giles-Corti & Donovan 2002; TNS 2014; Natural England 2015a; Nielsen & Hansen 2007; Coombes et al. 2010).
- A large study in England found that recreational walking was positively associated with % of greenspace (excl. gardens) at the local (1.7), 5, and 10 km scales (Lachowycz & Jones 2014).
- Frequency, or likelihood, of recreation visits is often influenced by site size, larger sites being more regularly or consistently used (Giles-Corti et al. 2005).
- In rural areas in England there is higher recreational physical activity, and recreational walking, compared to urban areas, the increased activity in these greener areas is not just related to more active rural jobs (Rind & Jones 2011).

Societal need for the benefits of access to nature varies spatially

- A large study in England found that mortality from all causes, and from circulatory disease, differs between populations with different exposure levels to greenspace. Physical environment can influence health inequalities (Mitchell & Popham 2008).
- Recent work in Scotland showed that mothers' perceived distance from nearby greenspace is associated with length of TV viewing in children of 6 yrs old (Aggio et al. 2015). Children in the most distant groups >20 min from greenspace also tended to have lower mental and physical health scores than those in the nearest group <5 min to greenspace. Because sedentary behaviour can be detrimental to health then this is of concern. Distances were self reported but are approximately <5 min (<300 m) compared to >20 min (>1,200 m)
- In New Zealand, both access to useable greenspace and increased proportion of greenspace in the larger neighbourhood were associated with decreased anxiety / mood disorder counts, as reported to doctors (Nutsford et al. 2013).
- Several studies have examined greenspace quality and type, in addition to coverage or area. In Australia, researchers examined the number, proportion and type of greenspace within 1,000 m network distance of residents homes, and assessed relationships to mental and physical health. Greenness, size and type of greenspace were inversely related to cardio metabolic risk (Paquet et al. 2013). The study is of interest in noting that it is not necessarily the number or proportion of nearby sites that is important to people, but the characteristics of those sites.
- There is most demand for greenspace in the central areas of municipalities where areas are surrounded by dense housing (La Rosa 2014).

Societal need for the benefits of access to nature varies between different populations

- In England research found that there was a relationship between greenspace occurrence and reduced cardiovascular mortality, but only amongst the most deprived areas of the community, and the relationship could not be explained just by increased levels of recreational walking (Lachowycz & Jones 2014).
- In Holland 15 out of 24 disease clusters had lower than expected rates in areas with more greenspace within 1 km of homes (Maas et al. 2009). The relationship was shown to be particularly important for children and lower socioeconomic groups (Maas et al. 2009).
- Other studies in Holland found similar positive relationship between self reported perceived health levels and the occurrence of greenspace at 1 and 3 km radius, again stronger impacts being shown in more deprived socio-economic groups (Maas et al. 2006).

Site management and ecosystem service planning

- There is now increasing interest and support for the active promotion of the benefits of nature to support health and well-being (Carpenter 2013).
- Examination of recreational access areas in relation to green infrastructure has been mapped for use in city scale planning (Caspersen & Olafsson 2010).
- Accessibility to greenspace varies, areas have different resources in terms of service supply and demand (Balfour & Allen 2014).
- There is now policy support for more accessible greenspace to address health (Balfour & Allen 2014).
- Levels of greenspace have varied in cities over time, both up and down (Dallimer et al. 2011), and therefore there are opportunities to influence availability of this changing resource, via land use planning.
- Likely future trends in outdoor recreation use in Scotland suggest that any success in increasing participation is likely to require intervention, that recreation activities will be concentrated into hotspots, and there will be a key need to “provide quality outdoor

recreation opportunities, infrastructure and services, particularly in proximity to places of work and residence" (Brown et al. 2010).
- Recent research showed that every 1% increase in the proportion of useable or total green space (within 3 km) was associated with a 4% lower anxiety or mood disorder treatment rate (Nutsford et al. 2013). Similarly every 100 m decrease in distance to the nearest useable green space resulted in a 3% lower anxiety or mood disorder treatment rate (Nutsford et al. 2013).

Information on the demand for accessible recreation locations is available in Britain (Greenspace 2007), England (Natural England 2015a) and Scotland (TNS 2014). British surveys have indicated that 92% of respondents visited parks and greenspaces, 70% of which were regular visitors (Greenspace 2007). Recent data from 2013-2014 for Scotland (Sc) and England (En) show that of visits to the natural environment (greenspace, opens spaces, the wider countryside and coast): 64% (En) to 66% (Sc) were on foot, 68% (En) to 60% (Sc) were within 2 miles (3.2 km) of start point, and 83% (En) to 85% (Sc) were within 5 miles (8 km) of start point.

Several previous studies have mapped the ecosystem service of recreation, access to nature or accessible nature (Herzele & Wiedemann 2003; East Midlands Regional Assembly & Partners 2006a; Kienast et al. 2012; Peña et al. 2015; Paracchini et al. 2014). However, the majority of existing research has examined demand or supply in isolation and few attempt to predict the flow of benefits. A good overview of the issues needed to consider when assessing greenspace access is presented by (Herzele & Wiedemann 2003). The importance of urban greenspace has now been recognised at a government level, for example in Scotland with the production of national greenspace mapping (AECOM 2011). Recent research highlights how it is important to consider both the supply and demand of cultural ecosystem services (Peña et al. 2015).

Studies that have examined accessibility and benefits of greenspace have used a wide range of distance, connectivity or proximity measures together with variable definitions of greenspace, site types or area. A particular issue that emerges is whether the benefits link most to overall levels of greenness in the local environment (not necessarily fully accessible), or to specific accessible areas, such as the nearest useable greenspace. Many studies examine the proportion of total greenspace within a distance buffer. It is then unclear how much of this resource is actually accessible to people. Only several health studies have actually assessed useable and accessible greenspace e.g. (Nutsford et al. 2013; Aggio et al. 2015; Nielsen & Hansen 2007).

Caution must be used in the interpretation of the associations between greenspace, access and health. Many factors inter-relate and the results of studies are often strongly influenced by the methods chosen. For example in Stoke a negative relationship was found between use and access distance to recreational greenspace (>2 ha) in sunnier weather, but a positive relationship during wetter weather (Cochrane et al. 2009). This was interpreted that in those areas with poor greenspace access levels, the residents may be prepared to walk further to access sites outside their area in times of good weather, but to stay more locally when the weather was bad (Cochrane et al. 2009). A recent government project in Scotland found no evidence of a relationship between the amount of greenspace in urban neighbourhoods and mortality or measures of morbidity. The exception was men living in deprived urban areas, where higher amounts of local greenspace were associated with a lower risk of mortality (Miller & Morrice 2014). This Scottish study also found no relationship to mental wellbeing, however "regular use of woods and forests appeared to be more protective of mental health than exercising in the gym or streets" (Miller & Morrice 2014).

In summary, greenspace can be beneficial to people by encouraging physical activity, both within greenspace itself but potentially also in the wider community, it may also be associated with other physical and mental health benefits which again may be related both to access within accessible greenspace sites, but also to general neighbourhood or local greenness levels. Pathways to explain the wider benefit of inaccessible greenspace include stress reduction and related community effects. Several studies indicate there is most demand for access to nature in deprived socio-economic communities (Maas et al. 2009; Miller & Morrice 2014; Mitchell & Popham 2008). The implications are complex, because use and access to greenspace is known to differ between different socio-economic groups (Kabisch & Haase 2014). Research has reported higher covers of vegetation, i.e. greener neighbourhoods, being related to higher socio-economic conditions (Pauleit et al. 2005; Pham et al. 2012). The quality of greenspace sites may also differ between areas such that certain neighbourhoods may experience multiple environmental deprivation. A final point relates to the issue of the inclusion of gardens. Gardens, as a form of greenspace, have received mixed research (Cameron et al. 2012), but the occurrence of gardens is known to vary between different types of housing stock and therefore the relative balance and importance of gardens versus other forms of greenspace to health and well-being is likely to vary. Studies have variously included or excluded gardens in their measures of greenspace links to health.

ES1 Accessible Nature Capacity

Models the availability of natural areas and scores them by their perceived level of naturalness.

- The frequency, or likelihood, of use of a site may be linked to site attractiveness, or site area as a proxy.
- The accessibility and connectedness of sites will affect their use and value to people.
- Naturalness or diversity features of a site may enhance the benefit of visits, or be a motivating factor for users to visit sites.
- Perceived biodiversity levels may be linked to reported well-being levels at greenspace sites.
- Perceived naturalness scores can be attributed to habitat types to indicate public perception of experience levels near, or within, such habitats.
- There are thresholds of site size, below which there is reduced, or no, capacity for the service, however the potential of very small pocket parks in urban areas should not be underestimated.

Areas of "Accessible" greenspace are mapped in order to indicate the areas where the service is most likely to occur. These are legally publicly accessible areas in England and Wales, and in Scotland indicate those areas of most likely public use. Private land, or land where access is not actively promoted, is considered to block the flow of this service because members of the public are not able, or likely, to access the site. Accessible areas are:

- 10 m either side of linear routes
    - Public Right of Way (England and Wales) or Core Path (Scotland)
    - Pavements (modelled from MasterMap, with areas along Motorways and Dual Carriageways removed)
    - Long distance walking route (GB)
    - Sustrans cycle route (GB)
    - Forestry Commission recreation route (GB)
- Publicly accessible areas and areas promoted for public use
    - Country parks (England and Scotland), data not available for Wales
    - Countryside Rights of Way access (England and Wales)
    - Local Nature Reserves, National Nature Reserves (GB)
    - Beaches and 100 m swim distance from them
    - Accessible woodlands ("Woodlands for People") mapped by the Woodland Trust
- All areas of Green Infrastructure labelled as "accessible" during the creation of the BaseMap models (see BaseMap Technical Report)
    - Typically: Playgrounds, general amenity greenspace, cemeteries, parks and public gardens and other areas mapped as accessible by Local Authority Open Space Surveys or Greenspace Scotland map

Protected area status, or measures of conservation importance (e.g. SSSSI status) were not used as indicators of accessible nature capacity because the general public may not be sensitive to the differences between sub types of rare habitats. Recent work in England tested the network of protected sites in different tiers against several measures of a coherent ecological network, one of which included measures of accessibility. Analysis showed the importance of Local Nature Reserves and Local Wildlife Sites in being accessible within urban areas whilst a lower percentage of other protected site categories (SSSI, AONB etc) occurred in, or near to, urban areas (Lawton et al. 2010).

Measures of perceived naturalness were selected to map site capacity. Natural habitats are scored based on results from two tranquillity and wilderness mapping studies which collected survey data on the public's perceived naturalness of different land cover types in England (Jackson et al. 2008) and Scotland (Carver et al. 2011; Carver et al. 2008), and applied these to Land Cover 2007 data habitat categories for mapping. We averaged the habitat scores from the two studies and assigned scores to the closest matching habitat categories identified in the BaseMap (See "Naturalness" field, and habitat link table in the toolkit). Areas classified as a mixture of habitat types were assigned the lowest naturalness score of any habitat present.

Several studies indicate that more diverse, natural, or higher biodiversity areas are important motivating factors for site use, or give higher benefits to people (Bertram & Rehdanz 2014; Bauman & Bull 2007; Diana E Bowler et al. 2010; Fuller et al. 2007; Carrus et al. 2015). Perceived naturalness scores were used because studies indicate that the public gain well-being benefits from habitats that are perceived to be more natural, or of higher biodiversity (Dallimer et al. 2012; Fuller et al. 2007).

Analysis is applied to "sites" above a user defined threshold. Accessible greenspace areas are identified. Naturalness scores are analysed to derive an indicator that represent naturalness at the site, and within a focal distance, to capture visitors experience of the nearby local environment. Focal analysis sums the scores of all cells within the selected local distance (default 300 m) for all areas of greenspace. This represent a typical local experience score that a person may experience as they undertake a short distance walk within the site. A 300 m distance relates to a short 5 min walk, once within a site. Non greenspace areas do not receive a capacity score. The focal search score and the cell based patch score are combined. The resulting score is standardised and represents the unrestricted accessible nature capacity. The same analysis is then conducted for all areas, rather than just accessible areas, to create score for all greenspace areas - the restricted accessible nature capacity.

A small site area threshold of 0.05 ha (500 m^2) is used because small pocket parks may be important sources of accessible nature in built up areas, and cumulatively these may contribute to neighbourhood character. This is smaller than the thresholds currently used in most accessibility analysis. The parameter can be altered by toolkit users to match local conditions.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click  icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES2 Capacity model inputs

Input data	Description	Data type	Save to
BaseMap_Final	Base Map (detailed habitat & land use map)	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
OSRoads	VectorMap Roads data	Vector (polyline)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
GI_Types	GI types mapped from GI or Open Space data	Vector (polyline)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
<u>Various access data</u> FC_recreation_routes_GB Country_parks_Eng_Scot Sustrans, LNR_GB, NNR_GB, Woods4People, Crow, Long_distance_path_Eng_ Scot, PROW _CORE_Paths	Access areas and routes	Vector (polyline) (polygon)	Saved to: ModelInputs\ES0CommonFiles \Inputs.gdb

ES2 Capacity model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	Tutorial Cell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m.
Focal distance for local naturalness score	300 m	Search distance (radius) applied to calculate the cumulative sum of naturalness values
Buffer distance for linear access features	10 m	Distance used to buffer linear access route features for analysis
Site area threshold (m)	500 m^2	Threshold area of individual greenspace, or accessible greenspace "patches" below which capacity is assumed to be zero (polygon site analysis). These are then removed from the analysis and do not contribute to the calculation

Parameter	Default	Explanation
		of the local sum naturalness score.
Minimum patch size (m)	500 m^2	Minimum size of areas below which an area is not considered to have capacity to significantly deliver the service. Note this is based on mapped capacity, not mapped greenspace areas, and therefore each "patch" includes any buffering or distance analysis. (raster patch analysis)
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Capacity is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended
Run access restrictions variables?	Yes	Include analysis of areas within and outside public access and use areas
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)

ES2 Capacity model outputs (ModelOutputs\ES3Access_nature_cultural \Outputs.gdb)

Output data	Description	Data type
Accessible_Nature_Capacity	The capacity for people to experience the benefits of natural landscapes	Raster
Accessible_Nature_CapacityUnrestricted	The capacity for people to experience the benefits of natural landscapes in publically accessible areas	Raster

ES2 Capacity model indicators (main)
(ModelOutputs\ ES3Access_nature_cultural \Indicators.gdb)

Indicator data	Description	Data type
Accessible_IndC	Areas defined as accessible to the public	Vector (polygon)
BaseMap_Accessible_Greenspace_IndC	All accessible greenspace areas	Vector (polygon)
BaseMap_Accessible_IndC	The BaseMap_FINAL data clipped to show only accessible areas	Vector (polygon)
BaseMap_Greenspace_ALL_IndC	All greenspace areas (accessible, non accessible and unknown)	Vector (polygon)
Local_Naturalness_SUM_IndC	Sum of naturalness score for greenspace sites within the local search neighbourhood, mapped to greenspace sites only	Raster
Local_Naturalness_SUM_Unr_IndC	Sum of naturalness score for greenspace sites within the local search neighbourhood, mapped to accessible greenspace sites only	Raster
Pavements1_IndC	Pavements (predicted) mapped from the BaseMap_FINAL data, excluding areas along motorways or dual carriageways	Vector (polygon)

Note - Several additional indicators are also produced, see Technical Report.

Notes & Limitations (capacity)

- No UK dataset exists which shows levels of access to each land use parcel. We therefore had to make assumptions on what land use types are generally accessible, but this method will not correctly identify all publically accessible greenspace.

- The identification of accessible areas is reliant on how accurate and comprehensive the input data are for: GI / Open Space, LNR, NNR, CROW Act land, PROW_Core_Paths, Sustrans. In rare cases these designations may not actually be publicly accessible.
- In particular where GI / Open Space survey data has been poorly mapped or contains multiple categories it may be unclear which areas are publicly accessible.
- The model assumes that areas identified as Man-made and Roadside within OS MasterMap data are pavements and that these areas are generally publicly accessible. In the vast majority of cases this is true, however in a minority of areas, such as private business parks or industrial estates there may not be public access and this data from pavements will be inaccurate.
- PROW_Core_Paths data vary in accuracy and will not reflect all public footpaths.

Modifications and actions to improve the model (capacity)
- The use of further literature to enable naturalness scores to be linked to a finer resolution or sub categories of habitat would be useful (such scores would ideally also be related to different human population characteristics).

ES2 Accessible Nature Demand

This model estimates the societal demand (need) for opportunities to access and enjoy natural landscapes across the study area by estimating the number of people likely to travel to an area for this activity and their need for the related health benefits.

- Parks and urban greenspace sites are particularly important for people.
- The demand for accessible nature is highest at short distances, near where people live, and declines with travel distance.
- Ideally mapping will use access points and detailed accessibility information.
- Ideally network analysis rather than buffer analysis would be used to map access demand.
- Most people travel to use greenspace sites on foot.
- Distance buffers can be used to assess the catchment population, and hence demand for individual sites.
- Site size can be used as a proxy for site attractiveness, likely occurrence of significant features and likelihood of longer distance travel by people.
- There is a higher societal need for accessible nature benefits in neighbourhoods with lower socio-economic conditions or higher levels of deprivation.
- Ideally demand mapping would not use set uniform standards, but would adapt these to local socio-economic characteristics such as preferences or likelihood for different transport types, age, mobility, health, and access to transport.

The literature review indicated that key determinants of demand were: site attractiveness, site proximity and local population characteristics.

Analysis created 3 indicators, each repeated at three spatial scales, to capture the different characteristic of use of local, versus more distant greenspace areas. The individual indicators and the way the indicators are combined across spatial scales can be altered by the user, although recommended defaults are applied.

Analysis method choice can result in different forms of demand maps. For example data can be attributed to either trip sources (homes), or to destination areas (greenspaces), e.g. the number of people within a set distance of a greenspace can be attributed to each greenspace. The later approach is recommended when the aim is to analyse and understand the demand for greenspace areas (La Rosa 2014).

Indicators for population density, local mean population health scores and distance to the nearest access points or footpaths are then calculated at each of three spatial scales, with the results applied to three scales of greenspace sites. Population size and general health scores from the Index of Multiple Deprivation (IMD) are used to indicate relative societal need or demand for the service. We do not refer to conscious demand for the health benefits of the service, we simply note that in areas of higher population or where general health is poorer that if people had access to semi-natural areas for recreation that there would be a higher general benefit to the population than in either areas of lower population or where health levels are currently high. As such the method does focus on marginal change in human benefits and not on maintaining the current health level of good health areas.

In order to account for limitations in both the mapping rules that identify domestic buildings and the reliability of the population size and Multiple Index of Deprivation statistics at low population density, thresholds are applied to the Local (default > 50) , Landscape (default > 500) and Region (default > 1,000) population measures. These can be modified by users.

Site access indicators are created for the three scales of greenspace site. A selection and modification of the data used to map publicly accessible areas are used to map each access indicator score as a proxy measure for travel demand to each type of site. For local scale greenspace sites, the areas will mainly be accessed by people on foot. A distance analysis from all pavements, surfaced paths, PROW / CORE paths and Sustrans cycle routes is mapped (default 600 m). The landscape scale analysis assumes that some site users may walk to the site whilst other will arrive by vehicle. Analysis examines the transport stop location (XY stops data) and also a dataset that generates a proxy for access points to parks, country parks or areas of the countryside. This data is generated by finding points of intersection between surfaced roads and any PROW / CORE paths, Sustrans cycle routes, FC recreation routes, or long distance paths. These are proxies for the locations of car parks, lay-bys or visitor centres at which people may park before walking in the countryside. The data is likely to overestimate these sites. Users can add local data by replacing the XY stops dataset with point data on car park locations, or these can be merged with the XY stops data. The default landscape travel distance is 2.4 km. The same analysis is conducted for region scale analysis again using a default walking distance of 2.4 km. The access distance scores are all masked to the mapped greenspace sites at each analysis scale. All scores are then inverted on a 1 to 100 scale, with 100 representing the areas very close to the access route or access point.

Three categories of greenspace are mapped in order to represent sites that are used locally, e.g. by walking or more distant sites that are likely to be accessed by cycling or vehicles or public transport.

Greenspace is identified as all areas of the BaseMap excluding gardens, water, sea, built up areas, infrastructure, paths and pavements. Agricultural areas are retained. Site area is identified in order to allow sites to be selected by size category. Analysis is used to dissolve boundaries between adjacent green areas, leaving sites split by roads or built up areas. This allow smaller urban greenspace sites to be identified, although rural areas often remain classified as several very large contiguous "sites" with this method. This method is then used to separately identify *local*, *landscape* and *region* scale greenspace sites. Default sizes applied are: 0.1 ha, 10 ha and 100 ha. Each category includes all sites above the size threshold, therefore the three data layers will overlap in many areas.

Guidance for setting accessibility standards for Local Authorities often use a short distance catchment of 300 m, from buffer analysis, to show that all populations should have access to a greenspace site within 5 min walk. This distance is considered too fine a resolution and too simplistic to use to assess the accessible nature resource at a local scale, where people may have a choice of several nearby sites, rather than just use their nearest site. Available evidence on typical travel distances was used to set three (*local*, *landscape*, *region*) catchment analysis distances. Most trips to parks, greenspace or to access the natural environment are over short distances. The information resulting from Natural England's Monitoring of Engagement with the Natural Environment (MENE) study used questionnaires with estimated distance bands to track visits (Natural England 2015b). The data from 2011-2014 was downloaded and analysed. The survey used distance ranges, the midpoints of these have been used to map the cumulative occurrence of trips, split by transport types, and comparing all source locations, to those trips from home. The analysis indicates almost 90% of trips by walking are less than 2.4 km, whilst almost 70% of trips by car are less than 12.8 km.

In England, health analysis found recreational walking was positively associated with total % of greenspace (excl. gardens) at the local (1.7), 5, and 10 km scales (Lachowycz & Jones 2014), and with increased physical activity at the 1.7 km scale (Mytton et al. 2012). Also in England a large study showed the health benefits of greenspace cover across LSOA census areas, these zones have an approximate mean radius of 723 m (Mitchell & Popham 2008).

Studies reporting associations between mental health and greenspace at very short distances < 500 m have been variable and contradictory (Nutsford et al. 2013; Aggio et al. 2015). The majority of studies examining health benefits have measured the % cover of greenspace at local scales greater than 500 m, typically up to 1, or 3 km radius.

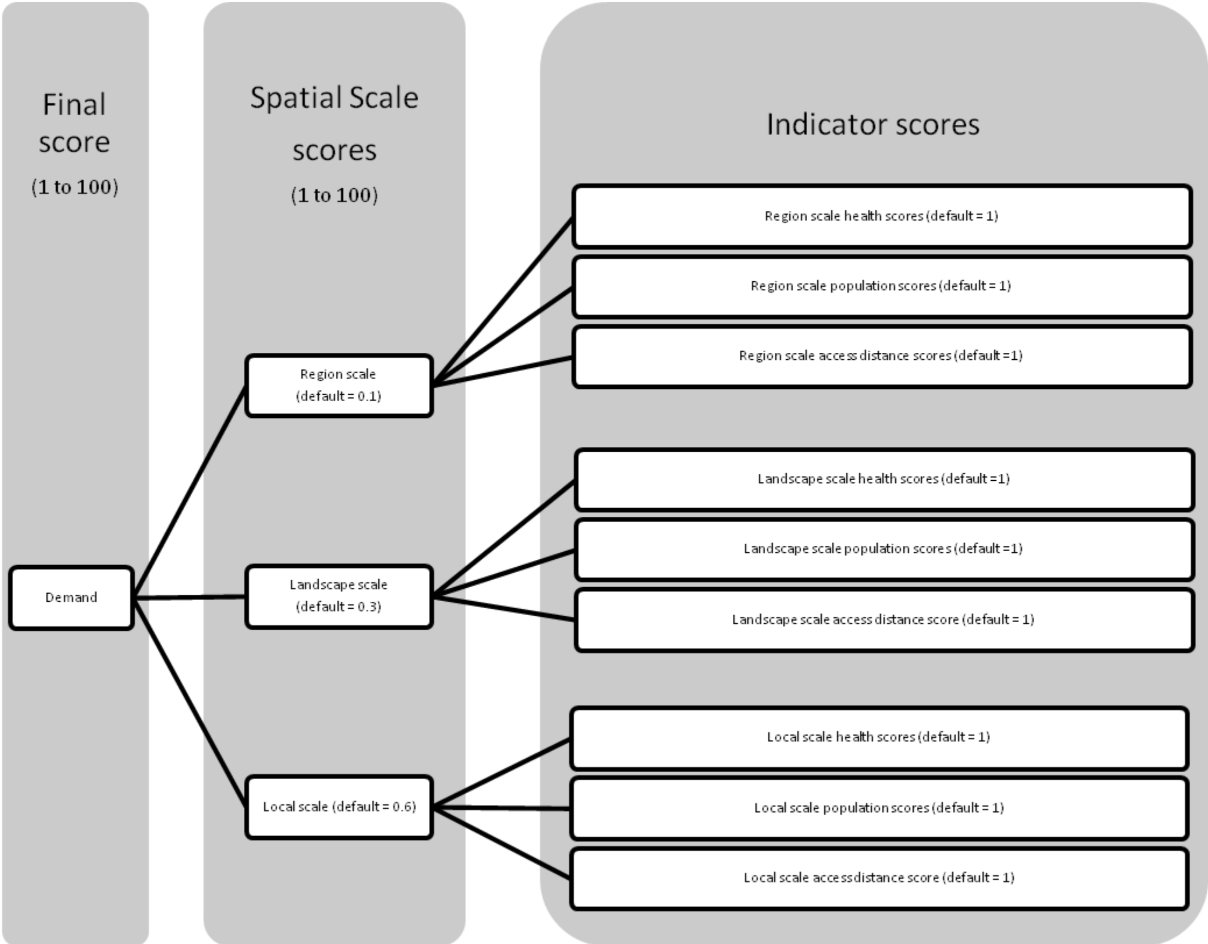
The insight from this range of studies was used to set the scales of analysis for demand catchment mapping at: *local* 0.6 km, *landscape* 2.4 km, *region* 12.8 km.

The scores for each spatial scale are combined to give most weighting to local scale factors, and only minor influence to region scale factors, to match the literature on greenspace site usage. The following values were selected to map the different scales of demand.

Table 30. Accessible nature demand analysis parameter settings

Catchment scale	Distance (radius) (km)	Site threshold (ha)	Travel method	Travel time estimate (min)			Score Weighting
				Walk	Cycle	Car	
Local	0.6	0.1	On foot	10	3	n/a	0.6
Landscape	2.4	10	On foot / vehicle	30	9	4	0.3
Region	12.8	100	Vehicle	n/a	48	20	0.1

Table 31. Accessible nature demand indicator weighting



Accessible Demand: Alternative model version

Two demand models have been produced. Users should clarify which is most appropriate for their Study Area and project purpose. The main model is described above and in the tables below. The method includes demand mapping that recognises that the size of greenspace contributes to demand. As such it may be considered to conflate issues of capacity and demand. A simplified "alternative" model has therefore also been included (this is similar to the versions present in Version 2.0 of EcoServ-GIS). This creates similar analysis with the following amendments:

- No greenspace analysis is conducted
- Demand is based on assessment of health, population and access scores
- Analysis is conducted at two scales only: local and landscape
- Results apply to all areas and thus give demand scores to areas of built environment, sealed surfaces and infrastructure.

In situations where future change in land use is of interest. e.g. in considering land use change from areas of sealed surfaces or developed land to alternative uses then this alternative model might be preferable. Other approaches could be to digitise any future created areas of greenspace into the BaseMap and run the main demand model. If the alternative demand model is used then users should test and be clear on the suitable settings for the "mask" analysis in the flow models (it may be appropriate to activate masks 2 and 3). Note that the datasets present in the Indicators.gdb may not match the data descriptions and should not be used for this model version.

To compare the outputs of both demand models the results would need to be moved and re-named.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES3 Demand model inputs

Input data	Description	Data type	Save to
Pop_socioec_points	Index of Multiple Deprivation scores and population data mapped to domestic buildings	Vector (point)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
BaseMap_FINAL	Base Map (detailed habitat & land use map)	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb
Pavements1_IndC	Predicted location of pavements	Vector (polygon)	No action needed. Already saved to: ModelInputs\ ES3Access_nature_cultural \Indicators.gdb
<u>Various access data</u> FC_recreation_routes_GB Country_parks_Eng_Scot Sustrans, LNR_GB, NNR_GB, Woods4People, Crow, Long_distance_path_Eng_Scot PROW_CORE_Paths, XY stops	Access areas and routes	Vector (polyline) (polygon)	Saved to: ModelInputs\ES0CommonFiles \Inputs.gdb

ES3 Demand model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m.
Greenspace habitats selection	Various	SQL selection to identify greenspace sites
Local greenspace area threshold	0.1 ha	Greenspace area below which there is assumed to be no demand for the service, at this scale
Landscape greenspace area threshold	10 ha	Greenspace area below which there is assumed to be no demand for the service, at this scale
Region greenspace area threshold	100 ha	Greenspace area below which there is assumed to be no demand for the service, at this scale
Local search neighbourhood	600 m	Search distance for population and health data
Landscape search neighbourhood	2,400 m	Search distance for population and health data
Region search neighbourhood	12,800 m	Search distance for population and health data
Local population threshold	50	Threshold below which population data is not used
Landscape population threshold	500	Threshold below which population data is not used
Region population threshold	1,000	Threshold below which population data is not used
Max access distance – local	600	Maximum use distance from access or entry points at a site
Max access distance – landscape	2,400	Maximum use distance from access or entry points at a site
Max access distance - region	2,400	Maximum use distance from access or entry points at a site
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Capacity is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended
Weight for local scale population scores	1	Weight that can be applied to the score before it is summed with other scores at this analysis scale to create the combined "local scale" score
Weight for landscape scale population scores	1	Weight that can be applied to the score before it is summed with other scores at this analysis scale to create the combined "landscape scale" score
Weight for region scale population	1	Weight that can be applied to the score before it is summed with other scores at this analysis scale to

Parameter	Default	Explanation
scores		create the combined "region scale" score
Weight for local scale health scores	1	Weight that can be applied to the score before it is summed with other scores at this analysis scale to create the combined "local scale" score
Weight for landscape scale health scores	1	Weight that can be applied to the score before it is summed with other scores at this analysis scale to create the combined "landscape scale" score
Weight for region scale health scores	1	Weight that can be applied to the score before it is summed with other scores at this analysis scale to create the combined "region scale" score
Weight for local scale access distance score	1	Weight that can be applied to the score before it is summed with other scores at this analysis scale to create the combined "local scale" score
Weight for local scale access distance score	1	Weight that can be applied to the score before it is summed with other scores at this analysis scale to create the combined "landscape scale" score
Weight for local scale access distance score	1	Weight that can be applied to the score before it is summed with other scores at this analysis scale to create the combined "region scale" score
Weight for combined local scores	0.6	Weight applied to the "local scale" score before it is summed with the other analysis scale scores
Weight for combined landscape scores	0.3	Weight applied to the "landscape scale" score before it is summed with the other analysis scale scores
Weight for combined region scores	0.1	Weight applied to the "region scale" score before it is summed with the other analysis scale scores
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)

ES3 Demand model outputs
(ModelOutputs\ES3Access_nature_cultural \Outputs.gdb)

Output data	Description	Data type
Accessible_Nature_Demand	Demand for accessible nature experiences	Raster

ES3 Demand model indicators
(ModelOutputs\ES3Access_nature_cultural \Indicators.gdb)

Indicator data	Description	Data type
AccessPoints_IndD	Proxy for the location of greenspace access points. These area all areas where linear access routes meet surfaced roads. These may represent access points to parks or the beginning of paths into the countryside from car parks, lay-bys or visitor centres.	Vector (points)
Greenspace _landscape_IndD	Greenspace sites above the landscape scale site area threshold	Vector (polygon)
Greenspace _local_IndD	Greenspace sites above the local scale site area threshold	Vector (polygon)
Greenspace_region_IndD	Greenspace sites above the region scale site	Vector

	area threshold	(polygon)
Landscape_Health_Scores_IndD	Mean health scores (IMD) within the landscape search neighbourhood	Raster
Landscape_popn_threshold_IndD	Population density above the landscape scale threshold	Raster
Local_Popn_Threshold_IndD	Population density above the local scale threshold	Raster
Log10_Land_Popn_IndD	Log10 conversion of the landscape scale population density (above threshold)	Raster
Log10_Local_Popn_IndD	Log10 conversion of the local scale population density (above threshold)	Raster
Log10_Regn_Popn_indD	Log10 conversion of the region scale population density (above threshold)	Raster
Min_Distance_Landscape_Access_ Inv_Score_IndD	Score (1 - 100) representing proximity to access points, landscape scale greenspace sites (high score, close proximity)	Raster
Min_Distance_Local_Access_ Inv_Score_IndD	Score (1 - 100) representing proximity to access points or routes, local scale greenspace sites (high score, close proximity)	Raster
Min_Distance_Region_Access_ Inv_Score_InD	Score (1 - 100) representing proximity to access points, region scale greenspace sites (high score, close proximity)	Raster
Region_Health_Scores_IndD	Mean health scores (IMD) within the region search neighbourhood	Raster
Region_popn_threshold_IndD	Population density above the region scale threshold	Raster

Note - Several additional indicators are also produced, see Technical Report.

Notes & Limitations (demand)

- The identification of Demand is limited by the way the model estimates both population size and typical health scores. These estimates will be more reliable in highly and densely populated areas compared to very sparse rural areas. The model currently addresses this issue by applying thresholds, below which population characteristics are not used. At present, these thresholds have been selected following visual examination of the data range within a variety of LSOA areas. They remain arbitrary and would benefit from further investigation and evidence to choose the appropriate threshold level.
- The identification of accessible areas is reliant on how accurate and comprehensive the input data are for; GI / Open Space, LNR, NNR, Crow Act land, PRoW, Sustrans.
- Distance is used to assess likely travel distance and likely use of sites by people. These can only be estimates of the probability of people accessing a site.

Modifications and actions to improve the model (demand)

- Euclidean distance is used to estimate likelihood of access and use of a site. Ideally future model enhancements would use actual travel routes to calculate distance, via least cost or network distance analysis.

ES3 Accessible Nature Service Flow Maps

This model overlays the Demand and Capacity maps to illustrate how well they align. The combined maps are then used to illustrate those areas where it is predicted people benefit from this ecosystem service (Benefiting Areas) or where interventions could be planned (Management Zones). The areas of Demand and Capacity are split into quintiles by value (or optionally by area) and these are used to identify categories from Highest to Lowest. Additionally those areas with capacity to deliver the service, within areas of demand, and which hold existing greenspace cover are identified as green infrastructure assets (GI_assets).

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES3 Service Flow Maps model inputs
ModelOutputs/ES3Access_nature_cultural /Outputs.gdb

Input data	Description	Data type
Accessible_Nature_Capacity	Accessible nature capacity across study area	Raster
Accessible_Nature_CapacityUnrestricted	Accessible nature capacity within publically accessible areas	Raster
Accessible_Nature_Demand	Accessible nature demand across the study area	Raster

ES3 Service Flow model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010
Set extent of service maps	StudyArea	This sets the area for which the Flows are mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.
Use quintiles by value	Yes	Capacity and Demand scores are split into five equal interval classes
Use quintiles by area	No	Capacity and Demand scores are split into five classes of equal area
BaseMap _FINAL	BaseMap _FINAL	The available habitat map used to map the habitats in the Masks below.
Mask 1	NOT: Water, Sea, urban, Infrastructure	Identifies all areas with management potential for change (greenspace areas and semi-natural habitats)
Mask 2	Urban	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring within all areas of mapped demand
Mask 3	Infrastructure	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring only within areas of highest or high mapped demand
Run Mask 2	No	Select to run the mask analysis
Run Mask 3	No	Select to run the mask analysis
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)
Set minimum patch size for shapefiles	200	Set threshold to omit small polygons during shapefiles conversion

Model outputs are created in the "Outputs" geodatabase for:

- ESBA and Gaps, ESBA and Gaps Prioritised, ESBA Management Zones, GI assets
- See Section 3.1 and Table 9 for definitions of these outputs.

8.4.8 Education Knowledge Toolbox

Tool Development: Chloe Bellamy (30%), Jonathan Winn (40%), Tom Fisher (30%)

The natural environment provides people with valuable opportunities to gain knowledge and practical skills. This may be informally through play (Fjùrtoft et al. 2000; Browning et al. 2013), or walks, via education events (Kimble 2014) or hobbies outside of school, via promoted or designed "nature trails" (Zimmerman & McClain 2014), via participation in citizen science (L. Davies et al. 2011), or from formal education within school time, or at residential education centres (Humberstone & Stan 2012; Collado et al. 2013). In addition, although an under-researched area, a recent review of the links between the environment and development in young childhood noted that access and use of greenspaces may be important for children's cognitive and motor development (Christian et al. 2015). Research in school students has found that higher connectedness to nature related to more holistic and innovative cognitive styles (Leong et al. 2014).

The education opportunities provided by the environment can be gained at any stage of life, but there is suggestion that early childhood experience of access to nature though e.g. play in woodland, can impact the use or likelihood of use of such areas later in life (Milligan & Bingley 2007). Additionally there is concern that reduced access to the outdoors and environmental experiences could impact on children's development and learning styles (Barratt Hacking et al. 2007). The notion that humans have a propensity for, and benefit from, connection to nature has been proposed (Wilson 1984; Kahn 1997). Recently the potential adverse effects of lack of such nature contact amongst children has been discussed via a potential "Nature Deficit Disorder" (Louv 2010), and this has often gained media and organisation attention (Moss & Young 2012). There is a relative lack of academic research directly examining this area. Research however has shown an association between exposure to the natural environment in children and attitudes to biodiversity and the natural world. Direct contact with nature can increase children's affinity with the natural world and affect later behaviour, such as intentions to further visit natural areas (Collado et al. 2013). Contact with nature in school children has been found to be positively associated with biophilia attitudes to wild species (W. Zhang et al. 2014). An interesting recent study of the broader psychological benefits of connection to nature found that those "individuals who were more emotionally attuned to natural beauty (i.e., those who perceive nature’s beauty) appear to reap the most positive benefits from being connected with nature" (J. W. Zhang et al. 2014). Although this is an area of active research it appears that exposure to nature via educational visits has potential to prime behaviours and experience for later life. This may be of increased importance given the concern that informal or recreation based access to nature is declining, for example with increased uptake of other activities or recreation (Pergams & Zaradic 2006).

Informal opportunities for knowledge generation or education occur where local neighbourhoods or nearby parks or greenspaces hold examples of habitats, ecosystems, or component species that might inspire thought, consideration or attention. Many such reserves include display panels or provide leaflets on the history, management or species present within the site, offering learning experiences, whilst guided walks may also be available.

The formal school environment presents many opportunities to incorporate the benefits of nature in learning. Recent reviews have reported benefits to school learning activities in the natural environment, including: increased awareness of environmental issues and natural science skills which may lead to the children adopting more sustainable and environmentally friendly behaviour now and in later life, greater motivation for studying science, improved educational attainment in a range of subjects, improved health and attention levels, better relationships between children, increased reported levels of self-efficacy and self-worth, motivation of otherwise apathetic children, and can help enforce school communities (KCL 2011; Rickinson et al. 2004). Outdoor activities and "fieldwork" can be particularly memorable to students and therefore help with learning and retention of facts (Rickinson et al. 2004). A review for Natural England highlighted several issues relevant to learning outside the classroom in natural environments (KCL 2010). These included that barriers exist to the effective delivery of learning in natural environments, there is a lack of a coordinated approach from the natural environment sector to working with schools at a local level, schools face a fear of accidents, the cost of trips or visits and teachers' confidence in using natural environments. The review recommended that schools be provided with a rationale for the benefits of learning in the natural environment, that staff should be given adequate support and that practices should be developed with providers that reflect local needs and opportunities (KCL 2010).

The exact benefits of the natural environment to learning and education in a formal school setting can be explored further. Reviews indicate that student's and pupil's education are impacted by the classroom and campus environment, both built and natural (Zandvliet 2014). The different situations where the benefits can occur are therefore: the school classroom, school grounds, visits to nearby areas, and residential education centres. In terms of frequency of occurrence, and therefore in likely strength of impact, these decline in this order.

Nature can be brought into the classroom as a topic for learning, but it can also be physically brought into class where specimens, species or vegetation are available from nearby sites for study. Research also indicates that classroom physical and environmental conditions can influence pupil education attainment levels (Barrett et al. 2015), and that students performance can be related to levels of nature exposure from school classroom and cafeteria windows, even after accounting for confounding variables between schools and student composition (Matsuoka 2010).

The presence of nature, habitats and vegetation within school grounds can also be important for education. Woodland, wildflower meadows and ponds offer obvious opportunities for learning about habitat and species identification, when available within school grounds. However, such habitats, if easily accessible to students, also offer opportunities for interaction with nature during free time, breaks or in lunch hour. Such interaction may then have benefits to educational outcomes at other times of the day. Research has shown that the volume of vegetation in school grounds can significantly influence the perceived restorativeness of play by students (Bagot et al. 2015). This impact of such stress reduction may then have a number of positive influences linked to behaviour, attention and learning, even some time after the exposure to nature. These further benefits are in common with those experienced from short trips to nearby sites, discussed below.

Access to nature at nearby greenspace sites, nature reserves or country parks can be used by schools to provide education opportunities not otherwise available within school. Such trips may be by foot or via short coach journeys. The availability of access to habitats such as woodland, rivers or meadows allows practical examples of such areas to be seen and experienced by students rather than learning through verbal lessons or media presentations. In examining different biodiversity learning environments in London a nature reserve visit was associated with considerable motivation experience for the children and allowed students to show a range of skills such as in species identification (Kimble 2014). The benefits of active learning in outdoor environments, and also the after effects of such exposure are becoming more fully appreciated. Research indicates that exposure to the natural environment can be beneficial for mental health and cognition (Bratman et al. 2015), thus fostering a positive learning environment. Some of these benefits are exemplified by the "Forest School" movement. These activities involve learning experiences centred around school woodlands or after short visits to nearby woodland sites, and have been reported to have positive impacts on education and behaviour, especially for some learning styles or personalities (O'Brien & Murray 2007). Research from a small cohort of Scottish school pupils showed that a Forest School (outdoor) environment was more restorative compared to indoor classroom settings (Roe & Aspinall 2011), additionally those students with the poorest behaviour initially were seen to benefit the most from the Forest Schools experience. This finding follows work that the use of natural settings for education activities can help to manage the behaviour of difficult children (Roe & Aspinall 2011).

Taken together, the body of work regarding formal education settings, indicates some interesting links between the natural environment and education and knowledge generation. It is difficult to quantify the exact benefits but due to the influence of access to the natural environment on attention, learning, memory and stress reduction that there are positive uses to be made of outdoor learning experiences, both formally by schools, and informally, where they occur in the immediate living environment. Several studies indicate that such benefits may be highest for those students with currently lower attainment levels, for example due to stress, attention deficit or anger issues. Therefore the benefits experienced are unlikely to be the same for different schools, school populations, or pupils, for example varying with socioeconomic group or age.

Outside of a formal education setting, there are also a number of studies which suggest how access to nature and the use of outdoor spaces may affect childhood cognitive development and mental health (Christian et al. 2015), factors which in turn might be expected to impact on educational attainment and knowledge in later life. There are therefore further indirect links between the natural environment and education. A recent cohort study in England found that poorer children (age: 3 to 5) in neighbourhoods with a higher cover of greenspace had fewer emotional problems, compared to less green neighbourhoods (Flouri et al. 2014). Research in rural America found that access to nearby nature or natural features was associated with the moderation of stressful life events in children (Wells & Evans 2003).

Few directly comparable mapping studies of the education ecosystem service were found during the review. However interesting work in the East Midlands, under the public benefits mapping system developed an education score based on the number of local schools and the index of deprivation education score (East Midlands Regional Assembly & Partners 2006b).

Several insights from the following research were used to construct the GIS model:

Capacity

- A study in Norway illustrated that different habitat types were used differently for play by children in a natural setting (Fjùrtoft et al. 2000), illustrating that more diverse sites might offer more capacity for play experience and the knowledge and education benefits that derive from these.
- An American study of young adults examined access to the natural environment (urban greenspace) compared to urban street environments (via a 50 min walk) led to improvements in mental health such as decreased anxiety, maintenance of positive effects and increased cognitive ability, such as attention span (Bratman et al. 2015). This shows the positive impacts of access to nature, although the authors noted the relationship was stronger for the stress reduction mental health benefits, and there was more mixed evidence for the cognitive benefits.
- A study in Michigan, America found that measures of students performance were related to levels of nature exposure from school classroom and cafeteria windows, even after accounting for confounding variables between schools and student composition (Matsuoka 2010).

- Forest School learning experiences centred around school woodlands or after short visits to nearby woodland sites, have been reported to have positive impacts on education and behaviour, especially for some learning styles or personalities (O'Brien & Murray 2007).
- School grounds and playgrounds can help provide a restorative setting for pupils and research has shown that the volume of vegetation in grounds can significantly influence the perceived restorativeness of play (Bagot et al. 2015).

Demand

- A wide range of support exists for the positive benefits of learning in natural environment settings but often these have not yet been effectively presented to decision makers (KCL 2011).
- Research from a small cohort of Scottish school pupils showed that a Forest School (outdoor) environment was more restorative compared to indoor classroom settings (Roe & Aspinall 2011), additionally those students with the poorest behaviour initially were seen to benefit the most from the forest schools experience.
- School location and multiple index of deprivation scores can be used to indicate demand for education benefits (East Midlands Regional Assembly & Partners 2006a).
- In a review of the links between the environment and development in young childhood a recent review noted that greenspaces may be important for children's cognitive and motor development, for example when comparing between neighbourhood or local landscape availability of natural play space (Christian et al. 2015).
- There is some indication that the impact of exposure to nature on children may influence behaviour more in urban than rural areas (Collado et al. 2015), suggesting demand increases with urbanisation.

ES1 Education Knowledge Capacity

Models the availability of semi-natural areas that are suitable for education activities and informal learning. These sites are graded according to the variety of nearby broad habitat types, from which children could learn.

- Accessible nature (greenspace, habitat, parks, school grounds) can be used for direct study, or as a location or setting for outdoor learning experiences.
- A more diverse local neighbourhood environment (both built and natural) offers more opportunity to learn and take notice, compared to more uniform local environment.
- Presence of greenspace and natural vegetation within school grounds may have particular benefits, especially where visible to students from within classrooms, or where accessible for use during play time.
- In the absence of strong guidance from the literature, number of broad habitats can be used as a proxy for site capacity. Site naturalness or site size could be alternative indicators of capacity.

To map capacity, areas of the natural environment are assumed to provide the opportunity to learn and gain skills. Areas of the BaseMap which are unclassified or uncertain are excluded. Arable land, and roads and rail verges are also excluded. All remaining habitat types are assumed to provide equal opportunities for education. Research suggests that sites with a variety of habitat types are better for play experience (Fjùrtoft et al. 2000). Diverse sites with more habitat types are logically considered to offer more opportunities for education than less diverse sites. Sites are therefore graded according to the variety of habitat types within an area that would be typically expected to be covered by a short local walk within the site (default 300 m). The greater the variety, the greater the capacity to provide education. A threshold is applied in order to aid the differentiation of sites, only areas with two or more habitat types within the search distance are considered to have capacity. Education is a service which occurs in situ; to gain knowledge from nature, children must be able to access a site. As such, capacity does not extend beyond the perimeter of accessible sites. A threshold is applied to identify sites which may be too small to support site visits or any level of education benefit use (default 0.5 ha).

Both restricted and unrestricted capacity areas are identified. Accessible areas are mapped in relation to a range of data sources used to identify legally accessible (England and Wales) or those sites more likely to be used (Scotland). The following data sources were used:

- 10 m either side of a Public Right of Way or Core Path, or pavement, or Sustrans National Cycle Network
- Areas with Countryside Rights of Way access (England and Wales)
- Beaches and a 100 m swim distance from these
- Local Nature Reserves and National Nature Reserves
- Playgrounds, general amenity greenspace, cemeteries, parks and public gardens
- Accessible woodlands (“Woodlands for People”) mapped by the Woodland Trust

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model” , from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES1 Capacity model inputs

Input data	Description	Data type	Save to
BaseMap_Final	Base Map (detailed habitat & land use map).	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
<u>Various access data</u> FC_recreation_routes_GB Country_parks_Eng_Scot Sustrans, LNR_GB, NNR_GB, Woods4People, Crow, Long_distance_path_Eng _Scot, PROW _CORE_Paths, XY stops	Access areas and routes	Vector (polyline) (polygon)	Saved to: ModelInputs\ES0CommonFile s \Inputs.gdb

ES1 Capacity model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m.
Buffer distance for linear access features	10 m	Distance used to buffer linear access features for analysis
Minimum site size	5,000 m^2	Threshold size below which greenspace sites are not considered to have capacity for education use
Neighbourhood search for Broad Habitat variety	300 m	Local search distance within which the variety of habitats is calculated
Minimum number of broad habitats in local search	2	Threshold habitat variety below which a site is not considered to have education use
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Capacity is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended

ES1 Capacity model outputs
ModelOutputs\ES3EducationKnowledge_cultural\Outputs.gdb

Output data	Description	Data type
Education_Capacity	The capacity for children to learn from the natural environment	Raster
Education_Capacity Unrestricted	The capacity for children to learn from the natural environment in publically accessible areas	Raster

ES1 Capacity model indicators
ModelOutputs\ES3EducationKnowledge_cultural\Indicators.gdb

Indicator data	Description	Data type
Accessible_IndC	Areas defined as accessible to the public	Vector (polygon)
AllGESHabVariety _IndC	Habitat variety within the local search distance	Raster
AllGESHabVariety2_ IndC	Habitat variety within the local search distance (cut to only Accessible areas)	Raster
GreenEducationSites _IndC	Green education sites greater than the minimum site threshold	Vector (polygon)
GreenEducationSites 2_IndC	Green education sites greater than the minimum site threshold (cut to only Accessible areas)	Vector (polygon)

Model limitations (capacity)

- The identification of accessible area is reliant on how accurate and comprehensive the input data are for: GI / Open Space, LNR, NNR, CROW Act land, PRoW, Core Paths, Sustrans. It is unlikely that these datasets will select all areas which are accessible to the public.
- The model assumes that areas identified as Manmade and Roadside within OS MasterMap data are pavements and that these areas are generally publicly accessible. In the vast majority of cases this is true, however in a minority of areas, such as private business parks or industrial estates there may not be public access and this data from pavements will be inaccurate.
- The model assumes that all broad habitat types provide equal opportunities for education and learning. Habitat types may vary according to their suitability for this activity (Fjùrtoft et al. 2000).
- The weighting applied to natural sites for education are based on a calculation of the variety of broad habitat types. Habitats can be classified according to a number of systems. Using a different system than the one used in EcoServ-GIS may provide different results. Further, using a system which classifies habitats at a finer scale than the broad scales applied in EcoServ-GIS may also provide different results.

Modifications and actions to improve the model (capacity)

- Future work could research the exact links between education use, learning and habitat diversity.
- Incorporate links to habitat patch size and quality.

ES2 Education Knowledge Demand

This model estimates the societal demand for opportunities to access natural areas for education and skill learning. It estimates the likelihood of people travelling to an area from an education establishment as well as the general need for education from the local and landscape scale population based on the number of children.

- Education and knowledge generation can be formal e.g. through schools, or more informally through general observation and experience in the natural environment, or via nature trails and walks.
- Use and exposure to the natural environment by children, e.g. via education visits, may help prime them for the positive benefits of use, later in life.
- Use of the outdoor and natural environment for education activities can have positive benefit to people, these may last beyond the site visit itself, and these may be more important for certain groups of society.
- Beneficial sub groups include those with behavioural issues impacting on learning, those who tend to have less access to, or who use greenspace less, such as lower socio economic groups. However much additional research is required in this area.
- Cost and fear of accidents may deter schools from undertaking visits to the natural environment.
- Distance to greenspace and semi-natural sites from schools may be considered a suitable correlate for cost of access and frequency of use for formal school education visits.
- Number of young people (<15) can be used as a proxy for the population with highest demand.
- Socioeconomic groups (e.g. IMD / SIMD) can be used to indicate those groups who have highest demand.

This model takes into account two broad areas: the need for green education sites for educational institutions and the need for green education sites for children to learn informally as part of their everyday lives. Indicators have been selected and weighted to reflect insights from the literature, but users can alter the weighting for example if only formal education use, or informal community use were of more interest.

The main indicators selected for use were:

- Number of young people in the local population (default <15)
- Education scores of the local population (IMD / SIMD)
- Travel distance from schools (buffer, Euclidean) (relative to a max travel distance, default 8 km)

These indicators are created as follows. The number of young people is calculated based on first calculating the local population size from the "House-pop" field in the "Pop_socioec" point dataset created by the BaseMap models. The local population size is then multiplied by data representing the proportion of the local population that is under a certain age. The default is under 15, "unprop15" field in the "Pop_socioec" point data. Other age ranges can also be analysed. The education scores are calculated from the relevant score in the Index of Multiple Deprivation (IMD / SIMD). Travel distance is based on the minimum Euclidean distance to the nearest school from the OSEducationFacilities dataset created by the BaseMaps. The score is inverted so that high scores represent the nearest distances. The scores are calculated based on a maximum travel distance. Therefore the travel distance scores have greater impact at the region and landscape, rather than local scales (see below for explanation of scales analysis). For each indicator type higher scores are representative of higher demand (higher number of young people, higher levels of education deprivation, closer distance to schools).

The overall level of demand is assumed to be higher at short distances closer to where young people live, and to schools. However it is noted that both family trips or school trips can offer significant educational benefits, but that the typical distance and frequency of both will tend to decline with distance from school or home. The analysis is therefore repeated at three spatial scales, and weighted by predicted impact on total demand.

The likelihood of trips occurring at the longer distances is assumed to be linked to the strength of attraction of the destination feature. Therefore at each scale the creation of each indicator analysis is "masked" to only return data for greenspace sites that fall within the following site-scale thresholds:

- Local scale greenspace sites - default > 1 ha
- Landscape scale greenspace sites - default > 10 ha
- Region scale greenspace sites - default > 100 ha

At each of the three scales: local, landscape and region, the indicators are first combined to create a single scale-specific score. The scores are given equal weight, although this can be altered by users. Indicators cannot be given a weight of 0.

The scores from the three scales are then combined to give a final score to each area of greenspace. This assumes that the value of the site at different scales is cumulative. If a site scores highly at both local and landscape scales it shows more demand than a site with just local high scores. This reflects its importance for local education use but also that it has a value for users who may travel there from more distant areas. In combining the three spatial scales more importance is given to local scores. The spatial scale weights can be altered by users. These weights can include 0, which would remove one of the spatial scales from the analysis, for example where only local scale or regional scale analysis was of interest. The default weight can be altered by users.

- Local scale (default 600 m) Importance weighting = 0.6
- Landscape scale (default 3 km) Importance weighting = 0.3
- Region scale (default 8 km) Importance weighting = 0.1

The default settings have been informed following examination of the literature and are intended to reflect the decreasing likelihood to travel to more distant sites but the greater attraction of larger greenspace sites. Because frequency of visits is assumed to be important for this service local sites have been given a higher importance weighting.

Education Demand: Alternative model version

Two demand models have been produced. Users should clarify which is most appropriate for their Study Area and project purpose. The main model is described above and in the tables below. The method includes demand mapping that recognises that the size of greenspace contributes to demand. As such it may be considered to conflate issues of capacity and demand. A simplified "alternative" model has therefore also been included (this is similar to the versions present in Version 2.0 of EcoServ-GIS). This creates similar analysis with the following amendments:

- No greenspace analysis is conducted
- Demand is based on assessment of education, population and school distance scores
- Analysis is conducted at two scales only: local and landscape
- Results apply to all areas and thus give demand scores to areas of built environment, sealed surfaces and infrastructure

In situations where future change in land use is of interest. e.g. in considering land use change from areas of sealed surfaces or developed land to alternative uses then this alternative model might be preferable. Other approaches could be to digitise any future created areas of greenspace into the BaseMap and run the main demand model. If the alternative demand model is used then users should test and be clear on the suitable settings for the "mask" analysis in the flow models (it may be appropriate to activate masks 2 and 3). Note that the datasets present in the Indicators.gdb may not match the data descriptions and should not be used for this model version.

To compare the outputs of both demand models the results would need to be moved and re-named.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model name and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES2 Demand model inputs

Input data	Description	Data type	Save to
BaseMap _FINAL	BaseMap habitat map	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb
Pop_socioec _points	Index of Multiple Deprivation scores and population data mapped to domestic buildings	Vector (point)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb
OSEducation Facility	Education facilities	Vector (point)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

ES2 Demand model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m.
Age range proportion	Un15prop	The default is the proportion of the Output Area population under 15. Other age categories are also included in the Pop_socioec_points data and can be selected by tying the field name.
Education score	EducatScor	The data field containing education scores used in the calculations.
Greenspace for Education habitat selection	Various SQL	Selection of BaseMap habitat types suitable for education usage.
Search neighbourhood distance(local)	600 m	Search distance used to calculate local population and education scores
Search neighbourhood distance(local)	3,000 m	Search distance used to calculate landscape population and education scores
Search	8,000 m	Search distance used to calculate region population and

neighbourhood distance(local)		education scores
Population threshold - local	50	Population threshold for local search areas to remove areas of sparse population density
Population threshold - landscape	500	Population threshold for landscape search areas to remove areas of sparse population density
Population threshold - region	1,000	Population threshold for region search areas to remove areas of sparse population density
Greenspace site area threshold - local	1	Site area threshold below which sites at this analysis scale are unlikely to be visited for education use
Greenspace site area threshold - local	10	Site area threshold below which sites at this analysis scale are unlikely to be visited for education use
Greenspace site area threshold - local	100	Site area threshold below which sites at this analysis scale are unlikely to be visited for education use
Maximum distance to schools - local	600 m	Search distance used measure distance to the nearest school at each analysis scale
Maximum distance to schools - landscape	3,000 m	Search distance used measure distance to the nearest school at each analysis scale
Maximum distance to schools - region	8,000 m	Search distance used measure distance to the nearest school at each analysis scale
Weight for local scale distance to schools scores	1	Weight applied before summing scores at this analysis scale
Weight for local scale number of young people scores	1	Weight applied before summing scores at this analysis scale
Weight for local scale education scores	1	Weight applied before summing scores at this analysis scale
Weight for landscape scale distance to schools scores	1	Weight applied before summing scores at this analysis scale
Weight for landscape scale number	1	Weight applied before summing scores at this analysis scale

of young people scores		
Weight for landscape scale education scores	1	Weight applied before summing scores at this analysis scale
Weight for region scale distance to schools scores	1	Weight applied before summing scores at this analysis scale
Weight for region scale number of young people scores	1	Weight applied before summing scores at this analysis scale
Weight for region scale education scores	1	Weight applied before summing scores at this analysis scale
Weight for local scale scores	0.6	Weight applied before summing scores to create the final score
Weight for landscape scale scores	0.3	Weight applied before summing scores to create the final score
Weight for region scale scores	0.1	Weight applied before summing scores to create the final score
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Demand is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended

ES2 Demand model outputs ModelOutputs\3EducationKnowledge_cultural\Outputs.gdb

Output data	Description	Data type
Education_Demand	Demand for Education benefits	Raster

ES2 Demand model indicators
ModelOutputs\ES3EducationKnowledge_cultural\Indicators.gdb

Indicator data	Description	Data type
DistancetoSchools_ region_IndD	Calculates Euclidean distance to the closest school within region distance	Raster
DistancetoSchools_ landscape_IndD	Calculates Euclidean distance to the closest school within landscape distance	Raster
DistancetoSchools_ local_IndD	Calculates Euclidean distance to the closest school within local distance	Raster
EducationScores_ landscape_InD	Mean education score from the IMD / SIMD (units as per source data) - Landscape	Raster
EducationScores_ local_InD	Mean education score from the IMD / SIMD (units as per source data) - local	Raster
EducationScores_ region_InD	Mean education score from the IMD / SIMD (units as per source data) - region	Raster
Greenspace_landscape _IndD	Sites greater than the size threshold - landscape	Vector (polygon)
Greenspace_local _IndD	Sites greater than the size threshold - local	Vector (polygon)
Greenspace_region _IndD	Sites greater than the size threshold - region	Vector (polygon)
GS_education_scores _landscape_IndD	Mean education scores from the IMD at this scale - cut to accessible areas	Raster
GS_education_scores _local_IndD	Mean education scores from the IMD at this scale - cut to accessible areas	Raster
GS_education_scores _region_IndD	Mean education scores from the IMD at this scale - cut to accessible areas	Raster
GS_NumberYngPeople _Landscape_InD	Number of Young People (<default age threshold) within analysis scale buffer (cut to only Accessible areas)	Raster
GS_NumberYngPeople _local_InD	Number of Young People (<default age threshold) within analysis scale buffer (cut to only Accessible areas)	Raster
GS_NumberYngPeople _region_InD	Number of Young People (<default age threshold) within analysis scale buffer (cut to only Accessible areas)	Raster
Min_Distance_ Landscape_Schools_ Inv_Score_IndD	Distance to the nearest school - inverse score (1 to 100)	Raster
Min_Distance_local _Schools_ Inv_Score_IndD	Distance to the nearest school - inverse score (1 to 100)	Raster
Min_Distance_region _Schools_ Inv_Score_IndD	Distance to the nearest school - inverse score (1 to 100)	Raster
NumberYoungPeople _landscape_IndD	Number of Young People (<default age threshold) within analysis scale buffer	Raster
NumberYoungPeople _local_IndD	Number of Young People (<default age threshold) within analysis scale buffer	Raster
NumberYoungPeople _region_IndD	Number of Young People (<default age threshold) within analysis scale buffer	Raster

Model limitations (demand)

- It is assumed that areas are more likely to be used for education purposes if they are situated close to an education facility. However, little data has been published reporting how far people tend to travel for opportunities to learn and gain skills in the natural environment.
- Without local knowledge, there is no way of differentiating schools from other educational institutions such as universities or colleges. Because of the more extensive literature on children and education in the natural environment, this model has a focus on people in education younger than 15 years of age.
- There is no way of weighting schools by the number of children who attend them, which may be an important factor in understanding demand for education.
- This model would benefit from further literature references in comparison to other services.

Modifications and actions to improve the model (demand)

- n/a

ES3 Education Knowledge Service Flow Maps

This model overlays the Demand and Capacity maps to illustrate how well they align. The combined maps are then used to illustrate those areas where it is predicted people benefit from this ecosystem service (Benefiting Areas) or where interventions could be planned (Management Zones). The areas of Demand and Capacity are split into quintiles by value (or optionally by area) and these are used to identify categories from Highest to Lowest. Additionally those areas with capacity to deliver the service, within areas of demand, and which hold existing greenspace cover are identified as green infrastructure assets (GI_assets).

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES3 Service Flow Maps model inputs
ModelOutputs/ES3EducationKnowledge_cultural /Outputs.gdb

Input data	Description	Data type
Education_Capacity	Education capacity across study area	Raster
Education_Capacity Unrestricted	Education capacity within publically accessible areas	Raster
Education_Demand	Education demand across the study area	Raster

ES3 Service Flow model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010
Set extent of service maps	StudyArea	This sets the area for which the Flows are mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.
Use quintiles by value	Yes	Capacity and Demand scores are split into five equal interval classes
Use quintiles by area	No	Capacity and Demand scores are split into five classes of equal area
BaseMap _FINAL	BaseMap _FINAL	The available habitat map used to map the habitats in the Masks below.
Mask 1	NOT: Water, Sea, urban, Infrastructure	Identifies all areas with management potential for change (greenspace areas and semi-natural habitats)
Mask 2	Urban	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring within all

Parameter	Default	Explanation
		areas of mapped demand
Mask 3	Infrastructure	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring only within areas of highest or high mapped demand
Run Mask 2	No	Select to run the mask analysis
Run Mask 3	No	Select to run the mask analysis
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)
Set minimum patch size for shapefiles	200	Set threshold to omit small polygons during shapefiles conversion

Model outputs are created in the "Outputs" geodatabase for:
- ESBA and Gaps, ESBA and Gaps Prioritised, ESBA Management Zones, GI assets
- See Section 3.1 and Table 9 for definitions of these outputs.

8.4.9 Green Travel Routes Toolbox

Tool Development: Jonathan Winn

Active travel, such as walking or cycling, is beneficial to health. There has been a decrease in physical activity levels over recent decades, e.g. with children more frequently being driven to school than walking or cycling (Mackett 2013). Active travel can potentially allow a large proportion of the population to meet the recommended targets for physical activity (Buehler et al. 2011). Comparison between countries suggests that there would be significant health benefit to people in England and Wales if physical activity increased to levels seen in countries such as Switzerland and the Netherlands (Götschi et al. 2015). Economic analysis has also indicated that there would be benefits to the NHS in England and Wales from increased walking and cycling by people in urban areas (Jarrett et al. 2012). In addition to the emphasis on physical health research also indicates that active travel is significantly associated with mental well-being compared to car travel, walking or driving (Martin et al. 2014).

The Marmot review recommends that action to reduce health inequalities occur across all determinants of health and that this includes a policy objective to "create and develop healthy and sustainable places and communities" (Marmot et al. 2010). These objectives fit well with the scope of green travel route creation.

It is widely acknowledged that policies to encourage further active travel are likely to be positive for community health (De Nazelle et al. 2011). However there may be occasional risk trade-offs, where for example there may be areas with potentially increased exposure to urban pollutants or accidents (De Nazelle et al. 2011). The relative exposure level experienced under different types of commuting are complex. Perhaps in contrast to expectations car commuting exposes commuters to high pollution loads (Karanasiou et al. 2014). This can be considered an argument for the uptake of green travel routes to allow active travel in locations away from roads and vehicles. Research has indicated that green travel routes will benefit from buffer zones between the route and roads, for example of woodland or trees, and that they should be between 5.8 and 14.2 m wide to reduce pollutants (Grange et al. 2014). Many of the health and well-being benefits of greenspace and parks (Forest Research 2010; Greenspace Scotland 2008) would be expected to also occur in green travel routes. Green travel or active travel route use is one of many benefits of areas managed as conservation buffers in the landscape (Bentrup 2008).

The exact relationship between features in the environment such as safe green travel routes and active uptake and use of such features by the local population can be difficult to predict, and may be complicated by for example the occurrence of efficient and easily available public transport systems (Broberg & Sarjala 2015). Relationships may also be more complex in rural areas due to the longer travel distances (Dalton et al. 2011). Therefore in this current work only urban areas are considered. Travel behaviour of British urban residents can differ between traditional urban and suburban neighbourhoods, and is strongly affected by residents attitudes (Aditjandra et al. 2013). Research suggests that creating more walkable local environments may result in higher activity and lower car use (Frank et al. 2007). Targeting behaviour of increased active travel to schools can be effective, and can have other benefits such as reduced CO^2 levels caused by school run transport (Bearman & Singleton 2014). Available studies suggest that often intervention and encouragements may be needed to ensure people undertake active travel choice options (Norwood et al. 2014).

When regular active travel is practised, use levels are likely to be higher where travel distances are shorter. Recent research in England indicates that active travel to school drops rapidly to almost 0% (walking or cycling) when the distance from school approaches 2 to 2.5 km (primary school) and 4 to 4.5 km (secondary schools) (Bearman & Singleton

2014). Mean distances were: walking 0.8 km (primary schools), 1.5 km (secondary schools) and for cycling 1.05 km (primary schools) and 2.08 km (secondary schools) (Bearman & Singleton 2014).

Several insights from the following research were used to construct the GIS model:

Capacity

- The design or characteristics of local neighbourhood environment can encourage more active use, although use levels are also be impacted by socioeconomic conditions and community characteristics (Aditjandra et al. 2013; Frank et al. 2007).

Demand

- Studies have used least cost analysis to examine connectivity and use of greenspace (Moseley et al. 2013).
- Children who have freedom to play outdoors and undertake active travel undertake more physical activity than those who do not (Schoeppe et al. 2013).
- Benefits of active travel in children are not just limited to school travel destinations (Smith et al. 2012).
- Much active travel use is over relatively short distances of 1 to 2 km (Bearman & Singleton 2014).
- Commuting to school is a significant opportunity for active travel (Bearman & Singleton 2014).

ES1 Green Travel Capacity

Models the availability of green travel routes that have capacity to provide health benefits to people.

- Green Travel Routes provide many benefits to people, the most important of which are likely to be increased physical exercise although many other linked positive benefits can occur.
- Little literature exists on which to assess capacity for this service, therefore an assumption is made that more natural and wider or larger areas of greenspace along travel routes will be more attractive to use by people.

Capacity analysis is conducted in two stages. The first examines the potential travel route network. The second examines the naturalness of the areas present along the travel network.

Initially analysis identifies potential travel routes (pavements, paths, cycle routes) and creates a route corridor map linking these. Analysis selects the longer linear routes so that only the larger areas of well-connected travel routes are examined. Small areas of isolated paths or pavement are ignored.

The travel routes are then buffered. Areas of greenspace are analysed in terms of perceived naturalness scores. A site based and a local based score are summed and used to represent naturalness at each focal cell. Only some areas of the mapped travel routes will hold any greenspace cover, and these areas of greenspace cover along a mapped route may not occur close enough together to impact the character of the route. The spatial occurrence of the greenspace areas, and the local naturalness distance analysis settings (default 300 m) both affect how the composite character of the route is assessed. The naturalness analysis creates a score that reflect the site and local nearby greenspace character. Small isolated areas of greenspace travel route are removed (default < 0.5 ha, or approx. 125 m length). The route is then buffered by + 20 m and – 10m to merge nearby areas of green travel route. A second threshold analysis is then applied to remove the shorter green travel route (default < 5 ha or approx. 830 m length). These settings can be altered by users if further local knowledge is available.

Capacity parameters are:

• Minimum route length	Default: 2,000 m
• Minimum green travel route area	Default: 5,000 m^2 (0.5 ha)
• Minimum green travel route area - Main	Default: 50,000 m^2 (5 ha)
• Focal distance for local mean naturalness score	Default: 300 m

Instructions:

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES1 Capacity model inputs

Input data	Description	Data type	Save to
BaseMap _Final	Base Map (detailed habitat & land use map).	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

ES1 Capacity model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	Tutorial Cell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m.
Minimum route length	2,000 m	Minimum length of combined linear travel routes. Used to remove small fragmented or unconnected travel routes
Minimum green travel route area	5,000 m^2	Minimum green travel patch area. This removes small areas of green travel route, greenspace areas, that are not connected to other green travel routes.
Minimum green travel route area - Main	50,000 m^2	Minimum green travel route area. Sets a threshold for whole route areas considered likely to be experienced or used as green travel routes.
Focal distance for local naturalness score	300 m	Local search distance (radius) within which the mean naturalness score is calculated
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)

ES1 Capacity model outputs ModelOutputs\ES3GreenTravel_cultural \Outputs.gdb

Output data	Description	Data type
GreenTravel _Capacity	The capacity for people to benefit from travel along green access routes	Raster

ES1 Capacity model indicators ModelOutputs\ES3GreenTravel_cultural\Indicators.gdb

Indicator data	Description	Data type
GreenTravelAccess_IndC	All buffered access routes	Vector (polygon)
GreenTravelAccessBM_IndC	Areas of greenspace present within the buffered access routes	Vector (polygon)
GreenTravelRoute_All_IndC	Green Travel greenspace areas before the site area threshold is applied	Vector (polygon)
Site_plus_local_naturalness_mean_Unr_IndC	Summary naturalness score created from site score plus focal search score	Vector (polygon)

Model limitations (capacity)

- The identification of access travel routes area is reliant on how accurate and comprehensive the input data are for: PRoW, Core Paths, Sustrans routes.

Modifications and actions to improve the model (capacity)

- Further research is required to link greenspace type or quality and capacity to deliver benefits, beyond the simplistic assumption that routes of higher perceived naturalness encourage more frequent and regular use and deliver higher benefits.

ES2 Green Travel Demand

This model estimates the societal demand for green travel routes, based on the location of popular travel destinations.

- Green Travel Routes provide many benefits to people, the most important of which are likely to be increased physical exercise although many other linked positive benefits can occur.
- The service is more relevant to urban areas.
- The service will occur most where people undertaken frequent regular journeys such as commuting to work, school or into town centres.

Demand is mapped by examining travel destination and origin locations within urban areas. Urban areas are mapped and buffered using a method that allows nearby urban areas to merge along close borders, in areas where travel between such areas might be expected. Destination points of town centres, schools and train stations are then used to model travel paths. The points are buffered then linked to the travel networks previously mapped in the capacity model. Least cost analysis is used to model travel along this route, with a user defined maximum travel distance. The default distance is set from research of cycle travel to English secondary schools: 4.5 km (Bearman & Singleton 2014). The travel cost score is then standardised and used to map Demand for Green Travel Routes.

Instructions
- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES2 Demand model inputs

Input data	Description	Data type	Save to
BaseMap _FINAL	BaseMap habitat map	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb
Urban_GB	Urban areas	Vector (polygon)	No action needed. Saved in: ModelInputs/ES0CommonFiles/Inputs.gdb
GreenTravelAccess _IndC	Modelled buffered green travel areas	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs /ES3GreenTravel/Indicators.gdb
Cites_Towns	Locations of cities and towns (centres)	Vector (points)	No action needed. Saved in: OpenData/OS_opendata.gdb
OSRailStation	Rail stations	Vector (points)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb
OSEduationFacilities	Education facilities	Vector (points)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/

SA_buffer_grid	Study Area buffer	Vector (points)	Outputs.gdb No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb

ES2 Demand model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010 for 10 m.
Maximum travel distance	4,500 m	Maximum likely travel distance along green travel routes to key destinations. Setting shorter distances will restrict the areas where the service is considered to occur.
Data extract area SA_buffer or StudyArea	SA_buffer	This sets the area for which the Demand is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea. The default SA_buffer is recommended
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)

ES2 Demand model outputs ModelOutputs\E3GreenTravel_cultural\Outputs.gdb

Output data	Description	Data type
GreenTravel_Demand	Demand for Green Travel routes	Raster

ES2 Demand model indicators ModelOutputs\ES3GreenTravel_cultural\Indicators.gdb

Indicator data	Description	Data type
Travel_Points_IndD	Key travel origin and destination points. Points buffered to create polygons.	Vector(polygon)

Model limitations (demand)

- It is assumed that all travel destinations have equal demand, however this is unlikely to be the case.
- The model does not separately differentiate between likely modes of travel such as walking or cycling.

Modifications and actions to improve the model (demand)

- Demand mapping would benefit from further justification of typical maximum travel distances.
- Demand could be weighted based on different modes of travel.
- Travel destinations could be weighted by importance, e.g. by population size or likely travel source distance.

ES3 Green Travel Service Flow Maps

This model overlays the Demand and Capacity maps to illustrate how well they align. The combined maps are then used to illustrate those areas where it is predicted people benefit from this ecosystem service (Benefiting Areas) or where interventions could be planned (Management Zones). The areas of Demand and Capacity are split into quintiles by value (or optionally by area) and these are used to identify categories from Highest to Lowest. Additionally those areas with capacity to deliver the service, within areas of demand, and which hold existing greenspace cover are identified as green infrastructure assets (GI_assets).

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog. Right click model name click “edit”, from “Model” menu click “Validate the entire model”, from “Model” menu click “Save". Close the model
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- The model default produces results for the Tutorial area, therefore set "Extent" and "Set cell size" for your Study Area (click icon to set the file path)
- Change any other parameters, if required
- Click OK to run the tool

ES3 Service Flow Maps model inputs
ModelOutputs/ES3Green_Travel_cultural /Outputs.gdb

Input data	Description	Data type
Green_Travel_Capacity	Green Travel capacity across the study area	Raster
Green_Travel_Demand	Green Travel demand across the study area	Raster

ES3 Service Flow model parameters

Parameter	Default	Explanation
Extent	Tutorial	The extent must be set as "SA_buffer" by the user (ModelOutputs/ES1BaseMap)
Set cell size	TutorialCell	The cell size must be set by the user as "SA010" (ModelOutputs/ES1BaseMap) Defines the resolution and extent at which the analysis will be carried out. Choose SA010
Set extent of service maps	StudyArea	This sets the area for which the Flows are mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.
Use quintiles by value	Yes	Capacity and Demand scores are split into five equal interval classes
Use quintiles by area	No	Capacity and Demand scores are split into five classes of equal area
BaseMap _FINAL	BaseMap _FINAL	The available habitat map used to map the habitats in the Masks below.
Mask 1	NOT: Water, Sea, urban, Infrastructure	Identifies all areas with management potential for change (greenspace areas and semi-natural habitats)
Mask 2	Urban	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring within all areas of mapped demand
Mask 3	Infrastructure	Identifies a further subset of areas potentially suitable for habitat creation for this service, occurring only within

Parameter	Default	Explanation
		areas of highest or high mapped demand
Run Mask 2	No	Select to run the mask analysis
Run Mask 3	No	Select to run the mask analysis
Export shapefiles	No	Option to export the results as shapefile data (results are located in the folder; shapefiles)
Set minimum patch size for shapefiles	200	Set threshold to omit small polygons during shapefiles conversion

Model outputs are created in the "Outputs" geodatabase for:

- ESBA and Gaps, ESBA and Gaps Prioritised, ESBA Management Zones, GI assets
- See Section 3.1 and Table 9 for definitions of these outputs.

8.5 Creating Multi-functionality maps

Tool Development: Chloe Bellamy (50%), Jonathan Winn (50%)

Many areas within a landscape produce several different ecosystem services; the "multi-functionality" of a site describes this. Producing an aggregate value of the services provided by each landscape parcel in order to provide an estimate of site multi-functionality can be difficult and can mask complexity. While areas with high multi-functionality are valuable resources, parcels of land providing a small range of benefits may be of high conservation concern if there is a large demand for the particular services they provide, or other areas providing the same service are scarce at the relevant spatial scale. However, prioritising those areas which are important for the greatest number of services can inform the targeted conservation of green infrastructure (Community Forest Northwest 2010) and multi-functionality maps can be used alongside individual service maps to help implement an ecosystem approach.

A series of models are provided below (with accompanying ArcMaps) to highlight the range of multiple benefits being delivered across the Study Area. These can be used as a starting point for further analysis. Models calculate the following for the services mapped: mean capacity, mean demand, mean GI assets capacity, multi-functionality score, priority multi-functionality score, number of ESBA types, and number of Management Zones. All the models need not be run. For ease of use these are divided between two categories of main and supplementary information (as reflected in the ArcMaps folders).

Main results:
- Priority multi-functionality score
- Priority ESBAs
- Management Zones
- GI assets mean capacity

Supplementary results:
- Multi-functionality score
- Mean multi capacity
- Mean multi demand
- Number of Services and Gaps

ES1 Multi-functionality per cell

Combines the output from the individual service maps to illustrate the number of services provided at each cell as well as the proportion of services required that are predicted to be delivered. Several data outputs are produced.

This model conducts analysis across all the services that have been mapped and produces output per analysis grid cell. To illustrate multi-functionality the model sums up the number of services where there is demand in each cell and then calculates the proportion of these that are met with some level of ecosystem service capacity ("multi-functionality"). Therefore a score of 1 indicates that all services with mapped demand have mapped capacity. Similarly a score of 0.5 indicates that half of the services for which there are mapped demand in a cell, have mapped capacity present. Cells scoring 0 have mapped demand but no capacity. Because this assessment includes the full range of capacity and demand in this calculation it may be considered too simplistic, as the delivery of a service in areas of low demand or capacity may not be considered important (for example in terms of influencing land management or policy). To allow landscape managers further data to compare, a "Priority multi-functionality" score is also produced using only those capacity and demand quintiles of intermediate and above in the calculation. Therefore a service is considered to be delivered at a cell if both demand and capacity are at least of intermediate quintile level. This focuses the mapping on those areas with a higher certainty in the benefits being delivered to people, or of the need for such benefits to be present. Results are also produced for the actual numbers of services and gaps per cell.

The ESBA and management zones across all services are also examined and summarised. The priority version of the ESBA analysis for each service is collapsed into three categories, from five. Highest and High become High, Lowest and Low become Low. The number of these categories is then calculated per cell to indicate the level of benefits being delivered to people. In situations where multiple "high" ESBA categories are present this indicates multiple benefits to people. As the number of services being examined will differ between landscapes this analysis is standardised and presented in the ArcMaps by presenting each of the analysis as tertiles. Therefore three datasets are mapped, each classified into high, medium and low number of each benefit category. These maps allow those areas to be easily identified where areas of land are expected to be delivering high benefits to people, across a number of services. Similar analysis is then conducted for the Management zones, to emphasise where categories of management action can be targeted to multiple ecosystem services. For example where conservation of land will protect several ecosystem service benefits or where habitat creation could deliver several future benefits to people. The multiple Management Zones categories are collapsed into four simplified zones to allow comparison across services. These are: Zone 1 Protect (A1 Protect, A2 Protect / Maintain), Zone 2 Maintain (A3 Maintain), Zone 3 Improve (A4 Improve), Zone 4 Create (B1 Create, B2 Create, A8 change habitat type, A9 change habitat type). The results are then presented as 4 data files each classified into three categories (high, medium, low) of the number of zones present of each type, per cell. These then indicate where there are multiple services that benefit from the protection of a site (e.g. ongoing funded management), or where habitat creation or land use change could deliver several future services from an area of land.

The analysis between the ESBA and Management Zones is similar but the emphasis and expected use of the maps is different.

Instructions
Run the toolboxes for each ecosystem service for your Study Area (N.B. results are more meaningful the more services you are able to map). Make sure you have run the service flow models as well as creating the service demand and capacity maps.

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog
- Right click model name: Edit, Validate, Save
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- Change any other parameters, if required
- Click OK to run the tool

Multifunctionality toolbox model inputs

Input data	Description	Data type	Save to
StudyArea	Study area boundary	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ES1BaseMap/ Outputs.gdb

Multifunctionality toolbox model parameters

Parameter	Default	Explanation
Data extract area SA_buffer or StudyArea	Study Area	This sets the area for the analysis, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the Study Area. Because in most cases service flow is only mapped up to the Study Area boundary, then the default is recommended
Export shapefiles?	N	Option to export select results as shapefile format. Only some of the results are exported.
Threshold limit for Shapefile conversion (m)	200	Threshold used to remove small patches before converting to shapefile

Multifunctionality toolbox model outputs
ModelOutputs\ES5Multifunctionality\Outputs.gdb

Output data	Description	Data type
ESBA benefits per cell	Attribute table used to display result in ArcMap	Table
ESBA Higher tertiles per cell	Dataset showing high / medium / low amounts of this ESBA category per cell	Raster
ESBA Intermediate tertiles per cell	Dataset showing high / medium / low amounts of this ESBA category per cell	Raster
ESBA lower tertiles per cell	Dataset showing high / medium / low amounts of this ESBA category per cell	Raster
Management zones Per cell	Attribute table used to display result in ArcMap	Table
Multifunctionality Per cell	The proportion of ecosystem services required at each cell that are predicted to be delivered	Raster
Number of gaps tertiles Per cell	Dataset showing high / medium / low amounts of this category per cell	Raster
Number of services tertiles Per cell	Dataset showing high / medium / low amounts of this category per cell	Raster
Priority multifunctionality	The proportion of ecosystem services required at	Raster

Output data	Description	Data type
per cell	each cell that are predicted to be delivered – calculated only where both capacity and demand are >= Intermediate	
Services and gaps per cell	Attribute table used to display results in ArcMap	Table
Zones 1 protect tertiles Per cell	Dataset showing high / medium / low amounts of this Zone per cell	Raster
Zones 2 maintain tertiles Per cell	Dataset showing high / medium / low amounts of this Zone per cell	Raster
Zones 3 improve tertiles Per cell	Dataset showing high / medium / low amounts of this Zone per cell	Raster
Zones 4 create tertiles Per cell	Dataset showing high / medium / low amounts of this Zone per cell	Raster

Multifunctionality toolbox model outputs
ModelOutputs\ES5Multifunctionality\Indicators.gdb

Output data	Description	Data type
Nmbr of ESBA Higher per cell	The number of ESBAs of this category, counted per cell	Raster
Nmbr of ESBA Intermediate per cell	The number of ESBAs of this category, counted per cell	Raster
Nmbr of ESBA lower per cell	The number of ESBAs of this category, counted per cell	Raster
Nmbr Zones 1 protect Per cell	The number of Zones of this category, counted per cell	Raster
Nmbr Zones 2 maintain Per cell	The number of Zones of this category, counted per cell	Raster
Nmbr Zones 3 improve Per cell	The number of Zones of this category, counted per cell	Raster
Nmbr Zones 4 create Per cell	The number of Zones of this category, counted per cell	Raster

Notes & limitations (multi-functionality)
It is important to remember that the multi-functionality maps only reflect the limited range of ecosystem services that have been mapped. Individual services may display multicollinearity at certain scales, affecting aggregate service scores. Some services will have a negative impact on the provision of others, and human management practises will also affect the balance of service delivery. Previous regional-scale studies have found that the provisioning services are most likely to have a negative impact on other services, whilst the regulating and cultural services are most likely to form synergistic relationships within their own service group (Raudsepp-Hearne et al. 2010). Statistical analysis can help identify common bundles of services across the landscape (e.g. Partitioned Canonical Analysis (PCA)), which can then be mapped instead of individual services (Raudsepp-Hearne et al. 2010; Maes et al. 2011).

Modifications and actions to improve the model (multi-functionality)
People's priorities will change over a continuum of land use types, from rural to urban areas, and this will have important implications for land use planning and decision making (Pankhurst 2010; Community Forest Northwest 2010). Pankhurst (2010) advocates visualising ecosystem services provided across the greenspace network as separate layers,

which shift in their relative importance according to the local land use context. Community Forest Northwest (2010) also recognised that some of the green infrastructure services they mapped in northwest England may need to be prioritised above others. They devised a strategy to this which involved scoring each service on three factors (1-3; low – high priority): the probability and magnitude of the climate-associated hazards addressed by the service, and the effectiveness and practicality for using green infrastructure as a solution. The sum of these scores could then be used to weight each service map. The priorities, demands and requirements of stakeholders and local decision makers used to inform these weighting decisions will vary in separate regions and across time (Wallace 2007). Therefore, to help understand the local importance of ecosystem services, stakeholders can be asked to weight services. A Likert-scale is the most easily implemented (Koschke et al. 2012). The same multi-criteria process used to weight service indicators can be used to weight the individual services when generating an aggregate score. Future updates to the EcoServ-GIS toolkit could include updating the multi-functionality toolbox to allow users to apply their own weights to individual services.

ES2 Multi GI Assets

Creates a mean GI assets score, indicating the current value of the GI resource to multiple services

To examine the demand present in the landscape for different services the mean demand score is calculated from all the services that have been examined. A threshold number of services is applied so the mean score is only mapped in areas where there is some level of demand for several services. The resulting map is one way to illustrate the capacity present in the landscape for a number of different benefits, required by people.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog
- Right click model name: Edit, Validate, Save
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- Change any other parameters, if required
- Click OK to run the tool

Multi GI assets model parameters

Parameter	Default	Explanation
Number of services threshold for multi analysis	>3	Threshold number of services used to limit the mapped analysis. Only areas with greater than the threshold have the mean score mapped.

Multi GI assets model outputs ModelOutputs\ES5Multifunctionality\Outputs.gdb

Output data	Description	Data type
GI_assets_mean	The mean score per cell, calculated across all mapped services	Raster
GI_assets_mean_agg_100m	The mean score per cell, calculated across all mapped services, aggregated by mean score to 100 m cells	Raster
GI_assets_mean_agg_500m	The mean score per cell, calculated across all mapped services, aggregated by mean score to 500 m cells	Raster

Notes & limitations (Multi GI assets)
The minimum number of services threshold can be used to target the resulting map to only areas that have a higher number of services. The threshold is arbitrary but serves to differentiate from areas that only have importance for a single service (which are well illustrated by the single service analysis maps).

ES3 Multi mean capacity (OPTIONAL)

Creates a map of mean capacity score to illustrate areas with capacity to deliver several services

To examine the capacity present in the landscape for different services the mean capacity score is calculated from all the services that have been examined. A threshold number of services is applied so the mean score is only mapped in areas where there is some level of capacity for several services. The resulting map is one way to illustrate the capacity present in the landscape to deliver a number of different current or future benefits to people.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog
- Right click model name: Edit, Validate, Save
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- Change any other parameters, if required
- Click OK to run the tool

Multi capacity model parameters

Parameter	Default	Explanation
Number of services threshold for multi analysis	>3	Threshold number of services used to limit the mapped analysis. Only areas with greater than the threshold have the mean score mapped.

Multi capacity model outputs ModelOutputs\ES5Multifunctionality\Outputs.gdb

Output data	Description	Data type
Capacity_mean	The mean score per cell, calculated across all mapped services	Raster
Capacity_mean_agg_100m	The mean score per cell, calculated across all mapped services, aggregated by mean score to 100 m cells	Raster
Capacity_mean_agg_500m	The mean score per cell, calculated across all mapped services, aggregated by mean score to 500 m cells	Raster

Notes & limitations (Multi capacity)
This score should be interpreted with care. It can represent areas that have high capacity for several different services, or it may be influenced by high capacity scores for few, but high scoring services. The minimum number of services threshold can be used to target the resulting map to only areas that have capacity for several different services. The threshold is arbitrary but serves to differentiate from areas that only have importance for a single service (which are well illustrated by the single service analysis maps).

ES4 Multi mean demand (OPTIONAL)

Creates a map of mean demand score to illustrate areas where people require several services

To examine the demand present in the landscape for different services the mean demand score is calculated from all the services that have been examined. A threshold number of services is applied so the mean score is only mapped in areas where there is some level of demand for several services. The resulting map is one way to illustrate the demand present in the landscape for a number of different benefits, required by people.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog
- Right click model name: Edit, Validate, Save
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- Change any other parameters, if required
- Click OK to run the tool

Multi demand model parameters

Parameter	Default	Explanation
Number of services threshold for multi analysis	>3	Threshold number of services used to limit the mapped analysis. Only areas with greater than the threshold have the mean score mapped.

Multi demand model outputs ModelOutputs\ES5Multifunctionality\Outputs.gdb

Output data	Description	Data type
Demand_mean	The mean score per cell, calculated across all mapped services	Raster
Demand_mean_agg_100m	The mean score per cell, calculated across all mapped services, aggregated by mean score to 100 m cells	Raster
Demand_mean_agg_500m	The mean score per cell, calculated across all mapped services, aggregated by mean score to 500 m cells	Raster

Notes & limitations (Multi demand)

This score should be interpreted with care. It can represent areas that have high demand for several different services, or it may be influenced by high demand for few, but high scoring services. The minimum number of services threshold can be used to target the resulting map to only areas that have demand for several different services. The threshold is arbitrary but serves to differentiate from areas that only have importance for a single service (which are well illustrated by the single service analysis maps).

8.6 Creating Ecological Networks Maps

Tool Development: Jonathan Winn

Ecological network, or habitat network analysis can be used to highlight areas where patches are more or less connected to a wider network of sites by assessing features of patches and the landscape such as patch size, landscape matrix composition and hypothetical species dispersal distances.

The benefits of the ecological networks method, and its limitations are well known. These include a requirement for good quality, ideally high resolution, land use maps, reliable habitat preference information for modelled species, dispersal distance requirements, and landscape permeability (cost) scores (Briers 2011). Some of these limitations have been addressed, e.g. by use of expert selection of dispersal distance scores (Hess & King 2002). The suggestion being to produce a series of maps to illustrate the range of values, for example for core area, dispersal distances, that could be relevant to a particular landscape. The network maps that are produced are typically considered indicative and care must be taken in their interpretation. For example it has been suggested that the maps can more reliably be used to examine the effect of alternative land-use changes to networks than to assess the current value of existing networks (Briers 2011). It is well known that selection of the method to define ecological networks influences the arrangement and performance of the mapped outcome (Théau et al. 2015).

There have been many calls for the use of landscape scale or ecological network planning initiatives in conservation management (Opdam et al. 2006) and there is a history of ecological network mapping in Europe (von Haaren & Reich 2006; Gurrutxaga et al. 2010; Jongman et al. 2004). Such networks need to be planned over large areas and timescales, with examples even accommodating for potential climate shifts, or spanning distances over neighbouring country borders, requiring collaborative network management (Rüter et al. 2014; Leibenath et al. 2010). Studies in the USA have suggested focussing on riparian corridor buffers can aid connectivity and species resilience in a network (Fremier et al. 2015).

Beyond focal species based habitat network mapping studies have shown that incorporating ad hoc collected species records can be useful to inform and improve ecological connectivity mapping, e.g. in the fens (Mossman et al. 2015). Additionally work has highlighted how the way landscape features are measured, modelled and mapped has a huge influence on the outcomes and interpretation of network mapping. For example features such as roads have been shown to be both beneficial or detrimental to small mammals, depending on the presence or characteristics of associated features such as road margins (Redon (de) et al. 2015). Therefore whilst ideally network mapping would use locally available species records, and vegetation mapping, frequently the availability of such information exceeds the ecological knowledge of species interactions, movements and land use interactions, available in the study landscape.

Ultimately most ecological network planning tools only offer a superficial glimpse into the current value of networks and the planning options that can help strengthen these networks. Caution must be expressed in any long term plans for such networks. Landuse change can occur very rapidly and there is high uncertainty in the likely future value of networks (Ingram & Steel 2010). Given these restrictions and potential applicability to different species groups or landscapes, measures of network connectivity based on both structural and functional connectivity may be relevant, and such importance may be defined by stakeholder engagement with landscape managers and stakeholders.

Network mapping has now been widely applied across the UK by conservation agencies, Local Authorities and Wildlife Trusts. The method applied here is based on the following methods: (Catchpole 2007; Watts et al. 2007; Watts et al. 2005; Lambeck 1997).

This tool uses the BaseMap_FINAL habitat map, together with optional habitat inputs, to map ecological habitat networks, using a least-cost focal species analysis method. A set of default values are provided, but users can modify the values:

- Minimum habitat patch size considered to be a “core” or “source” habitat area
- Size threshold of networks (networks below a threshold may not be functional)
- Focal species movement distances used to map each network size (core, meso, macro)

Within habitat maps, such as EcoServ-GIS or LCM2007 often the larger habitat polygons can be considered more reliably mapped compared to small areas of habitat that may be incorrectly mapped. This can arise for example by assuming that parts of a field, e.g. steep slopes or field corners, have the same habitat type as the majority of the field area. For example if a habitat map uses underlying OS MasterMap polygons to identify field boundaries (as EcoServ-GIS does) then small areas that do no align well with these boundaries or that are smaller than a field will often be missed. To compensate for this limitation, such sites can be added in as optional data within this ecological network analysis. There are issues related to the use of optional data. Ideally, a consistent habitat layer would be used with known accuracy and with all polygons mapped at a similar resolution. However when various data sources are available the choice must be weighed up between the potential extra “accuracy” of using selected survey-specific data sources vs. the consistency of a single habitat layer. An example is when the main habitat layer that is used to generate the “landscape matrix” is relatively coarse and so only the main larger blocks of habitat are mapped. This is the data that is then used to model the possible movement of species across the landscape. Detailed habitat surveys might then be selected for use for certain habitat groups (e.g. calcareous grassland). These can then be used to identify “source” areas of existing habitat. However it must be realised that in such cases the mapping of these selected areas of known habitat will be much higher resolution than the mapping of the landscape matrix. So even though additional accuracy has been introduced by using selected data, such accuracy does not occur when the landscape movement modelling across the landscape matrix. Such issues need to be understood by those conducting the network mapping.

ESn 1 Create landscape matrix rasters

Creates landscape raster datasets based on least-cost movement distances per habitat group.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- Change any other parameters, if required
- Note that using a coarse cell size (e.g. 20 m) will speed up analysis but may affect accuracy by omitting small or narrow habitat polygons
- Click OK to run the tool

ESn1 Create landscape matrix rasters

Input data	Description	Data type	Save to
Habitat layer with least cost values BaseMap_Final	Base Map (detailed habitat & land use map).	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

ESn1 Create landscape matrix rasters

Parameter	Default	Explanation
Set cell size for Matrix rasters (m)	5	Sets the grid cell size (in metres) for conversion to raster data
Grassland movement cost value field	CostGrass	Field within the habitat data that identified the cost of movement per habitat type
Heathland movement cost value field	CostHeath	Field within the habitat data that identified the cost of movement per habitat type
Mire movement cost value field	CostMire	Field within the habitat data that identified the cost of movement per habitat type
Pond movement cost value field	CostPond	Field within the habitat data that identified the cost of movement per habitat type
Woodland movement cost value field	CostWood	Field within the habitat data that identified the cost of movement per habitat type
Lowland wetlands movement cost value field	CostLWet	Field within the habitat data that identified the cost of movement per habitat type
Set raster extent and snap raster	SA010	Defines the resolution and extent of the analysis. Chose SA010 for 10 m.
Vector Study Area + buffer	SA_buffer_grid	This sets the area for which the data is mapped, either the wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.

ESn1 Create landscape matrix rasters (intermediate output – used by subsequent models)
ModelOutputs/ESn_Ecological_networks/Scratch.gdb

Output data	Description	Data type
Grass_MX	Landscape matrix least cost movement cost	Raster
Heath_MX	Landscape matrix least cost movement cost	Raster
Mire_MX	Landscape matrix least cost movement cost	Raster
Pond_MX	Landscape matrix least cost movement cost	Raster
Wood_MX	Landscape matrix least cost movement cost	Raster
LWet_MX	Landscape matrix least cost movement cost	Raster

Model limitations (landscape matrix)

- The analysis is limited by the approximate least cost, landscape matrix resistance values. These are taken from the literature and are used to indicate hypothetical species movement.

Modifications and actions to improve the model (landscape matrix)

- Ideally a wider range of focal habitats would be examined.
- The least cost landscape resistance values should be set from local knowledge or studies of locally important representative example species groups.

ESn 2 Select source habitat areas

This model selects and maps the location of "source" habitat, from which subsequent analysis builds the habitat networks. Habitat type is identified from the BaseMap_FINAL data (and also optionally from separate habitat-specific source data).

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- Change any other parameters, if required
- Note that using a coarse cell size (e.g. 20 m) will speed up analysis but may affect accuracy by omitting small or narrow habitat polygons
- Decide if any optional source habitat data is to be used (see note below)
- If certain habitat groups are not present in your Study Area, then un-tick the analysis
- Click OK to run the tool

Optional data can be used to identify areas of "source" habitat (e.g. at a finer resolution than the BaseMap, or if specific surveys have been conducted). All optional habitat data (vector, feature class) must be saved in the Input Geodatabase with the following "code" in part of the filename. The "code" allows the optional data to be selected by the models; if it does not contain the right text it will not be selected. It does not matter if there is more than one file for each habitat group. Examples could include street tree data, urban grassland surveys or pond surveys.

- Grassland data. Name must contain the code "GRASSR", e.g. AONB_GRASSR
- Heathland data. Name must contain the code "HEATHR", e.g. AONB_HEATHR_2
- Mire data. Name must contain the code "MIRER", e.g. LWS_MIRE
- Lowland wetlands. Name must contain the code "LWETR" e.g. surv56e_LWETR
- Ponds data. Name must contain the word "PONDR", e.g. PONDR_2
- Woodland data. Name must contain the code "WOODR", e.g. 4WOODR82

ESn 2 Select source habitat layers

Input data	Description	Data type	Save to
BaseMap _Final	Detailed habitat & land use map.	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb

ESn 2 Select source habitat layers

Parameter	Default	Explanation
Set cell size for rasters (m)	5	Sets the grid cell size (in metres) for conversion to raster data. This should match the value used in Model "ESn_1 Create landscape matrix"
Select threshold for source habitats	1,000	A threshold size can be set for patches of source habitat. This can be used if you want to consider that very small patches should <u>not</u> be used to build the habitat networks. E.g. if you consider that a woodland smaller than 0.25 ha is unlikely to hold certain typical woodland species. Any polygons / patches below the threshold will be ignored. The default is 1000 sq m which is 0.1 ha,(approx 30 m x 30 m).

Parameter	Default	Explanation
Grassland: expression for source / core semi-natural habitats	HabBroad = 'Grassland, semi-natural' OR HabBroad = 'Maritime cliff and slope' OR HabNmPLUS = 'Linear habitats'	Polygons that will be considered "source" habitat, from which to build the habitat networks. Users can alter the selection. This selection includes coastal grassland and "linear habitats" which often will hold grasslands. For a stricter definition these can be omitted.
Heathland: expression for source / core semi-natural habitats	HabBroad = 'Heathland'	Polygons that will be considered "source" habitat, from which to build the habitat networks. Users can alter the selection.
Mire: expression for source / core semi-natural habitats	HabBroad = 'Grassland, Marshy' OR HabBroad = 'Mire' OR HabBroad = 'Swamp' Or HabBroad = 'Saltmarsh'	Polygons that will be considered "source" habitat, from which to build the habitat networks. Users can alter the selection. This uses a broad and inclusive selection of "mires" that is most applicable to mapping in the lowlands, including coastal areas. For upland areas a more strict selection of only HabBroad = 'Mire' should be used.
Ponds (or ponds and streams): expression for source / core semi-natural habitats	HabNmPLUS = 'Water (inland),(unknown),' AND Shape_Area <10000 AND Shape_index <= 5	Polygons that will be considered "source" habitat, from which to build the habitat networks. Users can alter the selection. Because ponds are often not separately mapped within the habitat BaseMap a selection is used to locate likely pond sites. This uses area and shape to select smaller round water habitat areas. Users should experiment to find a setting that best identifies these patches for their area. Alternatively other GIS techniques could add data to the BaseMap that labels pond sites, allowing those field to be selected here. If the focal habitat type of "Ponds, and Streams" is planned to be mapped then the area and shape selections can be removed.
Woodland: expression for source / core semi-natural habitats	HabBroad = 'Woodland, broadleaved'	Polygons that will be considered "source" habitat, from which to build the habitat networks. Users can alter the selection. If semi-natural, or ancient woodland status is present within the BaseMap, these can be used to build separate habitat networks.
Lowland wetlands: expression for source / core semi-natural habitats	HabBroad = 'Grassland, marshy'	Polygons that will be considered "source" habitat, from which to build the habitat networks. Users can alter the selection. Optional selections include a wide definition that includes all areas of water habitat and includes saltmarsh to include coastal connectivity (assuming that almost all areas of standing or running water hold some wetland species, and thus can be considered source habitat). Other options include: HabBroad = 'Grassland, marshy' OR HabNmPLUS LIKE '%Fen%' OR HabNmPLUS LIKE '%Flush%')
Study Area + buffer	SA_buffer_grid	Sets wider extent of the Study Area plus the buffer zone (SA_buffer) or just the StudyArea.

Parameter	Default	Explanation
Set raster extent and snap raster	SA010	Defines the resolution and extent of the analysis. Chose SA010 for 10 m.
Run grassland	Yes	Run analysis for this habitat group. Un-tick if absent from the Study Area
Run heathland	Yes	Run analysis for this habitat group. Un-tick if absent from the Study Area
Run mires	Yes	Run analysis for this habitat group. Un-tick if absent from the Study Area
Run ponds	Yes	Run analysis for this habitat group. Un-tick if absent from the Study Area
Run woodlands	Yes	Run analysis for this habitat group. Un-tick if absent from the Study Area
Run lowland wetlands	Yes	Run analysis for this habitat group. Un-tick if absent from the Study Area

ESn 2 Select source habitat layers (temporary outputs, used by later models)
ModelOutputs/ESn_Ecological_networks/Scratch.gdb

Output data	Description	Data type
Source_Gr_EX	The location of source habitat used to create the ecological networks (grassland)	Vector
Source_H_EX	The location of source habitat used to create the ecological networks (heathland)	Vector
Source_M_EX	The location of source habitat used to create the ecological networks (mires)	Vector
Source_LW_Ex	The location of source habitat used to create the ecological networks (lowland wetlands)	Vector
Source_P_EX	The location of source habitat used to create the ecological networks (ponds)	Vector
Source_W_EX	The location of source habitat used to create the ecological networks (woods)	Vector

ESn 2 Select source habitat layers (Indicators, used by later models)
ModelOutputs/ESn_Ecological_networks/Indicators.gdb

Output data	Description	Data type
Grasslands_Source_Ind	The location of source habitat used to create the ecological networks (grassland)	Vector
Heath_Source_Ind	The location of source habitat used to create the ecological networks (heathland)	Vector
Mires_Source_Ind	The location of source habitat used to create the ecological networks (mires)	Vector
LWetlands_Source_Ind	The location of source habitat used to create the ecological networks (lowland wetlands)	Vector
Ponds_Source_Ind	The location of source habitat used to create the ecological networks (ponds)	Vector
Woods_Source_Ind	The location of source habitat used to create the ecological networks (woods)	Vector

Model limitations (source habitat)

- Ideally the habitat source data used to build these selections would be of a consistent standard, mapped to the same level of habitat hierarchy, however this will often not be the case.

Modifications and actions to improve the model (source habitat)

- Future versions could incorporate tick boxes to allow different selection of habitat data, rather than the need to type in selection features.
- It would be preferable to allow the habitat patch size threshold to be set separately for each habitat group.

ESn 3 Create ecological networks

This model uses the landscape cost rasters and the habitat source data (created in the previous two models) to map ecological networks. Three scales are produced: core, meso and macro. Initial analysis parameters are set, but can be altered by the user.

Instructions
- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog
- Right click model name and Open (close and reopen ArcCatalog if the model is slow to open)
- Change any other parameters, if required
- Click OK to run the tool

ESn 3 Create ecological networks - inputs

Input data	Description	Data type	Save to
BaseMap _Final	Detailed habitat & land use map.	Vector (polygon)	No action needed. Previous model output saved to: ModelOutputs/ ES1BaseMap/ Outputs.gdb
Scratch	Geodatabase. Location of temporary and intermediate data	Gdb	No action needed. Previous model output saved to: ModelOutputs/ ESn_1_Ecologicla networks/ Scratch.gdb

ESn 3 Create ecological networks - parameters

Parameter	Default	Explanation
Extent	-	This should be set to SA_buffer (ModelOutputs\ES1BaseMap\Outputs.gdb
RunCode	addID Code	Code to classify the analysis run
Maximum cost distance	4,000	Set a maximum distance from any source habitat for the distance calculations.
Set core distance – grassland	150	The maximum distance that a hypothetical focal “core” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set meso distance –grassland	1,000	The maximum distance that a hypothetical focal “meso” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set macro distance - grassland	1,500	The maximum distance that a hypothetical focal “macro” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set core distance – heathland	250	The maximum distance that a hypothetical focal “core” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set meso distance –heathland	1,000	The maximum distance that a hypothetical focal “meso” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set macro distance - heathland	1,500	The maximum distance that a hypothetical focal “macro” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set core distance – mires	150	The maximum distance that a hypothetical focal “core” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set meso distance –mires	2,000	The maximum distance that a hypothetical focal “meso” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set macro distance - mires	3,000	The maximum distance that a hypothetical focal “macro” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set core distance – ponds	50	The maximum distance that a hypothetical focal “core” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set meso distance –ponds	500	The maximum distance that a hypothetical focal “meso” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set macro distance - ponds	1500	The maximum distance that a hypothetical focal “macro” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set core distance – woodland	250	The maximum distance that a hypothetical focal “core” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set meso distance –woodland	1,000	The maximum distance that a hypothetical focal “meso” species could move through favourable habitat, in metres.

Parameter	Default	Explanation
		The distance is reduced by matrix cost resistance.
Set macro distance - woodland	2,000	The maximum distance that a hypothetical focal “macro” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set core distance – lowland wetlands	150	The maximum distance that a hypothetical focal “core” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set meso distance –lowland wetlands	1,000	The maximum distance that a hypothetical focal “meso” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Set macro distance – lowland wetlands	1,500	The maximum distance that a hypothetical focal “macro” species could move through favourable habitat, in metres. The distance is reduced by matrix cost resistance.
Select threshold size for Grassland networks	10,000	A threshold size can be set for mapped habitat networks. If a network does not meet this size limit it will be ignored, and will not appear on the maps. The default is 10,000 sq m which is 1 ha, (100 m x 100 m).
Select threshold size for Heathland networks	10,000	A threshold size can be set for mapped habitat networks. If a network does not meet this size limit it will be ignored, and will not appear on the maps. The default is 10,000 sq m which is 1 ha, (100 m x 100 m).
Select threshold size for Mire networks	10,000	A threshold size can be set for mapped habitat networks. If a network does not meet this size limit it will be ignored, and will not appear on the maps. The default is 10,000 sq m which is 1 ha, (100 m x 100 m).
Select threshold size for Ponds networks	10,000	A threshold size can be set for mapped habitat networks. If a network does not meet this size limit it will be ignored, and will not appear on the maps. The default is 10,000 sq m which is 1 ha, (100 m x 100 m).
Select threshold size for Woodlands networks	10,000	A threshold size can be set for mapped habitat networks. If a network does not meet this size limit it will be ignored, and will not appear on the maps. The default is 10,000 sq m which is 1 ha, (100 m x 100 m).
Select threshold size for Lowland wetlands networks	10,000	A threshold size can be set for mapped habitat networks. If a network does not meet this size limit it will be ignored, and will not appear on the maps. The default is 10,000 sq m which is 1 ha, (100 m x 100 m).
Create grassland networks	Yes	Un-tick to remove this network from the analysis
Create heathland networks	Yes	Un-tick to remove this network from the analysis
Create mire networks	Yes	Un-tick to remove this network from the analysis
Create pond networks	Yes	Un-tick to remove this network from the analysis
Create woodland networks	Yes	Un-tick to remove this network from the analysis
Create lowland wetland networks	Yes	Un-tick to remove this network from the analysis

ESn 3 Create ecological networks - outputs
ModelOutputs/ESn_Ecological_networks/Outputs.gdb

Output data	Description	Data type
Grassland_all_networks	All network scales mapped (3:core, 2:meso, 1:macro)	Raster
Grassland_all_source_only	Source habitat coded by network type (3:core, 2:meso, 1:macro)	Raster
Grassland_network a core NX	The mapped “core” network	Vector
Grassland_network b meso NX	The mapped “meso” network	Vector
Grassland_network c macro NX	The mapped “macro” network	Vector
Heathland_all_networks	All network scales mapped (3:core, 2:meso, 1:macro)	Raster
Heathland_all_source_only	Source habitat coded by network type (3:core, 2:meso, 1:macro)	Raster
Heathland_network a core NX	The mapped “core” network	Vector
Heathland _network b meso NX	The mapped “meso” network	Vector
Heathland _network c macro NX	The mapped “macro” network	Vector
Mires_all_networks	All network scales mapped (3:core, 2:meso, 1:macro)	Raster
Mires_networks_ source_only	Source habitat coded by network type (3:core, 2:meso, 1:macro)	Raster
Mires_network a core NX	The mapped “core” network	Vector
Mires _network b meso NX	The mapped “meso” network	Vector
Mires _network c macro NX	The mapped “macro” network	Vector
Ponds_all_networks	All network scales mapped (3:core, 2:meso, 1:macro)	Raster
Ponds_all_source_only	Source habitat coded by network type (3:core, 2:meso, 1:macro)	Raster
Ponds_network a core NX	The mapped “core” network	Vector
Ponds _network b meso NX	The mapped “meso” network	Vector
Ponds _network c macro NX	The mapped “macro” network	Vector
Woods_all_networks	All network scales mapped (3:core, 2:meso, 1:macro)	Raster
Woods_all_source_only	Source habitat coded by network type (3:core, 2:meso, 1:macro)	Raster
Woods_network a core NX	The mapped “core” network	Vector
Woods _network b meso NX	The mapped “meso” network	Vector
Woods _network c macro NX	The mapped “macro” network	Vector
LowWetland_all_networks	All network scales mapped (3:core, 2:meso, 1:macro)	Raster
LowWetland_all_source_only	Source habitat coded by network type (3:core, 2:meso, 1:macro)	Raster
LowWetlands_network a core NX	The mapped “core” network	Vector
LowWetlands_network b meso NX	The mapped “meso” network	Vector
LowWetlands_network c macro NX	The mapped “macro” network	Vector

Note: due to settings, not all the outputs may be created for each run of the models.

ESn 4 Select top networks by area

This model selects the top ten (or optionally the top five) ecological networks per habitat group, *for map presentation purposes*.

Instructions

- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- Change any parameters
- Click OK to run the tool

ESn_4_Select top networks by area

Parameter	Default	Explanation
Select top 5 or top 10	"OBJECTID" <= 10	This selects only the largest top 10 or top 5 habitat networks for each mapped focal habitat group. Use the settings: “OBJECTID" <= 10 (in order to select the top ten networks) Or “OBJECTID" <= 5 (in order to select the top five networks)

ESn_4_Select top networks by area
ModelOutputs/ESn_Ecological_networks/Outputs.gdb

Output data	Description	Data type
Grassland_network a core NX Top	The mapped “core” network	Vector
Grassland_network b meso NX Top	The mapped “meso” network	Vector
Grassland_network c macro NX Top	The mapped “macro” network	Vector
Heathland_network a core NX Top	The mapped “core” network	Vector
Heathland _network b meso NX Top	The mapped “meso” network	Vector
Heathland _network c macro NX Top	The mapped “macro” network	Vector
Mires_network a core NX Top	The mapped “core” network	Vector
Mires _network b meso NX Top	The mapped “meso” network	Vector
Mires _network c macro NX Top	The mapped “macro” network	Vector
Ponds_network a core NX Top	The mapped “core” network	Vector
Ponds _network b meso NX Top	The mapped “meso” network	Vector
Ponds _network c macro NX Top	The mapped “macro” network	Vector
Woodlands_network a core NX Top	The mapped “core” network	Vector
Woodlands _network b meso NX Top	The mapped “meso” network	Vector
Woodlands _network c macro NX Top	The mapped “macro” network	Vector
LWetlands_network a core NX Top	The mapped “core” network	Vector
LWetlands_network b meso NX Top	The mapped “meso” network	Vector
LWetlands_network c macro NX Top	The mapped “macro” network	Vector

Note: due to settings, not all the above outputs may be created for each run of the models.

Model limitations (select top networks by area)

- The model assumes that the largest networks are the most important or significant. This is not necessarily true. The model is provided because it can be useful to visually highlight the largest networks.

Modifications and actions to improve the model (select top networks by area)

- Future versions could incorporate analysis to illustrate the % of the landscape occupied by each network (core, meso, macro), for each habitat group, as an output statistic.

8.7 Creating Biodiversity Opportunity Areas maps

Toolkit Development: Jonathan Winn

These models map two sets of “Biodiversity Opportunity Areas”: *Habitat Buffer* sites and *Habitat Creation* sites. The method builds on the work of the Ecological Network mapping and uses the same broad categories of habitats. For each of the broad habitat groups, analysis examines conditions that are likely to be suitable for habitat creation or habitat buffering. These areas are then mapped where they occur within the zones previously identified by the Ecological Network mapping.

The analysis is simplistic but allows user-defined buffer distances together with the mapping of identified “constraints”. The constraints are areas where habitat restoration, for a particular habitat type, is unlikely to occur for socio-economic or ecological factors. Opportunities are only identified within the previously identified Ecological Networks, as these are areas within which habitat colonisation of new habitat is expected to be highest. The following parameters, can be altered:

- Maximum distance from existing habitat for habitat buffer sites
- Minimum distance from existing habitat for habitat creation sites
- Constraints habitats for each habitat network
- Slopes conditions that represents constraints to habitat creation or buffering
- Elevation conditions that represents constraints to habitat creation or buffering
- The network type (Core, Meso, Macro) used to determine the areas considered suitable for Habitat Buffering or Habitat Creation

In many situations the buffer and creation distances used will be the same. Similarly, the Ecological Network used to determine the areas where both buffer and creation sites are mapped will often be the same. However the flexibility is given for users to map these separately, for example in the situation where buffer sites could be applied to the core network, but creation sites could be mapped within the wider macro network. Such an analysis would represent the protection and buffering of the main resource, and the promotion and creation of "stepping stone" sites.

This model must be run separately for each habitat group. Two example models are provided that can be further modified for additional habitat groups. These are Lowland wetlands and woodlands.

The “Lowland wetlands” model parameters are as follows:

- A narrow distance of 25 m is used to reflect possible buffer creation areas
- Minimum patch sizes of 2,500 (0.25 ha) are used to map creation and buffering sites
- Only opportunity areas that occur within 500 m of the nearest waterbody are mapped
- Only opportunity areas that occur on gentle to flat slopes (<= 6 degrees) are mapped as these will have the highest potential for wetland creation, with minimal cost
- Only opportunity areas less than 300 m elevation are mapped
- Buffer areas are mapped using both the “core” and “meso” networks
- Creation areas are mapped using both the “meso” and “macro” areas

The “Woodland” model parameters are as follows:

- A distance of 100 m is used to reflect possible buffer creation areas
- Minimum patch sizes of 2,500 (0.25 ha) are used to map creation and buffering sites
- No elevation, slope, or distance to water settings are applied

- Buffer areas are mapped using both the “core” and “meso” networks
- Creation areas are amped using both the “meso” and “macro” areas

Note that adding additional habitat to the general habitat constraints layer can further target the mapping of habitat creation or buffer sites. If the resulting maps are considered too restrictive, but the insight from using the ecological network mapping method is considered useful, then a series of ecological network maps could be run using larger macro distance settings, this would result in more mapped areas when the biodiversity opportunity areas are then re-run. Note also that it is a default setting of these models not to map any habitat creation or buffer areas where land has been mapped as current habitat areas by the ecological network models (Indicators geodatabase in the ecological networks folder). If files are present (%habitat%_all_Ind) then these will not be considered as options for habitat creation or buffering.

ESo 1 Biodiversity Opportunity Mapping

This model creates a set of potential "Biodiversity Opportunity Areas" where either habitat *creation* or habitat *buffering* might be suitable. The models must be run once for each habitat group. Two examples are provided, these can be modified and saved for further habitat groups. The use of a geology (or soils) layer is optional.

Instructions
- Close all ArcGIS software, if running (ArcMap, ArcCatalog)
- Open ArcCatalog
- Right click model and Open (close and reopen ArcCatalog if the model is slow to open)
- Change any parameters
- Click OK to run the tool

ESn 1 Biodiversity Opportunity Mapping (Parameters and Inputs)
Setting are per analysis, run once per habitat

Parameter	Default	Explanation
Habitat	N/A	Select the habitat group for this analysis. (Model is run for each group)
Set analysis cell size (Range 5m to 20m)	10 m	Sets the grid cell size (in metres) for the raster data analysis. Smaller cell sizes may give more detailed results, but will take longer to run. See User Guide for estimated model run times.
Habitat data layer	BaseMap FINAL	The habitat layer used to locate the habitat types. This has been designed using EcoServ-GIS BaseMap_FINAL (other habitat data sources could be tested in its place)
Select habitat all source areas	(Vector)	Select the vector file mapping the locations of all existing habitat areas
Threshold size for <u>buffer</u> sites	2,500 m (0.25 ha)	Set the minimum size of buffer sites to be mapped. Any identified sites / patches below this size will be ignored.
Select the maximum distance from source area for <u>buffer</u> sites	variable	Set the maximum distance for which buffer sites will be mapped, in metres distance from existing sites. A higher buffer distance will result in larger buffer sites.
Threshold size for <u>creation</u> sites	2,500 m (0.25 ha)	Set the minimum size of buffer sites to be mapped. Any identified sites / patches below this size will be ignored.
Select the maximum distance from source area for <u>creation</u> sites	variable	Set the maximum distance for which buffer sites will be mapped, in metres distance from existing sites. A higher buffer distance will result in mapped sites further away from existing habitat patches.
Select all general constraints (to habitat creation or buffering)	various	Set the habitat types for which any conservation activity will not be possible. These areas will then be removed from the analysis. (e.g. it is not possible for sites to be created where there are existing roads or houses). This can be further modified to remove selected habitat types from the mapping.
Use distance to water constraints?	Y	Tick this if you wish to set constraints based on distance to water (streams, ponds, lakes)
Use Geology constraints?	Y	Tick this if you wish to set constraints based on Geology type
Use elevation constraints?	Y	Tick this if you wish to set constraints based on Elevation
Use slope	Y	Tick this if you wish to set constraints based on Slope

Parameter	Default	Explanation
constraints?		steepness
Select geology input data	Dummy variable	Select the vector feature class geology source data (only if you have separately sourced this)
Set geology types that are constraints for this habitat group	Peat	Select the categories that are constraints (only if you have separately sourced geology data)
Select streams, rivers or water habitats	HabBroad = "water, fresh"	Select the habitat from the listed Habitat data source that identify areas of water habitat
Set threshold below which distance to water is considered a constraint	-1	Set this if you want areas close to water to be a constraint (e.g. to only identify buffer and creation sites further away from existing watercourses or ponds)
Set threshold below which distance to water is considered a constraint	50,000	Set this is you want areas further away from water to be a constraint (e.g. to only identify buffer and creation sites close to existing watercourses or ponds).
Set lower elevation threshold below which elevation is a constraint	-50	Set this is you want low elevation areas to be a constraint (e.g. this could be used to separately target upland or lowland versions of habitats)
Set higher elevation threshold above which elevation is a constraint	1,000	Set this is you want high elevation areas to be a constraint (e.g. this could be used to separately target upland or lowland versions of habitats)
Set lower slope threshold below which slope is a constraint	-5	Set this is you want low slope areas to be a constraint (e.g. to only prioritise steep grassland slopes)
Set higher slope threshold above which slope is a constraint	100	Set this if you want high slope areas to be a constraint (e.g. to only prioritise gentle or flat wetland areas)
Select core network for locating the habitat buffer sites	-	Select habitat network
Select meso network for locating the habitat buffer sites	-	Select habitat network
Select meso network for locating the creation sites	-	Select habitat network
Select macro network for locating the creation sites	-	Select habitat network

Parameter	Default	Explanation
Include meso network in creation site analysis	Y	Includes this network data in the analysis
Include macro network in creation site analysis	Y	Includes this network data in the analysis
Include core network in buffer site analysis	Y	Includes this network data in the analysis
Include meso network in buffer site analysis	Y	Includes this network data in the analysis

ESn 1 Biodiversity Opportunity Mapping Outputs
ModelOutputs/ESo2Biodiversity_Opportunity_Mapping/Outputs.gdb

Output data	Description	Data type
%habitat%_bfp_OX	All identified potential habitat "buffer" areas	Vector
%habitat%_buffersT_OX	Potential habitat "buffer" areas above the user defined threshold size	Vector
%habitat%_CS_OX	All identified potential habitat "creation" areas	Vector
%habitat%_creation_OX	Potential habitat "creation" areas above the user defined threshold size	Vector

Note: %Habitat% will be replaced by the User defined habitat name in all saved results

Model limitations (Biodiversity Opportunity Mapping)

- The method is simplistic and assumes that habitat buffering / creation <u>within</u> the networks is a priority
- The method relies on habitat type data and is therefore limited by the availability of up to date habitat survey information
- Important arable habitats / species are not represented by this mapping
- The method is entirely dependent on the parameters and data used to map the Ecological Networks. If different data or threshold distances are used to create new Ecological Network maps then new Biodiversity Opportunity Areas maps should also be re-created.
- The mapping assumes that no "source" or key habitat for one habitat group is suitable for conversion into any other group. However this may not always be the case, especially across larger mapped polygon core sites.

Modifications and actions to improve the model (Biodiversity Opportunity Mapping)

- Ideally a wider range of focal habitats would be examined.
- Topographic position could be added as an optional constraint.
- Hydrology / Wetness Index could be added as an optional constraint.

8.8 Exporting ArcMaps to PDFs

Tool Development: Script downloads, and Jonathan Winn

Although the main toolkit outputs are GIS data, in many situations PDF maps are useful to share amongst project partners. The following model assists with this. By using the mapping of selected areas of interest within the "StudyAreaScales" dataset (ES1BaseMap\Outputs), separate maps can easily be produced for selected sites, neighbourhoods or landscapes. The models create PDF maps from the results of the analysis without the need to open or edit any ArcMaps.

ES1 Export Habitat BaseMaps ArcMaps to PDFs
ES2 Export Ecosystem Services ArcMaps to PDFs
ES3 Export Multifunctionality ArcMaps to PDFs
ES4 Export Ecological Networks ArcMaps to PDFs

Note that the PDFs will open automatically in sequence when each stage of the model completes.

Toolbox model parameters

Parameter	Default	Explanation
Source folder of ArcMaps MXDs to convert to PDF	various	The folder that contains the ArcMaps to be exported. Defaults are set, however other folders could be selected
PDF text name	various	Used to name the PDF files
PDF Folder Output 1 per ArcMap	Main PDF 1 per map	The location where the separate PDFs are exported. A single PDF is created for each ArcMap AND for each mapped area within the "StudyAreaScales" dataset. THESE ARE ALL DELETED ON EACH NEW ANALYSIS RUN, IF USEFUL THEY SHOULD BE COPIED ELSEWHERE.
PDF Folder Output Combined PDFs 1 per SubArea	various	The location where appended PDFs are saved, one per mapped "StudyAreaScales". These PDFs list all the available maps, collated into files per mapped SubArea.

Note: if many services have been run, and many sub areas have been mapped, this export process may be slow.

8.9 Troubleshooting

1. You may receive warning messages when running a model. These are not a problem. However, if you receive error messages that prevent the model from running, try closing and re-starting ArcCatalog (and ArcMap if it is open) and running the model again. **Making sure that ArcCatalog is closed and then reopened before and after each model run** will ensure the models work as expected. If this does not work then re-start your PC and try running the model again. *Make sure to check the list of known issues for this version of the* toolkit (Annex 19.). If you receive the same error again then try the following in this order.
2. Remember to replace tutorial input data.
3. Confirm that the Install and Run steps in Part II have been followed exactly.
4. Confirm the Spatial Analyst extension is enabled.
5. Confirm Geoprocessing options set to “overwrite the outputs of Geoprocessing options”
6. Open the model in edit mode, validate and check that no input data are missing. Save the validated model. Close and re run.
7. Examine the input data in ArcMap and check the following:
    - Remember to replace tutorial input data with data for your area
    - Have you included any "optional" data that may be expected by the model
    - Have you "unticked" any optional parameters that you do not have data for
    - Are all data named and formatted exactly as instructed?
    - Inspect the input data in ArcCatalog and view the extent in ArcMap, do the input data look as you would expect them to look? (check location, extent, categories, filenames)
    - Are data projected using the British National Grid coordinate system?
    - Are there any unnecessary fields in any input data (especially those containing long strings of text) that could be removed?
    - Run the “Repair Geometry” tool on input vector data to fix any geometry errors
    - If the model you are attempting to run has a ”RunCode” field then re-try the model with a different "RunCode", for example by adding an extra letter or incrementing a number.
8. Check settings for Windows Update. Change your settings to automatically download updates but to check before installing, this will stop the computer automatically re-starting, for example if you left the models to run overnight.
9. Delete and re-create the “Scratch” and “Outputs” file Geodatabase within the service model subfolder that is causing problems. If you do this you will have to re-run any previous models that had created data in these Geodatabases.
10. Ensure that the data files are not in use by another program to prevent data locking.
11. Occasionally a model may become corrupted. In such a case, create a new empty model, set model properties as "store relative path names", then copy and paste the model contents from the problem model into the new blank model. Rename the new model and save.
12. Reinstall the entire EcoServ-GIS folder and start from the beginning.

If you receive a red error message, please take a screen shot of the message as it appears on screen and within an email, listing the Model name and Version, send to **ecoserv-gis@outlook.com**. Although the toolkit is not supported it may be possible to investigate such errors.

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ANNEX 1: EXAMPLE ANALYSIS TIMES

Time to run each model on a Dell Inspiron 620 Core i3 @ 3.3GHz with 8 GB RAM and a 64 BIT operating system at a 10 m resolution. Area calculated from StudyArea + buffer (SA_buffer). Polygons within BaseMap_FINAL. (k = thousands, m = millions).

Model	Local scale TUTORIAL data 400 km^2 Polygons = 620k	County scale South Downs NP 3,500 km^2 Polygons =2.4m
ES1a Study Area With Sea	35 min	1 hr 40 min
ES1b Study Area No Sea	35 min	1 hr 40 min
ES2 Collate	5 min	< 15 min
ES3 Add Open Space Typology (Optional)	15 min	1 hr
ES4 Add LCA (Optional)	1 hour	< 2 hrs
ES5 Add BAP Habitat (Optional)	20 min	<40 min
ES6 Add Slopes (Optional)	1 hour 10 min	< 3 hrs
ES7 Add Elevation (Optional)	1 hour 10 min	< 3 hrs
ES8 Add Woodland survey (Optional)	< 30 min	<1 hr
ES9 Add LCM2007 (Optional)	1 hour	< 3 hrs
ES10 Add Urban AWI	5 min	< 10 min
ES11 Classify BaseMap Habitats	30 min	1 hr 40 min
ES12 Add Attributes link table	10 min	< 30 min
ES13 Socioeconomic	10 min	< 30 min
Total BaseMap models	3 hrs to 6 hrs	about 2 days
Total Air Purification models	1 hr	< 3 hrs
Total Carbon models	<15 min	< 30 min
Total Local climate models	< 50 min	1 hr 40 min
Total Noise models	55 min	1hr 50 min
Total Pollination models	20 min	30 min
Total Water Purification models	2 hr	3hr 45min
Total Accessible Nature models	1 hr 5 min	2 hrs 10 min
Total Education models	1 hr	3 hr
Total Green Travel models	45 min	2 hr
Total Multi-functionality	1 hr	< 3 hrs
Total Ecological networks	1 hr 15 min	< 4 hrs
Total Biodiversity Opportunity areas	45 min	1 hr 30 min

ANNEX 2: BASEMAP OUTPUT FILENAMES

Outputs located in ES1BaseMaps\Indicators.gdb and ES1BaseMaps\Outputs.gdb (Depending on the model run, not all of these will necessarily exist.)

Filename	Content
domestic_buildings	Location of predicted domestic buildings
Pop_socioec_points	Socioeconomic data mapped to domestic household locations. (Population, Multiple Index of Deprivation)
BaseMap_FINAL	OS MasterMap updated by all available information to define each polygon by Habitat Type Code. This version is used by all service models.
BaseMap_FINAL_%CODE%_V%Date%	OS MasterMap updated by all available information to define each polygon by Habitat Type Code. This version is used by all service models.
BaseMap01	OS MasterMap clipped to study area, with new added data fields. This version is used by subsequent models.
BaseMap01a_%CODE%_V%Date%	OS MasterMap clipped to study area, with new data fields added. Archive version, labelled by Code to define the StudyArea and analysis run, plus date.
BaseMap01b_%CODE%_V%Date%	OS MasterMap clipped to study area, with new data fields added. Archive version, labelled by Code to define the StudyArea and analysis run, plus date.
BaseMap03_GI	OS MasterMap updated by GI / Open Space Survey data. This version is used by subsequent models.
BaseMap03_GI_%CODE%_V%Date%	OS MasterMap updated by GI / Open Space Survey data. Archive version, labelled by Code to define the StudyArea and analysis run, plus date.
BaseMap04_LCA	OS MasterMap updated by LCA (or equivalent) data. This version is used by subsequent models.
BaseMap04_LCA_%CODE%_V%Date%	OS MasterMap updated by LCA (or equivalent) data. Archive version, labelled by Code to define the StudyArea and analysis run, plus date.
BaseMap05_BAP	OS MasterMap updated by national, local or combined BAP data. This version is used by subsequent models.
BaseMap05_BAP_%CODE%_V%Date%	OS MasterMap updated by national, local or combined BAP data. Archive version, labelled by Code to define the StudyArea and analysis run, plus date.
BaseMap06_Slopes	OS MasterMap updated by slopes / steepness data. This version is used by subsequent models.
BaseMap06_Slopes_%CODE%_V%Date%	OS MasterMap updated by slopes / steepness data. Archive version, labelled by Code to

Filename	Content
	define the StudyArea and analysis run, plus date.
BaseMap07_Elevation	OS MasterMap updated by Elevation data. This version is used by subsequent models.
BaseMap07_Elevation_%CODE%_V%Date%	OS MasterMap updated by Elevation data. Archive version, labelled by Code to define the StudyArea and analysis run, plus date.
BaseMap08_SNW	OS MasterMap updated by Scottish Native Woodland Survey data. This version is used by subsequent models.
BaseMap08_SNW_%CODE%_V%Date%	OS MasterMap updated by Scottish Native Woodland Survey. Archive version, labelled by Code to define the StudyArea and analysis run, plus date.
BaseMap09_LCM	OS MasterMap updated by Land cover Map 2007 data. This version is used by subsequent models.
BaseMap09_LCM_%CODE%_V%Date%	OS MasterMap updated by Land cover Map 2007. Archive version, labelled by Code to define the StudyArea and analysis run, plus date.
BaseMap10_Urban	OS MasterMap updated by Urban and Ancient Woodland Inventory data. This version is used by subsequent models.
BaseMap10_Urban_%CODE%_V%Date%	OS MasterMap updated by Urban and Ancient Woodland Inventory. Archive version, labelled by Code to define the StudyArea and analysis run, plus date.
BaseMap11_Habitats	OS MasterMap updated by ecosystem service attributes table. This version is used by subsequent models.
BaseMap11_Habitats_%CODE%_V%Date%	OS MasterMap updated by ecosystem service attributes table. Archive version, labelled by Code to define the StudyArea and analysis run, plus date.

ANNEX 3: SERVICE MODEL OUTPUT FILENAMES

Outputs located in <Service>\Outputs.gdb and <Service>\Shapefiles (Depending on the model run, not all will necessarily exist).

Location	Filename	Type	Content
Shapefiles	<service>_capacity.shp	Shapefile	A shapefile version, converted to 10 polygon classes.
Shapefiles	<service>_demand.shp	Shapefile	A shapefile version, converted to 10 polygon classes.
Shapefiles	<service>_shpt_Capacity_Quintiles_by_area.shp	Shapefile	A shapefile version, converted to 5 polygon classes.
Shapefiles	<service>_shpt_Capacity_Quintiles_by_value.shp	Shapefile	A shapefile version, converted to 5 polygon classes.
Shapefiles	<service>_shpt_Demand_Quintiles_by_area.shp	Shapefile	A shapefile version, converted to 5 polygon classes.
Shapefiles	<service>_shpt_Demand_Quintiles_by_value.shp	Shapefile	A shapefile version, converted to 5 polygon classes.
Shapefiles	<service>_shpt_GI_assets.shp	Shapefile	A shapefile version, converted to 10 polygon classes.
Shapefiles	<service>_shpt_ManagementZones.shp	Shapefile	A shapefile version.
Shapefiles	<service>_shpt_ServiceBenefitingAreas.shp	Shapefile	A shapefile version.
Shapefiles	<service>_shpt_ServiceBenefitingAreas_Prioritised.shp	Shapefile	A shapefile version.
Shapefiles	<service>_unrestricted_capacity.shp	Shapefile	A shapefile version.
Outputs	<service>_Capacity	Raster	The main Capacity map results. Values 1 to 100
Outputs	<service>_Capacity_0_100	Raster	The main Capacity map results. Values 0 to 100
Outputs	<service>_Capacity_5Quintiles_by_Area	Raster	Capacity results reclassified into 5 Quintiles, by area
Outputs	<service>_Capacity_5Quintiles_by_Value	Raster	Capacity results reclassified into 5 Quintiles, by value
Outputs	<service>_CapacityUnrestricted	Raster	Capacity map for areas where there are no restrictions on service flow (not all services). Values 1 to 100
Outputs	<service>_CapacityUnrestricted_0_100	Raster	Capacity map for areas where there are no restrictions on service flow (not all services). Values 0 to 100
Outputs	<service>_Demand	Raster	The main Demand map results. Values 1 to 100.
Outputs	<service>_Demand_0_100	Raster	The main Demand map results. Values 0 to 100.
Outputs	<service>_Demand_5Quintiles_by_Area	Raster	Demand results reclassified into 5 Quintiles, by area
Outputs	<service>_Demand_5Quintiles_by_Value	Raster	Demand results reclassified into 5 Quintiles, by value
Outputs	<service>_Demand_All_One	Raster	All areas with some demand
Outputs	<service>_ESBA_and_Gaps	Raster	All Ecosystem Services Benefiting Areas and Gaps.
Outputs	<service>_ESBA_and_Gaps_Prioritised	Raster	All Ecosystem Services Benefiting Areas and Gaps. Prioritised.
Outputs	<service>_ESBA_ManagementZones_Prioritised	Raster	All Management Zones Prioritised.
Outputs	<service>_GI_Assets	Raster	Capacity areas within the mapped ESBA areas.

Note: rarely reclassification may result in fewer than 5 quintiles for a service or Study Area. This occurs where there is not sufficient variation in the mapped data to allow 5 quintiles to be produced.

ANNEX 4: DATA SUPPLIED WITH THE TOOLKIT

The following datasets are supplied within the toolkit. These analysis steps do not need to be followed, because these are already present in the toolkit. These notes are provided for reference only, in case data need to be updated with future releases, or where users may wish to supply their own copy of locally available versions of these datasets.

<u>BaseMap Data Inputs</u>

AWI_GB and AWI_GB_ASNW (Ancient Woodland Inventory)	Required for toolboxes: ES1BaseMap; ES3WildlifeWatching

Ancient woodlands are areas of land that have had woodland cover since 1600 AD. Any of these sites over 2 ha in size have been mapped and these data can be obtained from different sources, depending on the country. Data for England, Wales and Scotland have been combined into a single file.

- Data sourced for each country: Ancient Woodland Inventory 2001 (Wales), Ancient Woodland Inventory v2.6 (England), Ancient woodland Inventory Scotland (2000) (Scotland).
- Extract polygons containing ancient semi-natural woodland that has not been replanted (status is “ASNW”)
- Export this selection as AWI_ASNW_GB to *ModelInputs/ES0CommonFiles/Inputs.gdb*

District_unitary_region (UK District boundaries)	Required for toolboxes: ES1BaseMap; several service models

Boundary-Line™ data contains information on electoral and administrative boundaries across Great Britain.

- Export to the following Geodatabases, using the name *“District_unitary_region”:*
- *ModelInputs/ES0CommonFiles/Inputs.gd*

OA_2011_GB (Output Areas and Data Zones 2011)	Required for toolboxes: ES1BaseMap

Polygon census area data and linked attribute information from the 2011 census. Used for mapping population densities, household size and a range of social data. A GB scale dataset has been created by combining the Output Areas from England and Wales with the Data Zones in Scotland. This analysis used the Scottish 2011 census results data, but the 2001 data Zone boundaries, as available in 2014.

- GIS files downloaded to map the 2011 census boundaries for Output Areas (Data Zones 2001 in Scotland).
- Downloaded the table data from Scottish government data website and ONS. Data is available separately for England and Wales, and Scotland.
- Available census data was joined to the GIS file in stages.
- Merge the files and remove overlaps along the border.
- Additional fields were added and calculated to provide the required data fields on age ranges, and social diversity metrics.
- See BaseMap Technical Report for further details.
- Export the data to *ModelInputs/ES1BaseMap/Inputs.gdb* with the name “OA_2011_GB”

IMD_England, IMD_Scotland, IMD_Wales (Index of Multiple Deprivation data)	Required for toolboxes: ES1BaseMap

These scores are the result of a qualitative study of deprivation. The analysis was conducted separately in each country, and the data cannot be compared across country boundaries.

- Downloaded the latest “Indices of deprivation <year> : Indices and domains” excel spreadsheet
- Copy across the rows from the individual domain worksheets (Income; Employment; Health & Disability; Education Skills & Training; Barriers to Housing & Services; Crime; Living Environment), excluding the “LSOA CODE” columns
- Rename the columns headers as outlined to match those used in the current dataset within the toolkit.
- Link the tables to the appropriate country based GIS boundary file (2001 versions) (e.g. LSOA 2001)
- Export to *ModelInputs/ES1BaseMap/Inputs.gdb* with the name “IMD_England” or “IMD_Scotland” or IMD_Wales”

New column headers for the IMD data

Original column header	New column header
IMD SCORE	IMDScor
RANK OF IMD SCORE (where 1 is most deprived)	IMDRank
INCOME SCORE	IncomeScor
RANK OF INCOME SCORE (where 1 is most deprived)	IncomeRank
EMPLOYMENT SCORE	EmployScor
RANK OF EMPLOYMENT SCORE (where 1 is most deprived)	EmployRank
HEALTH DEPRIVATION AND DISABILITY SCORE	HealthScor
RANK OF HEALTH DEPRIVATION AND DISABILITY SCORE (where 1 is most deprived)	HealthRank
EDUCATION SKILLS AND TRAINING SCORE	EducatScor
RANK OF EDUCATION SKILLS AND TRAINING SCORE (where 1 is most deprived)	EdcuatRank
BARRIERS TO HOUSING AND SERVICES SCORE	HouseScor
RANK OF BARRIERS TO HOUSING AND SERVICES SCORE (where 1 is most deprived)	HouseRank
CRIME AND DISORDER SCORE	CrimeScor
RANK OF CRIME SCORE (where 1 is most deprived)	CrimeRank
LIVING ENVIRONMENT SCORE	EnvioScor
RANK OF LIVING ENVIRONMENT SCORE (where 1 is most deprived)	EnvioRank

Urban_GB (Urban zones)	Required for toolboxes: ES1BaseMap; ES2LocalClimate

England and Wales. Built Up areas (BUA) (2011). ONS data related to the census maps urban agglomerations, cities, and smaller towns with an extent of at least 20 ha. Urban areas within 200 m of each other were merged when this data was produced.
Scotland: Settlements (2010). NRS boundary data for settlements of high density postcodes with more than 500 population.

- Download Built Up Areas (BUA 2011) data from ONW website.
- Download Settlements 2010 from the NRS website.
- Merge the two datasets.
- Export the shapefile to the geodatabase using the name “Urban_GB”
- *ModelInputs/ES1CommonFiles/Inputs.gds*

Ecosystem Service Models Data Inputs

Country_Parks_Eng_Scot
Location of designated Country Parks, typically managed by Local Authorities for access, recreation and education use. Note that data were not available for Wales. • Downloaded data from Natural England and Scottish Natural Heritage websites. • Merge data together and repaired geometry. • Export these vector data using the name "Country_Parks_Eng_Scot" to the geodatabase: • *ModelInputs\ES0CommonFilesl\Inputs.gdb*

CRoW (Countryside Rights of Way) (En)
"The Act provides a new right of public access on foot to areas of open land comprising mountain, moor, heath, down, and registered common land, and contains provisions for extending the right to coastal land." JNCC. • CRoW data downloaded from Natural England (CRoW Act 2000 - Access Layer) • If additional polygon data are available showing publically accessible land, merge this with the CROW layer • Export these vector data using the name "CRoW" to the geodatabase: • *ModelInputs\ES0CommonFilesl\Inputs.gdb*

FC_RECREATION_ROUTES_GB
Location of managed recreation routes, e.g. cycle tracks or marked trails within the Forestry Commission estate. • Downloaded data from Forestry Commission website. • Export vector data using the name "FC_RECREATION_ROUTES_GB" to the geodatabase: • *ModelInputs\ES0CommonFilesl\Inputs.gdb*

Lond_Distance_Path_Eng_Scot
Location of longer distance walking routes, trails and long distance paths. Data were not available for Wales. • Downloaded data from Natural England and Scottish Natural Heritage websites. • Download dates are shown where no data version was listed by suppliers. • Source data files were: Natural England: England_Coast_Path_Route.shp (2014), National Trails (2013) and Scotland: John Muir Way (2014). No other long distance routes were available for Scotland, but would be presumed to occur within the relevant Local Authority produced Core Paths data. • Export vector data using the name "Lond_Distance_Path_Route_GB" to the geodatabase: • *ModelInputs\ES0CommonFilesl\Inputs.gdb*

LNR _GB
(Local Nature Reserves)

"To qualify for LNR status, a site must be of importance for wildlife, geology, education or public enjoyment." Natural England. Similar criteria apply in Wales and Scotland.

- Data were download from Natural England, Natural Resources Wales, and Scottish Natural Heritage.
- Files were merged for each country.
- Export these vector data using the name "LNR_GB" to the file geodatabase:
- *ModelInputs\ES0CommonFiles\Inputs.gdb*

NNR_GB
(National Nature Reserves)

"NNRs were initially established to protect sensitive features and to provide 'outdoor laboratories' for research. Their purpose has widened since those early days. As well as managing some of our most pristine habitats, our rarest species and our most significant geology, most Reserves now offer great opportunities to the public as well as schools and specialist audiences to experience England's natural heritage." Natural England. Similar criteria apply in Wales and Scotland.

- Obtain NNR data for your area.
- Export these vector data using the name "NNR_GB" to the file geodatabase:
- *ModelInputs\ES0Commonfilel\Inputs.gdb*

Sustrans
(National Cycle Network)

A series of safe, traffic-free lanes and quiet on-road routes that connect to every major city and passes within a mile of 55% of UK homes. This is a vector dataset of the location of the cycle network. The Version included here dates: Sept 2013.

- Source the data from the current Sustrans GIS officer.
- A model in the Data Preparation Toolkit was used to prepare the data.
- Merge the three datasets which combine to make the Sustrans National Cycle Network.
- Select and use only the non road routes. Where" On road" = "0"
- Repair Geometry and imported to:
- *ModelInputs\ES0CommonFilesl\Inputs.gdb*

Woods4People
(Accessible woodlands)

"Woods for People is a project funded by the Woodland Trust with support from the Esmee Fairbairn Foundation, the Forestry Commission and the Environment and Heritage Service (Northern Ireland) to create and maintain a UK-wide dataset of accessible woodland." (Woodland Trust)

- Sourced data from Woodland trust GIS Officer
- Exported the shapefile to the geodatabase using the name "Woods4People"
- *ModelInputs\ES0CommonFilel\Inputs.gdb*

XYStops (Public transport stops)
"[This dataset is used as a] national system for uniquely identifying all the points of access to public transport in GB. It is a core component of the national transport information infrastructure and is used by a number of other UK standards and information systems. Every GB station, coach terminus, airport, ferry terminal, bus stop, etc., is allocated at least one identifier." HM Government. • Downloaded the NaPTAN data in zipped CSV format from HM Government • Saved the "Stops.csv" file as a 97-2003 version (.xls) spreadsheet • Navigated to this excel spreadsheet in ArcCatalog • Expand this spreadsheet icon in ArcCatalog to see the Stops$ worksheet • Right click on this and select "Create Feature Class → From XY Table... • Set the X Field as "Easting" and the Y Field as "Northing" • Set the coordinate system as British National Grid • Saved the output feature *using the name "XYStops"* (remove any dollar signs from name) to: • *ModelInputs\ES0CommonFilesl\Inputs.gdb*

ANNEX 5: LICENSE AND COPYRIGHT SUMMARY - PER DATASET

Data filename and content	Scale	License	Attribution
%area name%_GI (Green Infrastructure or Open Space survey)	Various	Check with Local Authority supplier	Check with Local Authority data supplier
AWI_GB (Ancient Woodland Inventory)	En	Natural England Open License.	© Natural England copyright [2014]. Contains public sector information licensed under the Open Government Licence v1.0.
AWI_GB (Ancient Woodland Inventory)	Wa	Forestry Commission spatial licence.	Contains, or is based on, information supplied by the Forestry Commission.© Crown copyright and database rights [2014]. All rights reserved. Ordnance Survey Licence number 100021242.
AWI_GB (Ancient Woodland Inventory)	Sc	OS Open Data licence	Copyright Scottish Natural Heritage. Contains Ordnance Survey data © Crown copyright and database right (2014)
BAP (Distribution of BAP habitats)	En	Terms of Use for Natural England's Data	Contains, or is derived from, information supplied by Ordnance Survey. © Crown copyright and database rights [2014]. Ordnance Survey 100022021.
Country_Parks_ Eng_Scot	En	Natural England Open License.	© Natural England copyright [2014]. Contains public sector information licensed under the Open Government Licence v1.0.
Country_Parks_ Eng_Scot	Sc	Open Government licence v.3	© Scottish Natural Heritage. Contains Ordnance Survey data (c) Crown copyright and database right (2014)
CRoW (CRoW Act 2000 Access)	En	Natural England Open License.	© Natural England copyright [2013]. Contains public sector information licensed under the Open Government Licence v1.0.
DTM (50 m, coarse DTM)	GB	OS Open Data Licence.	Contains Ordnance Survey data © Crown copyright and database right [2014]
District_unitary Region (Boundaries)	GB	OS Open Data Licence.	Contains Ordnance Survey data © Crown copyright and database right [2014]
FC_RECREATION _ROUTES_GB (Managed recreation routes)	GB	Forestry Commission Terms of Use	Contains, or is based on, information supplied by the Forestry Commission. © Crown copyright and database rights [2014]. All rights reserved. Ordnance Survey Licence number 100021242.
IMD_England, IMD_Wales, IMD_Scotland (Indices of Multiple Deprivation)	GB	Open Government licence	Contains public sector information licensed under the Open Government Licence v3.0.
LCM 2007 (Land cover map)	UK	-	© NERC (CEH) 2011 © Crown copyright and database right [2014] © third-party licensors

Data filename and content	Scale	License	Attribution
LNR_GB (Local Nature Reserves	En	Natural England Open License.	© Natural England copyright [2014]. Contains public sector information licensed under the Open Government Licence v1.0.
LNR_GB (Local Nature Reserves	Wa	Open Government licence v.3	Contains Natural Resources Wales information © Natural Resources Wales and database right (2015). Contains Ordnance Survey Data. Ordnance Survey Licence number 100019741. Crown Copyright and Database Right (2011)
LNR_GB (Local Nature Reserves	Sc	Open Government licence v.3	© Scottish Natural Heritage. Contains Ordnance Survey data (c) Crown copyright and database right (2014)
MasterMap		OS licence	Contains Ordnance Survey MasterMap data © Crown copyright and database right [2014] [PSMA/OSMA MasterMap Licence Agreement Number]
NNR_GB (National Nature Reserves	En	Natural England Open License.	© Natural England copyright [2014]. Contains public sector information licensed under the Open Government Licence v1.0.
NNR_GB (National Nature Reserves	Wa	Open Government licence v.3	Contains Natural Resources Wales information © Natural Resources Wales and database right (2015). Contains Ordnance Survey Data. Ordnance Survey Licence number 100019741. Crown Copyright and Database Right (2011)
NNR_GB (National Nature Reserves	Sc	Open Government licence v.3	© Scottish Natural Heritage Contains Ordnance Survey data (c) Crown copyright and database right (2014)
OA_2011_GB (Output Area 2011 and census attribute data	En, Wa	Open Government licence	Contains public sector information licensed under the Open Government Licence v3.0.
OA_2011_GB (Data Zones 2001 and census attribute data	Sc	Open Government licence	Copyright Scottish Government, contains Ordnance Survey data © Crown copyright and database right (2014) Ordnance Survey licence number 0100024655
OSVectorMap (District)	GB	OS Open Data Licence.	Contains Ordnance Survey data © Crown copyright and database

Data filename and content	Scale	License	Attribution
			right [2014]
Sustrans (National Cycle Networks)	GB	-	© Sustrans, and Ordnance Survey. Contains Ordnance Survey data © Crown copyright and database right (2014)
Urban _GB	E, Wa	Open Government licence	Contains public sector information licensed under the Open Government Licence v2.0.
Urban _GB	Sc	Open Government licence OS Open Data licence	Contains NRS data © Crown copyright and database right [2014] Contains Ordnance Survey data © Crown copyright and database right [2014]
Woods4People (Public access woods)	GB	N/A.	Notify the woodland trust via 'gis@woodlandtrust.org.uk' that you are using the woods for people data for the purposes of running EcoServ-GIS.
XYStops (Public Transport)	GB	Open Government licence	Contains public sector information licensed under the Open Government Licence v2.0.

ANNEX 6: LICENSE COPYRIGHT - BASEMAP WITH SOCIO-ECONOMIC POINTS

Country	Census	Gov	ONS, NRS	SNH	NE	MM	OD	FC	CEH	Copyright statement for maps
England	OA	IMD	Urban		AWI	X	X		LCM	© Natural England (2015). © NERC (CEH) 2014 © Crown copyright and database right [2014] © third-party licensors. Contains public sector information licensed under the Open Government Licence v3.0. Contains Ordnance Survey data © Crown copyright and database right [2015]. Ordnance Survey Licence number 100022021.
Wales	OA	WIMD	Urban			X	X	AWI	LCM	© Natural Resources Wales. All rights reserved. © NERC (CEH) 2014 © Crown copyright and database right [2014] © third-party licensors. Contains, or is based on, information supplied by the Forestry Commission. Contains public sector information licensed under the Open Government Licence v3.0. Contains Ordnance Survey data © Crown copyright and database rights [2015]. All rights reserved. Ordnance Survey Licence number 100021242. Ordnance Survey Licence number 100019741.
Scotland	Data Zones	SIMD	Urban	AWI		x	X		LCM	©Scottish Natural Heritage © Scottish Government. © NERC (CEH) 2014 © Crown copyright and database right [2014] © third-party licensors. Contains public sector information licensed under the Open Government Licence v3.0. Contains Ordnance Survey data © Crown copyright and database right (2015). Contains NRS data © Crown copyright and database right [2015]. Ordnance Survey Licence number 0100024655

Note: if all the BaseMap optional models are not run when creating the BaseMap then not all these licence conditions will be required. ONS: Office for National Statistics, SNH: Scottish Natural Heritage, NE: Natural England, MM: OS MasterMap, OD: Ordnance Survey Open Data, FC: Forestry Commission, CEH: Centre for Ecology and Hydrology

ANNEX 7: LICENSE COPYRIGHT - PER SERVICE

Services group	Country	Copyright statement for maps
Air Purification, Carbon Storage, Local Climate Regulation, Noise Regulation, Pollination, Water Purification	En	© Natural England (2015). © NERC (CEH) 2014. © Crown copyright and database right [2014] © third-party licensors. Contains public sector information licensed under the Open Government Licence v3.0. Contains Ordnance Survey data © Crown copyright and database right [2015]. Ordnance Survey Licence number 100022021.
	Wa	© Natural Resources Wales. All rights reserved. © NERC (CEH) 2014. © Crown copyright and database right [2014] © third-party licensors. Contains, or is based on, information supplied by the Forestry Commission. Contains public sector information licensed under the Open Government Licence v3.0. Contains Ordnance Survey data © Crown copyright and database rights [2015]. All rights reserved. Ordnance Survey Licence number 100021242. Ordnance Survey Licence number 100019741.
	Sc	©Scottish Natural Heritage © Scottish Government. © NERC (CEH) 2014. © Crown copyright and database right [2014] © third-party licensors. Contains public sector information licensed under the Open Government Licence v3.0. Contains Ordnance Survey data © Crown copyright and database right (2015). Contains NRS data © Crown copyright and database right [2015]. Ordnance Survey Licence number 0100024655
Accessible Nature, Education, Green travel	En	© Natural England (2015). © Sustrans, and Ordnance Survey. © NERC (CEH) 2014 © Crown copyright and database right [2014] © third-party licensors. Contains public sector information licensed under the Open Government Licence v3.0. Contains, or is based on, information supplied by the Forestry Commission. Contains Ordnance Survey data © Crown copyright and database right [2015]. Ordnance Survey Licence number 100022021. Ordnance Survey Licence number 100021242.
	Wa	© Natural Resources Wales. All rights reserved. © Sustrans, and Ordnance Survey. © NERC (CEH) 2014 © Crown copyright and database right [2014] © third-party licensors. Contains, or is based on, information supplied by the Forestry Commission. Contains public sector information licensed under the Open Government Licence v3.0. Contains Ordnance Survey data © Crown copyright and database rights [2015]. All rights reserved. Ordnance Survey Licence number 100021242. Ordnance Survey Licence number 100019741.
	Sc	©Scottish Natural Heritage © Scottish Government. © Sustrans, and Ordnance Survey. © NERC (CEH) 2014 © Crown copyright and database right [2014] © third-party licensors. Contains public sector information licensed under the Open Government Licence v3.0. Contains, or is based on, information supplied by the Forestry Commission. Contains Ordnance Survey data © Crown copyright and database right (2015). Contains NRS data © Crown copyright and database right [2015]. Ordnance Survey Licence number 0100024655. Ordnance Survey Licence number 100021242.

ANNEX 8: DATA LICENSE CONDITIONS

License	Example data	Distribution	Adapt, modify, combine	Commercial use
OS Open Data / Open Government v2.0.	50m DTM, UK District boundaries, OS VectorMap	Yes	Yes	Yes
Natural England Open under the Open Government v1.0.	AWI, Crow Act LNR, NNR	Yes	Yes	Yes
Forestry Commission spatial data licence (3)	AWI (Wales)	Yes	Yes	No
Natural England Terms of Use for Information and Data. V 23 July 2013 (1)(4)	BAP	Yes *	Yes	No (2)
Open Government Licence v2.0.	IMD, OA 2001, OA 2011, Data Zones, Census attribute tables, Urban, Public transport stops, Wind Speed data	Yes	Yes	Yes
(Sustrans), and Ordnance Survey	NCN (Sustrans)	Yes *	Yes *	unknown
notify Woodland Trust via 'gis@woodlandtrust.org.uk'	Woods4people	Yes	Yes	unknown

Note (1) "Natural England creates (or derives) and then publishes a range of information and data. Wherever possible we make data available under the Open Government Licence. However, where this is not possible, we use these Terms of Use to set out how information and data may be used by third parties including Natural England's customers and partners".
Note (2) Definition. Commercial = Use of the Data, or the provision or receipt of a Service, that involves making a Financial Gain. Natural England's definition of Commercial applies to organisations regardless of whether they are commercial or non-commercial (e.g. charitable). Financial gain = Where there is a revenue or credit above any reasonable costs that were incurred in making available or supplying a copy of the Data. This includes activities making use of the Data that leads to, or is intended to lead to, income-generating work in any way whatsoever.
* = verified via email with data suppliers.
Note (3) Assess the licence terms annually.
Note (4) Apply for commercial use license if needed. Renew license annually. Cannot be used in web mapping without prior consent. Include a copy of license if data is forwarded.

ANNEX 9: BAP AND HABITAT DATA NOTES

The preparation and use of Biodiversity Action Plan (BAP) data within EcoServ-GIS can involve signification processing and analysis time. Users should always carry out a cost benefit analysis before they commit this time. Some services are impacted more than others by its omission. In general we recommend that the BaseMap is created to be as accurate as possible and this involves this use of BAP data to map semi-natural habitats. However if users are interested in the broader use of the maps at a county scale or are prepared to understand the limitation in the use of poorer quality habitat mapping then the use of just national BAP data allows this process to be speeded up.

The purpose of using BAP data, (both local and nationally available) is to ensure that known semi-habitats are included within the EcoServ-GIS mapping. Several sources are available for the data: Local Authorities, Wildlife Trusts or Local Record Centres, Natural England, Natural Resources Wales or Scottish Natural Heritage.

EcoServ-GIS requires a single habitat layer (without overlaps) showing a single main BAP or semi-natural habitat per polygon. There are different options to create such a layer. Available data may be local or national and may be in the form of a single data layer showing several habitat types, or several data layers each showing a single habitat type. When several single habitat layers exist they may overlap and show the same area of land as potentially being classified as different habitat types.

Local BAP data may be available as single habitat layers, or as combined data layers showing multiple habitat types. In some counties or regions a complete coverage digital habitat map in either Phase 1, NVC or IHS codes. National BAP data may be available as separate habitat layers, one for each habitat type or as combined national datasets.

Various data preparation models are included in the toolkit that could be used as examples of how to combine available habitat data. This text and the accompanying data preparation models are provided for background information only. They have not been designed for use by users of the toolkit as, often the situations will differ between local areas, BAP partnerships etc. However the text and the model may be able to be adapted for local use.
This is a record of how the local and national BAP data were combined into approximate Phase 1 habitat types in England.

- Local BAP data combined into a single data layer (overlaps removed)
- National BAP "Priority (single) habitat layer" was used
- Where available the individual separate BAP data layers for Brownfield and wood pasture and parkland were also used (however these older individual habitat layers are no longer available to download and so may not be available to use)
- Each data stage and input data used is noted for future reference
- Analysis within GIS is used to merge the two datasets, with preference being given to local data in any areas where there is overlap.

<u>Method Notes and Limitations (Example from England analysis)</u>
The use of BAP data within EcoServ-GIS assumes that most of the important habitats have been mapped and classified within a Study Area and therefore assumptions are made about certain habitats types if they have not been mapped as BAP habitat. Unfortunately many areas do not have comprehensive habitat mapping available and in such cases habitats will be classified by default as improved grassland / arable or amenity grassland even though they may be semi-natural or BAP habitat types. If the areas are not mapped as BAP habitat then there is no way for the toolkit to determine their habitat importance.

Toolkit users will frequently be well aware of the strengths and limitations of local habitat mapping. These caveats must be noted and applied when interpreting the final EcoServ-GIS maps. All instances where data is deleted or removed from a habitat layer or BAP layer due to known data or quality limitations should be recorded and noted in the toolkit metadata. For example in England the information is available in the Natural England inventory downloads to define the certainty of classification and the data quality used. Users can limit the BAP data to the more certain categories and higher data quality – which will lead to fewer areas of habitat being updated into the BaseMap, but will allow a higher degree of certainty to be given to these. Alternatively, a wider use of data can be made, however in such cases it must be accepted that there will be lower accuracy of the BAP data included in the models, this might result in areas being classified as BAP habitat from historic data when the BAP habitats are actually no longer present. An example in England is to use only those polygons mapped where the field "PRIDET" = "definitely is". Unfortunately, these exact field names and categories vary slightly between the different inventories so the user will have to view each in turn and decide which polygons to use. As of the release of the Priority single habitat layer these priority classification data fields have been changed. The current recommended method uses only polygons where a "main" priority BAP habitat has been identified and not areas where only "additional" secondary habitats are mapped. Finally, several habitat types previously present in the separate Natural England BAP layers are no longer present in the Priority Single Habitat Layer. The only habitat layers from the NE national habitat layers, separate layers that are not in the current combined layer are – Woodland park + pasture, Undetermined grassland and Brownfield.

Interpretation of national BAP inventories (Natural England)

BAP Priority habitat (broad habitat in brackets)	Component Phase 1 habitats	Corine (1991) and NVC	Interpretation notes Overlap or accuracy rules
Blanket bog (Bogs)	E1.6.1 Blanket bog, E1.7 Wet modified bog E1.8 Dry modified bog	4.1.2 Peatbogs (NVC = M1, M2, M3, M15, M17, M18, M19, M20)	Limitation. Only larger areas were mapped.>5ha
Coastal floodplain grazing marsh	None reported		Based in part on GIS modelling of where wet conditions occur. No definition in the NE download. Not easily linked to a broad habitat
Coastal sand dunes (Supra littoral sediment)	(B3) Calcareous grassland, H6 Sand dune, H6.4, H6.5, H6.6, H6.7, H6.8	(NVC = H1, H11, SD4-17, SD18)	The inventory allows overlap with other habitat type. E.g. woodland on dunes
Coastal vegetated shingle			Aerial photos and surveys
Deciduous Woodland (Broadleaved mixed and yew woodland)	A111, A112, A131, A132, A21, A31, A33, (A41) (A43)	(NVC = W1-W17)	Compiled from previous habitat specific woodland inventories. Below a width of 5m wide a wood is considered a linear feature. Note 1
Fens (Fens, marsh and swamp)	E2 Flush and spring, E3 Fen F1 Swamp	4.1.1 Inland marshes (NVC = All M except 15,16,17,22,23. All S.)	Various data compilation sources, including aerial photo analysis and use of SSSI data
Limestone pavement			Only some counties covered.
Lowland calcareous grassland (Calcareous grassland)	B3, B31, B32, (B21)	3.2.1 Natural grassland, 3.2.4 Transitional woodland / shrub (NVC = CG1-CG9, MG2)	Compiled from various sources including field survey.
Lowland dry acid grassland (Acid grassland)	B1, B11, B12, (C1), (D5), (D6), (H6)	3.2.1 Natural grassland (NVC = U1-U4, U20a, SD10b, SD111b, SD12)	Compiled from various sources including field survey.
Lowland heathland (Dwarf shrub heath)	D1,D2,D3, D5, D6, (H6.6), (H8.5)	Moors and heathland (NVC = H1-H12, M15, M16)	Compiled from various sources including field survey.
Lowland meadows (Neutral grassland)	B2.1, B5	3.2.1, 2.3.1 (NVC = MG4, MG5, MG8, (MG11, MG13, MG6))	Compiled from various sources including field survey.
Lowland raised bogs (Bogs)	E1.6.2	51 Raised bogs	Compiled from various sources including field survey.

BAP Priority habitat (broad habitat in brackets)	Component Phase 1 habitats	Corine (1991) and NVC	Interpretation notes Overlap or accuracy rules
Mudflats (Littoral sediments)		4.2.3 Intertidal flats	Compiled from various sources including OS MasterMap.
Maritime cliff and slope (Supra littoral rock)	Many possible. Key are H5, H8.1, H8.2, H8.3, H8.4, H8.5, J1.3	None noted (NVC = Many NVC can be recorded in this habitat)	Compiled from various data, including remote sensed and field collected data.
Purple moor grass and rush pastures (Fen, marsh and swamp)	B5 Wet marshy grassland. (E3.1, E3.2, F1, A2)	3.2.1 Natural grassland (NVC = M22-M26)	Compiled from various sources including field survey.
Reedbeds		None noted	Compiled from various sources including field survey.
Saline lagoons (Saline lagoons)		4.2.3 Intertidal flats, 5.1.2 Water bodies	Compiled from various sources. Noted snapped to OS boundaries.
Traditional orchards			
Undetermined grassland			Unknown grassland types from various survey sources.
Upland calcareous grassland	B3	(NVC = CG9 – CG14)	Compiled from various sources at various dates. Includes field survey and remote sensing data.
Upland haymeadows		(NVC = MG3)	Fields surveys. Many dated. Many not accurately mapped.
Upland heathland (Dwarf shrub heath)	D1 Dry heath, D2 Wet heath, D5 Dry heath AG mosaic, D6 Wet heath AG mosaic	Moors and heathland (NVC = H4, H8, H9,H10,H12, H16, H18, H21, M15, M16)	Complex mix of data used to produce the inventory including GIS modelling and remote sensed data.
Wood pasture + parkland			Various data compilation, plus aerial photo surveys. Churchyards and cemeteries excluded. Does not include SE region.

Note 1. there appears a difference between the definition of the Deciduous woodland BAP type and the data. The definition includes semi-natural woods, PAWS, or ASNW, or planted woods where they contain more than 50% native species and new planted native woodlands. The inventory data includes the FC NIWT, it appears the woodland does cover both plantation and semi-natural stands.

ANNEX 10: LINK BETWEEN SERVICES AND DATA SUPPLIED BY THE USER

The BaseMap created by the toolkit can include 'optional' datasets. These are: Open Space / Green Infrastructure, Landscape Character Assessment and Locally Important BAP habitats. The inclusion of these datasets improves the quality of the BaseMap which in turn will improve the quality of the outputs from certain service models. Without optional data, the quality of the BaseMap may be lower. The inclusion of the Open Space / Green Infrastructure survey is highly recommended. The impact of missing optional data on *Service Models* is summarised in the following table. Those services which are greatly affected by missing data are highlighted.

Service model	Impact of low quality BaseMap	Input data required by user		
		OS / GI	PROW / Core paths	VectorMap
Air purification	Low	-		VectorMap
Carbon	Low	-		
Local climate	Low	-		
Noise regulation	Low	-		VectorMap
Pollination	High	-		
Water purification	High	-		VectorMap
Accessible nature	High	OS / GI	PROW	
Education	High	OS / GI	PROW	VectorMap
Green travel	Moderate	-		

Note. Users should be aware that even for models that use more complex habit information from the BaseMap that often the link between habitat type and ecosystem service features is applied at a broad habitat classification level. For example within the context of woodland most ecosystem service values link through to broad woodland types of broadleaved, mixed and coniferous, but do not consider semi-natural woodland status. Such semi-natural status information may be used during map production to classify habitat types in detail for presentation purposes, but is not used within model mapping logic.

ANNEX 11: DATA PREPARATION CHECKLIST – SUMMARY

Toolbox	Dataset	Task description	Time required	
			Min	Max
All	Various	Assess data dependency table Annex 10. Decide which are key datasets to acquire.	<1 day	1 day
All	Various	Understand the extent to which using higher quality input data will result in a better quality BaseMap, and the impact this can have on service models. The BaseMap is based on best available habitat information. Not all input data are required.	1 day	2 days
ES1Basemap	MasterMap	Source, examine, analyse and import to a Geodatabase	2.5 days	7 days+
ES1Basemap	StudyArea1	Copy, or digitise and Import to a Geodatabase	10 min	10 min
ES1Basemap	OSVectorMap	Download selected tiles, copy to folder	20 min	1 hr
ES1Basemap	GI / Open Space	Source, examine, analyse and Import to a Geodatabase	2.5 days	7 days+
ES1Basemap	BAP (optional)	Source, examine, analyse. Discuss with data suppliers and/or local experts and import to a Geodatabase	3 days	13 days
ES1Basemap	LCA (optional)	Source, examine, analyse and import to a Geodatabase	3 days	10 days
ES1Basemap	LWS	Source, examine, analyse and import to a Geodatabase	1 day	3.5 days
ES1Basemap	DTM (optional)	Source, examine, analyse and import to a Geodatabase	3 hrs	2.5 days
Several	PROW_CORE	Source, examine, analyse and import to a Geodatabase. Include additional local data where available.	1 day	3 days
ES2WaterPurification	Soils (optional)	Source, examine, analyse and Import to a Geodatabase.	4 hrs	1 day
Total estimate without optional data			10 days	24 days
Total estimate with optional data			17 days	50 days

ANNEX 12: DATA PREPARATION CHECKLIST – FULL

Toolbox and dataset	Task description	Time required	
		Min	Max
ES1Basemap (All datasets)	Create an ArcMap to view all the source data for each of the following datasets, to compare extent, coverage and the categories mapped and to use this to ensure data has been compiled for the whole study area and that no areas are missing. This map can then be referred to during the following data collation and analysis stages.	1 hr	4 hrs
ES1Basemap	Source data via the partnership with PSMA or OSMA partners. Ideally a single data supply or download. Ensure no duplicate polygons present in the data.	2 days	5 days+
(MasterMap)	Import to a Geodatabase	<30 min	<30 min
	Make sure these essential fields are all present and named exactly as in the User Guide – TOID, Theme, DescGroup, DescTerm, Make, PhysLev (see detailed Data Preparation Section)	10 min	2 hrs
	Confirm that the text separator used between multiple DescTerm entries is a semi-colon and a space (;) not a comma with no space (,). If this is not the case use then view and edit the attribute table within ArcMap and use “Find and replace”, on the selected DescTerm field to find replace any instances of commas with a semi-colon and a space. Note that if an alternative separator has been used you will need to use an alternative find and replace.	5 min	30 min
	Check that all polygons have values for TOID, DescGroup, Make fields (no fields should be empty or NULL)	10 min	10 min
	Check and Repair geometry	30 min	1 hr
	If necessary, merge datasets into one layer	0 hrs	4 hrs
	Find Identical – Based on TOID – if present investigate and remove duplicates. Tick the box for “output only identical records” The Tool is in Arc Toolbox \ Data management Tools \ General \ Find Identical	< 20 min	40 min
	Delete all polygons that are <= 0.7 in the Shape_area field	10 min	10 min
	Check for and remove spatial overlaps if they are present. See ArcGIS help on “Topology rules”. Create a Feature Dataset, Import the MasterMap feature class. Create a Topology rule for “Must Not Overlap”. Validate Topology Rule. Double Click topology, view the “Errors” tab, > Generate Summary and view summary results.	1 hr	1 hr
	If errors (overlaps) are present then use the Tool at Arc Toolbox \ Data management Tools \ Topology \ Export Topology Errors. The topology errors (overlaps) then need to be removed. This final step may need GIS expert advice. Carry this out in ArcMap. If there are errors, the exported Errors table can be used with the “Select by location” to select features in the original	1 hr	7 hrs+

Toolbox and dataset	Task description	Time required	
		Min	Max
	MasterMap data that intersect the overlapping error polygons. In the MasterMap data a new field can then be added and labelled as "overlapping errors" for these selected polygons. Each overlapping error polygon can be viewed and dealt with. Alternatively the "Error Inspectors" can be used to examine each error. If there is not time to deal with errors they could all be deleted, this will result in gaps in the final dataset. This is likely to be the preferred option.		
	Check and fix geometry again after the overlap polygons edits	30 min	1 hr
	Index the "Toid" field to speed up searching and analysis (Data Management Tools > Indexes > Add Attribute Index)	10 min	10 min
	Export to *ModelInputs/ES1BaseMap/Inputs.gdb* using the name "MasterMap_Area"	15 min	15 min
ES1Basemap	Ensure your study area boundary is one polygon / one attribute record (it can be a multipart polygon)	5 min	5 min
(StudyArea1)	Check and Repair Geometry if necessary (Data Management Tools > Features)	5 min	5 min
	The StudyArea1 file is used to create another StudyArea boundary that matches whole MasterMap polygons. The process selects polygons that occur within a 40 m buffer of the StudyArea1 file. If the StudyArea1 boundary is poorly digitised, or there are particular large MasterMap polygons near the boundary that you wish to include or exclude from the area then the input StudyArea1 file should be edited accordingly.	30 min	2 hrs
	Copy your study area boundary to *ModelInputs/ES1BaseMap/Inputs.gdb* using the name "StudyArea1"	5 min	5 min
ES1Basemap	Download the tiles that fall within your study area + buffer area zone	10 min	30 min
(OS VectorMap)	Save these to (unzipped) individual folders, named by each 100 km square, into "OSVectorMap" in *ModelInputs/ES1BaseMap*	10 min	30 min
ES1Basemap (various)	View Annex 9 that illustrates which service models are influenced more or less by less detailed BaseMaps. Consider the trade off between the additional complexity of the BaseMap resulting from more data input vs. the additional time to run the extra BaseMap models. Confirm which BaseMap models to run and which data to collect.	1 hr	3 hrs
ES1Basemap	Check the Ecosystem Services of interest for your Study Area. Confirm that the GI / Open Space data is required. (See Annex 9)	2 days	5 days+
(GI / Open space)	Source Open Space / GI data from each Local Authority, including those within the buffer zone where possible or practical. Allow significant time for data sourcing and ensure that Metadata accompanies each dataset to allow each category to be defined accurately. Ideally organise a meeting with each local authority to discuss the available data, its date, updates, accuracy, resolution and their views on its use in this EcoServ-GIS project. Record the dataset name,	2 days	5 days+

Toolbox and dataset	Task description	Time required	
		Min	Max
	version and update the metadata checklist. Ensure it is clear which polygons have public access.		
	The degree to which the digitised boundaries from the Open Space or GI survey match the underlying OS MasterMap data will influence the way the data is transferred within the toolkit. If time is available any areas where the two boundaries do not match could be updated in the GI data layer (e.g. by merging smaller sites into a larger polygon, or by moving boundaries). Any such edits will ensure the data is correctly transferred into the BaseMap.	3 hrs	2 days+
	If you have data from multiple local authorities, check for any spatial overlaps between them. If these are found, make sure the overlap is removed by deleting the overlapping polygon from the least up-to-date or least accurate dataset.	30 min	4 hrs
	Make sure that all layers are projected using the British National Grid coordinate system.	5 min	10 min
	Add a text field “GI_coder” to each layer (if this field name already exists, first rename the existing field).	10 min	20 min
	Optionally add and use a text field “Typology” to each layer (if this field name already exists, first rename the existing field). This is not used by the toolkit, but may be helpful as a reference field.	10 min	20 min
	Populate the “GI_coder” field using the attribute information provided and the terms listed in the Data Preparation section. Any greenspace types mapped which do not fit into these categories can be ignored – they will not be used by the model.	30 min	7 hrs+
	Delete any polygons that do not have a "GI_coder" value. There should be no "0" or NULL values.	10 min	10 min
	Run the “Repair Geometry” tool to check for potential geometry problems – fix as necessary	20 min	1 hr
	View the data in ArcMap against the study area boundary and other data and check its coverage and content is as expected (e.g. the extent, attribute types, etc)	10 min	30 min
	Save the datasets from each local authority to *ModelInputs/ES1BaseMap/Inputs.gdb* – make sure that each data layer is named with “_GI” at the end e.g. “Durham_GI”, “Darlington_GI”, “Gateshead_GI” . The number of GI datasets should match the number of local authorities in your Study Area.	10 min	30 min
ES1Basemap (BAP)	The preparation and use of this dataset can be time consuming to produce. There are two options. Using nationally mapped Biodiversity data or using locally mapped Biodiversity data. The toolkit will run using just the national data but habitat will be mapped more coarsely and the relative impacts of this should be understood (see Annex 9). The aim of using this data is to ensure that where existing areas of higher quality habitat are known and have been	-	-

Toolbox and dataset	Task description	Time required	
		Min	Max
	mapped, they are reflected in the BaseMap habitat classifications. There is currently no option to use a full coverage digital habitat map in place of this data, although these types could be extracted from such as map and used in place of the BAP data.		
	Discuss the availability of local vs. national BAP data with the Local Authority / Local Records Centres / Wildlife Trust / Government conservation body and with the EcoServ-GIS Partnership or project Steering Group. Assess the relative merits and use of locally available versus nationally available BAP data, e.g., locally collected BAP data versus the national maps.	4 hrs	2 days
	Decide if using the national dataset, a local BAP dataset, or a combination of the two, as described below. (A method is presented that allows local BAP habitat data to be used in preference to national BAP data, but where national is present but no local data is present, then the national data will be used to fill the gaps).).	2 hr	4 hr
	If using a single source BAP dataset (either the local data or the national data) then prepare the data so that the field heading and codes match the habitat classification table in the Data Preparation section. Add and populate the "BAPCode" text / string field. Check and fix the data geometry. Check for and remove any overlapping polygons.	5 hrs	2 days
	Alternatively if both "local" and "national" data are to be used then the two datasets need to be sourced, examined and then merged into one data layer. A set of Data Preparation models are supplied that may help with this process. (See Toolboxes). Add a short number field called "BAPcode" and a text field called "BAPhabitat" and use habitat information provided to populate with the appropriate codes using "Select by Attributes" and the Field Calculator.	4 hrs	2 days
	Source the Local and National data for the study area, check geometry, check overlapping polygons within each dataset (not between datasets) and examine the data fields for NULL values.	3 hrs	2 days
	Where the data has data quality attributes (e.g. the estimated reliability of the habitat mapping or habitat classification) then use these categories to decide if any records / polygons are considered unreliable or unsuitable and delete these from the data.	2 hrs	1 day
	Use the models provided or manually merge the two datasets (local and national) to create a single dataset of BAP type as follows: Edit each dataset to include the data fields specified in the User Guide (BAPCode, BAPPrioirty). Merge the two vector datasets together Convert the vector data to raster at 2m cells, based on BAPCode, with BAPPriority as the priority field. Convert the raster back to vector data.	1 day	3 days

Toolbox and dataset	Task description	Time required	
		Min	Max
	View the data in ArcMap against the study area boundary and other data and check its coverage and content is as expected (e.g. extent, attribute types, correspondence with known spatial features).	10 min	30 min
	Export this merged layer to *ModelInputs/ES1BaseMap/Inputs.gdb* using the name "BAP".	10 min	10 min
ES1Basemap (LCA)	Confirm that LCA data is required or will make a big impact on resulting maps. (See Annex 9). The LCA data is used to fill in "gaps" in the knowledge of habitat coverage, particularly in the case of agricultural land, arable, improved pasture, but also brownfield and industrial / quarry sites. If a separate dataset is available to identify arable land coverage this can be used here. If the BAP habitat dataset / habitat cover data is considered to be very high quality or has a high or full coverage of the study area, then this LCA would be unlikely to add further information and is therefore not needed.	1 days	4 days+
	Source locally available LCA data files. Verbally discuss these files with local providers to determine if they are likely to be of use. Organising a face to face meeting is likely to be most productive. For example to discuss: Did the LCA map areas at a good resolution, Does it include an attribute file to classify LCA type similar to the categories required here? Are documents or metadata available to describe the mapped GIS codes? Does LCA cover the whole study area? Is the quality of the LCA similar or very different between neighbouring counties?	1 days	4 days+
	The LCA data is used to give a classification to unknown areas o f the map which are not already classified by other datasets such as MasterMap, BAP and open space survey data. Question whether including the data will be beneficial for classifying unknown areas. The LCA can be important for classifying areas of amenity green space, agriculture or moorland. For example, if the LCA maps golf courses or cemeteries which are not already mapped by the open space data then it is probably worth including. Furthermore, if it classifies agriculture to a specific type (arable, pasture or mixed) then it is also worth including.	1 hr	4 hrs
	Examine the LCA attribute data. Identify the appropriate field to base the reclassification on View the extent and resolution of the mapped polygons. Use available PDFs, websites or discussions with local authority staff to map the main land use categories.	1 day	3 days+
	If there are several files, check for and remove spatial overlaps	1 hr	4 hrs
	Merge separate datasets into one layer	30 min	1 hr
	Add a new Long Integer field "LCA_coder"	10 min	10 min
	Populate this new field by categorising each polygon into one of the 14 habitat/land use classes	1 hr	5 hrs+

Toolbox and dataset	Task description	Time required	
		Min	Max
	View the data in ArcMap against the study area boundary and other data and check its coverage and content is as expected	10 min	30 min
	Export to *ModelInputs/ES1BaseMap/ Inputs.gdb* using the name “LCA”.	10 min	10 min
	If you chose not to use the LCA data or LCA data is unavailable an alternative is the use of a locally available digital habitat dataset or the, Corine Land Cover Matrix 2006.	1 day	2 days
ES1Basemap	Source LWS data from Local Records Centre, Environmental Records Centre, Local Authorities	5 hrs	2 days
(LWS)	Check each file is projected in British National Grid	10 min	20 min
	If multiple files, merge together	1 hr	2 hrs
	Check for and remove overlapping polygons.	1 hr	5 hrs
	Check and repair geometry	30 min	2 hrs
	View the data in ArcMap against the study area boundary and other data and check its coverage and content is as expected	10 min	30 min
	Save as one vector layer in *ModelInputs/ES1BaseMap/Inputs.gdb.as "LWS"*	10 min	10 min
ES1Basemap	Where possible source a fine resolution DTM at 5 m or 10 m cells	2 hrs	2 days
(DTM)	Alternatively use the supplied 50 m DTM. However note that this will produce lower resolution outputs for the BaseMap and for some of the service maps. If using the supplied 50m DTM there is no need to cut this to the study area boundary	-	-
	View the data in ArcMap against the study area boundary and other data and check its coverage and content is as expected	10 min	30 min
	Import the raster to the Geodatabase, using the name “DTM”: *ModelInputs/ESoCommonFiles/Inputs.gdb*	30 min	1 hr
Several services	Source data from each Local Authority, including those in the buffer zone where possible / practical. This is expected in Polyline feature class format (Vector)	3 hrs	1.5 days
(PROW/	Where there are additional local knowledge or data available on permissive access routes, then merge these with the data if required	2 hrs	1 day
CORE PATHS)	Ensure all data are projected in British National Grid, Check and fix geometry	10 min	30 min
	View the data in ArcMap against the study area boundary and other data and check its coverage and content is as expected	10 min	30 min
	Import data to Geodatabase. Name as PROW_CORE_PATHS *ModelInputs/ESoCommonFiles/Inputs.gdb*	1 hr	3 hrs

ANNEX 13: METADATA CHECKLIST

This checklist can be used to record the version of each input data sources used in a particular run of the toolkit. This is important to complete because several data inputs such as BAP, GI, LCA etc can have a large influence on the content of the BaseMap and thus each of the resulting service maps. It may be that custom or updated data were used in place of certain datasets and this can be used to record where these were used. For example it is good practice to record which habitat (BAP) data was used, which PROW_CORE paths version was used and which Open Space Survey were used in case the toolkit analysis is repeated in the future.

Metadata list for Model Run = ____

Data used / input data versions	Supplier (e.g. Natural England, Council)	Dataset filename	Version or date /downloaded	Quality control / data selection
Example 1: VectorMap	OS Open Data – website	OS VectorMap TM District	Version: "03/2014"	None
Example 2:Landscape Character Assessment	Gateshead Council	Character Area Sheets (xls.)+ Landscape Character Areas.shp	No version name or date. Field survey was 2006. Supplied by council in 2012.	Inspected visually against aerial photos. Main landscape type manually coded from survey .xls sheet into the GIS polygon.
MasterMap Digital Terrain Model (DTM) Green Infrastructure / Open Space Surveys VectorMap Landscape Character Assessment LCA (or equivalent) PROW_CORE_PATHS BAP data (note if national, local or combined)				

ANNEX 14: INPUT DATA SUPPLIED WITH THE TOOLKIT

This table lists the version of each input data present within the toolkit. The version name and / or the number of rows can be used to verify which version is being used (for example if newer versions of these data sources become available).

ModelInputs in either ES0CommonFiles or ES1BaseMap

	Rows / polygons (+ version and date where known)					
Dataset	GB	E+Wa	E+Sc	E	Wa	Sc
AWI_GB_ASNW	74,817			50,744 (v2.6)	13,309 (2011)	10,533 (v3.0)
BAP				937,190 (v1.0)		
Country Parks Eng Scot			469			
CroW				10 (2012)		
District unitary region	380 (2012)					
FC recreation routes GB	2921 (2014)					
IMD_England				32,482 (2011)		
IMD_Scotland						6,505 (2011)
IMD_Wales					1,896 (2011)	
Island or Sea1*	17 (2012)					
LNR_GB	2,315			2,138 (2001)	83	83 (2014)
Lond_Distance _Path_Eng_Scot			562 (2013, 2014)			
NNR_GB	2,059			850 (2012)	73	1,122
OA_2011_GB	227,759					
Sustrans	12,243 (Feb 2014)					
Urban_GB	4,516	4014				502 (2012)
Woods4People	30,103 (v10)					
xystops	406,873 (2012)					

*Created from District Unitary Region data

ANNEX 15: TOOLKIT DATA SIZES (GB)

This table lists the expected data size for the main toolkit folders before and after it has been run. Note that Study Area size, optional settings and the number of services mapped will determine the exact amount of data produced.

Folder	Size (GB)	
	As supplied	After models run
ArcMaps	0.5	< 1
Model Inputs	1.5	5
Model Outputs	-	50 to 120
Model Results	-	5
Open Data	0.6	0.6
Toolboxes	0.3	0.3
Total	2.9	60 to 130

ANNEX 16: SERVICES GRADED AND DEMAND TYPE

Service	Environmental capacity	Demand (need)	Regulatory need	Societal demand
Air purification	Graded	Graded	*	*
Carbon storage	Graded	Location only	*	
Local climate regulation	Graded	Graded	*	*
Noise regulation	Graded	Graded	*	*
Pollination	Graded	Graded	*	
Water purification	Graded	Graded	*	
Accessible nature experience	Graded	Graded		*
Education / knowledge	Graded	Graded		*
Green travel corridor	Graded	Graded		*

Notes. "Graded" illustrates quantified indicators have been used, "Location only" notes where either no grading has occurred, or all the area has been considered to have a similar level. "Regulatory need" illustrates the relative level of risk of an event requiring regulation. "Societal need" quantifies the relative benefits to society, if the service were present.

ANNEX 17: SERVICES WITH GAPS AND RESTRICTED BENEFITING AREAS

Service	Gaps	Restricted Service
Accessible nature experience	N/A	*
Education	N/A	*
Green travel corridor	*	N/A
Carbon storage	N/A	N/A
Local climate regulation	*	N/A
Noise regulation	*	N/A
Pollination	*	N/A
Water purification	*	N/A

Restricted Service areas are only identified and mapped where they highlight an area that could deliver a service if the restriction could potentially be removed. Such as with public access.

ANNEX 18: FREQUENTLY ASKED QUESTIONS

Q. How long does it take in total to compile data and run the models?

A. Between 1 and 4 months staff time, not including any waiting time that may be required whilst GIS data is supplied. This does not include time for report production.

Q. Is there a maximum or minimum size Study Area the toolkit applies to?

A. The recommendation is for Study Areas between 1,500 and 5,000 km^2. Users should be aware of the limitations outside these sizes.

Q. What buffer distance should I use?

A. Most of the Service models will take into account data within 0.3, 0.5 or 3 km of a central cell. A 3 km buffer is a recommended minimum. Using a 5 km will give more "context" to the Capacity and Demand maps. Some services carry out analysis up to 8 or 11 km but generally the use of very wide buffers will cause unacceptable time costs in acquiring data from adjacent Local Authorities.

Q. What if source data is available for part of the Study Area, or from some Local Authorities but not from others?

A. The options are to either only use information that is of a broadly similar standard across the whole Study Area or alternatively to use the best available information but highlight in the final report that data were missing for certain areas. This can be achieved by including a map to highlight from which part of the Study Area data were missing. The recommendation would be for the latter approach as this allows quick and easy updating if the data does become available later on.

ANNEX 19: LIST OF "KNOWN ISSUES" FOR THIS VERSION

Version 3.3

- Dialogue box / Parameters list
    - The Tools can be very slow when parameters are altered in the Tool dialogue box, when ticking or unticking optional features. In such cases, only click once, and be patient.
    - To help avoid slow dialogue boxes, make sure to close and reopen ArcCatalog after each model run,
    - Occasionally it may be necessary to close and re-open ArcCatalog twice before the models open quickly.
- Default Parameters
    - The default analysis is set to SA010 (10 m cells).
    - The current toolkit Version has NOT been fully tested using SA050 (50 m cells).
- Sea polygons
    - Due to the analysis method used, when the BaseMap is created with sea polygons, there can occasionally be gaps in the coverage of the sea within harbour areas or estuaries. These could be filled by GIS methods at the BaseMap review stage.
- Messages when validating models
    - When a model is validated warning messages may appear listing that datasets will be overwritten, or that duplicate names exist.
    - These messages are expected and can be ignored.

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