



Bedfordshire Natural Capital Assessment

Part 1: Mapping, valuation, and opportunities for enhancement across Bedfordshire

Authors:

Dr Jim Rouquette, Dr Mark Ashby & Dr Valentina Zini

Reviewed by:

Dr Alison Holt, Natural Capital Solutions

Contact details:

Dr J.R. Rouquette

Natural Capital Solutions Ltd

www.naturalcapitalsolutions.co.uk

jim.rouquette@naturalcapitalsolutions.co.uk

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Executive Summary

This report describes a project to produce a detailed natural capital (habitat) basemap for the whole of Bedfordshire, to model and map the physical and economic benefits (ecosystem services) that flow from the natural capital, and to identify opportunities to enhance accessible natural greenspace, biodiversity and a range of ecosystem services. It was commissioned by the three local authorities of Bedfordshire: Luton Borough Council, Bedford Borough Council and Central Bedfordshire Council, through the Bedfordshire Local Nature Partnership. This report is the first of four, and presents results for the whole of Bedfordshire, as well as providing background and methodological details.

The baseline – natural capital assets

The first part of the project was to produce a detailed map of the current habitats present across Bedfordshire. This used Ordnance Survey MasterMap polygons as the underlying mapping unit and a series of different data sets to classify each polygon to a detailed habitat type. The final basemap covered an area of 123,543 ha or 1,235 km² and contained 1,109,436 polygons, each of which was classified to an appropriate habitat type.

- The basemap shows that Bedfordshire is dominated by arable and improved grassland, together covering 66% of the area (82,089 ha).
- Woodland and scrub habitats cover 9% (11,423ha) of the area.
- Semi-natural and marshy grasslands make up 2%, while water is just 1% of the area.
- Built-up areas and infrastructure cover 8% of the land area, with gardens comprising 5%.
- The basemap showed that Bedfordshire is much more rural in the North, with the majority of built-up areas and infrastructure in the southern half of the county.

To gain a more complete picture of the natural capital baseline across Bedfordshire, a range of additional maps were created to give an indication of environmental quality across a broad set of criteria, covering air, water, agricultural quality, site protection and public access.

Habitat change over 80 years

The basemap showing habitats in 2020 was then matched and compared to a map of land-use and habitats from the 1930s. Semi-natural grassland and arable were the dominant habitat types in the 1930s, occupying 42.2% and 41.3% of the area of Bedfordshire respectively, built-up areas and gardens occupied 9.5% and woodland 4.9%. There were no improved grasslands. By 2020 semi-natural grasslands had declined by 95% (almost 50,000 ha removed), whilst heath and marsh (wetland) habitats had declined by 91%. In contrast, arable had increased by 36%, built-up areas and gardens had increased by 74% and woodland by 85%. Improved grassland has increased from zero to 15,300 ha. These profound changes are likely to have had a major impact on biodiversity and ecosystem service delivery across the county.

Modelling and mapping ecosystem services (benefits)

In total, 10 ecosystem services were modelled and mapped: carbon storage and sequestration, air purification, noise regulation, local climate (urban heat) regulation, water flow regulation, water quality (soil erosion) regulation, food production, timber production, and accessible nature. Maps showing the demand for air purification, noise regulation, local climate regulation and accessible nature were also produced. Demand was focussed on the urban centres in Bedfordshire, especially in Bedford and Luton,

but smaller towns such as Leighton Buzzard, Flitwick, Biggleswade and Sandy were also hotspots for demand. The capacity to provide these services was highest in central and northern Bedfordshire in areas away from urban centres where woodland and other semi-natural habitats mainly occurred. Such areas should be protected and expanded, even if not significant for biodiversity. Across the county, there is a mismatch between demand and supply.

Baseline ecosystem service valuation (monetary flows)

Overall, the natural capital assets of Bedfordshire deliver £208.3 million annually, with a present value of £6.6 billion over 50 years. The most valuable ecosystem service is air quality regulation, generating £90.4 million in benefits annually, with a present value of £3.3 billion over 50 years. Also particularly valuable, are recreation and physical health benefits, delivering annual benefits of £84.2 and £31.6 million in value respectively, with a present values (over 50 years) of £2.1 and £1.2 billion.

Woodlands in Bedfordshire are sequestering 79,950 tonnes of carbon per year (tCO₂e) at an annual value of £5.5 million and a present value of £323 million. However, agricultural GHG emissions outweigh carbon sequestration as agriculture emits 113,000 tCO₂e per year, at a cost of £7.8 million annually, and a present value of £457 million. Therefore, land use and agriculture across Bedfordshire produces net emissions of approximately 33,000 tCO₂e per year. To move towards net zero (assuming no changes in agriculture) would require the planting of approximately 3,750 ha of broadleaved woodland, occupying about 3.0% of the land area of Bedfordshire.

Habitat opportunity mapping

Habitat opportunity mapping is a Geographic Information System (GIS) based approach used to identify potential areas for the expansion of key habitats to meet different objectives, whilst taking constraints into account. Opportunity maps were created for three different broad habitat types – semi-natural grassland, broadleaved and mixed woodland, and wet grassland and wetland – and for six different ecosystem services.

- Semi-natural grasslands are evenly dispersed across Bedfordshire. However, although a number of these patches are ecologically connected into a network, many patches remain disconnected, but there is good opportunity to enhance connectivity through habitat creation.
- Broadleaved and mixed woodland habitat networks are concentrated in the north and centre of Bedfordshire, across the Yardley Whittlewood Ridge and the Greensand Ridge. Habitat creation could further increase connectivity in these areas.
- Wet grassland and wetland habitat networks are much less significant in Bedfordshire, with only a few small and widely dispersed habitat patches across the county, most of which are ecologically isolated from each other, and opportunities are mostly focussed on expanding existing habitat patches.

Opportunities for water flow regulation are present over much of Bedfordshire, with the majority of opportunities relating to areas of arable fields on sloping land. In contrast, the vast majority of opportunities to improve water quality by reducing soil erosion are located adjacent to watercourses. The best opportunities to ameliorate air pollution were located in and around urban areas and along the main road network and a similar pattern was revealed when considering opportunities to reduce noise pollution. Opportunities to regulate local climate (reduce urban heat) tended to fall on the outer fringes of urban areas, due to the large number of constraints in urban centres. Opportunities for

increasing access to the natural environment were concentrated in a ring around the edges of urban areas, when based on creating new habitats, but were often slightly further from towns, but in more natural habitats, such as woodland, when considering opening up access to existing sites.

Combined opportunities for new habitats

Opportunity maps were combined to highlight areas where new habitat can be created that provides opportunities to enhance more than one of the services mapped previously. Maps were created showing the total number of opportunities that could be delivered by creating new broadleaved woodland, semi-natural grassland, or wet grassland, first treating all opportunities equally, and then by restricting combined opportunities to areas that present a biodiversity opportunity.

Conclusions and next steps

The maps and GIS layers produced for this project have a wide range of potential applications and next steps. We outline some possible projects for enhancing the outputs and taking this work forward, focussing particularly on:

1. Mapping habitat quality (condition) and ground-truthing the basemap. This would improve the accuracy of the basemap, especially for heathland, which is under-represented on the current map. Mapping condition would enable habitat restoration to be considered alongside the habitat creation opportunities identified here. It would also then be possible to create a baseline biodiversity assessment using the Biodiversity Metric tool, for assessing biodiversity net gain.
2. It is recommended that the maps are refined further in relation to existing plans and priorities, and that a workshop is held with local stakeholders to ground-truth locations, provide rules to target certain habitats or certain ecosystem services in different locations, and to prioritise locations to take forward. Work should also be undertaken to identify the sensitivity of sites to disturbance. This would highlight where enhancing access was and was not appropriate, and where alternative nearby sites could be created to relieve pressure at sensitive sites.

The opportunity maps can be used to assist with the development of local nature recovery strategies, green infrastructure strategies and planning, locating the best places for biodiversity offsetting and net gain initiatives, for agri-environment scheme targeting, woodland creation for carbon offsetting, and as an important step towards producing a natural capital investment plan for the area.

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1. Introduction

The three local authorities making up Bedfordshire have identified the need for an assessment of its natural capital, the benefits that this provides and the opportunities to enhance it, particularly in light of its economic and social development ambitions. Natural capital refers to the stock of assets provided by the natural environment with capacity to produce goods and services that are of value to people (NCC 2014)¹, often classified into provisioning, regulating and cultural ecosystem services (EEA, 2016², Hein et al., 2016³). Natural capital comprises land and minerals, fresh, tidal and marine waters, air, species and ecological systems, together with supporting natural processes and functions³. In many respects, it supports all forms of other capital on which human systems depend, whether man-made, human or social. However, many of the outputs produced by natural capital, such as the regulation of flooding and atmospheric gases by woodlands, are not included in the decisions of individuals or organisations. This is because they often involve non-priced public goods that are not traded in the market place, and are not subject to formal property rights and entitlements (TEEB, 2010⁴). Elements of natural capital are therefore liable to be overused, degraded, depleted and eventually lost, with consequences for long term welfare and the sustainability of economic systems. There is now much greater awareness of the role of natural capital in the design and achievement of economic and social development strategies, with strong links to business and enterprise⁵. Furthermore, the central role of natural capital in delivering quality of place is being increasingly recognised.

Bedfordshire lies at the heart of the OxCam Arc, a strategic growth area with developing plans for additional housing, new road and rail links and other infrastructure. This presents both a challenge and an opportunity with regard to the natural environment. A challenge if the environment and environmental regulations are seen as a hindrance to development, but a great opportunity if development can be planned to deliver benefits to both people and the natural world, potentially unlocking large sums of money to deliver ambitious nature recovery and public access programmes. But to achieve those ambitions it is important that people are aware of the current stock of natural capital, the benefits that it provides (and the demand for those benefits), and the best opportunities to enhance those natural capital assets.

Natural capital is also becoming increasingly embedded across multiple policy domains, including the likely inclusion of a mandatory requirement for biodiversity net gain for all new developments subject to the provisions of Town and Country Planning Act, as set out in the Environment Bill. There is further ambition, as expressed in the Government's 25 Year Plan for the Environment, to move towards environmental and natural capital net gain in the future, backed by changes to the National Planning Policy Framework and the new Planning White Paper. The Environment Bill also sets out the requirement for nature recovery networks and strategies, while the recently enacted Agriculture Act paves the way for a new Environmental Land Management Scheme (ELMs), with a central tenet of farmers and land managers being paid public money for public goods, based on natural capital

¹ NCC 2014. Towards a Framework for Defining and Measuring Changes in Natural Capital. Working Paper 1, Natural Capital Committee.

² EEA 2016. Common International Classification of Ecosystem Services (CICES) , European Environment Agency, Copenhagen. <https://cices.eu/>

³ Hein, L., Bagstad, K., Edens, B., Obst, C., de Jong, R., Lesschen, J.P. (2016). Defining Ecosystem Assets for Natural Capital Accounting. PLoS ONE, 11(11): e0164460. doi:10.1371/journal.pone.0164460

⁴ TEEB. 2010. The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Earthscan, London and Washington

⁵ TEEB. 2012. The Economics of Ecosystems and Biodiversity in Business and Enterprise. Earthscan. London; New York.

principles. Further policy alignment is achieved through the requirements for action on climate change and commitments to go carbon neutral, including the planting of large areas of new woodland.

Luton Borough Council, Bedford Borough Council and Central Bedfordshire Council, therefore, commissioned this project, in conjunction with the Bedfordshire Local Nature Partnership, to produce a natural capital assessment for Bedfordshire, with the following five aims:

1. Create a detailed natural capital (habitat) basemap based on the best available existing data.
2. Model and map the benefits (the ecosystem services) that flow from the natural capital present across the county and the demand for those benefits, where possible.
3. Calculate the monetary value of those benefits wherever possible.
4. Identify the current provision of accessible natural greenspace within the Bedfordshire region and how this compares against national standards.
5. Create habitat opportunity maps for biodiversity enhancement and for a range of ecosystem services, showing where new habitats could be created that are most appropriate from an ecological point of view, or provide the best opportunities for enhancing a range of benefits, whilst taking constraints into account.

1.1 The natural capital and ecosystem services framework

The natural environment underpins people's wellbeing and economic prosperity, providing multiple benefits to society, yet is consistently undervalued in decision-making. Natural Capital is defined as *"...elements of nature that directly or indirectly produce value or benefits to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions"* (Natural Capital Committee 2014). It is the stock of natural assets (e.g. soils, water, biodiversity) that produces a wide range of ecosystem services that provide benefits to people. These benefits include food production, regulation of flooding and climate, pollination of crops, and cultural benefits such as aesthetic value and recreational opportunities (Fig. 1).

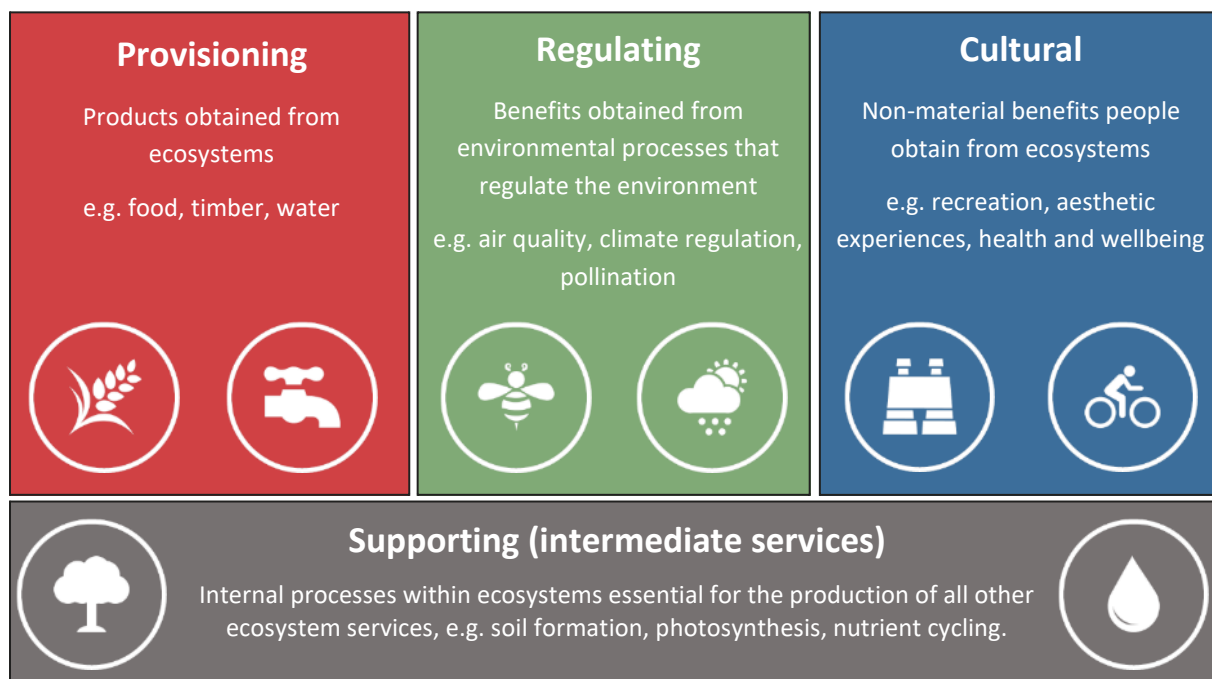


Figure 1 Key types of ecosystem services (based on MA 2005 and EEA 2016).

Much work is progressing on how to deliver the natural capital and ecosystem services approach on the ground and how to use it to inform and influence management and decision-making. One of the most important steps is to recognise and quantify ecosystem service delivery (the physical flow of services derived from natural capital). Additional insight can be gained by taking a spatial perspective on the variation in ecosystem service supply and demand across a study area using a Geographic Information System (GIS). Maps are able to highlight hotspots and coldspots of ecosystem service delivery, highlight important spatial patterns that provide much additional detail, and are inherently more user friendly than non-spatial approaches. When information on supply and demand for ecosystem services is known, it is also then possible to determine objectively the best areas to create habitat to increase the supply of each particular ecosystem services in a process known as habitat opportunity mapping. By overlaying opportunity areas for each objective, it is possible to identify areas where changing habitats could deliver multiple benefits.

1.2 Report structure and scope

A key first step in any natural capital project is to understand the natural capital assets present across the study area. To this aim, Section 2 begins by describing how the baseline natural capital assets were mapped, before presenting the resulting habitat map and outlining the habitats present across Bedfordshire. It also highlights the most important habitats for biodiversity, and maps designated sites. We also include a range of additional maps to give a more complete picture of the state of natural capital across Bedfordshire, covering air, water, and agricultural quality, and public access. Section 3 then compares the habitats present in 2020 with a map of land-use and habitats from the 1930s, highlighting the land use in both periods and the change over 80 years.

Section 4 uses the natural capital basemap to model and map the ecosystem services delivered. We assess ten different ecosystem services and whenever possible we also map the demand for these services across the area. Section 5 estimates the annual monetary flows from seven ecosystem services and Section 6 assesses accessible natural greenspace in relation to national standards.

Section 7 then considers opportunities for enhancing biodiversity and ecosystem services across Bedfordshire. We consider three different broad habitats – broadleaved and mixed woodland, semi-natural grassland, and wet grassland and wetland – and six different ecosystem services. The individual opportunity maps are then overlain in Section 8, to identify opportunity areas where multiple benefits could be delivered, creating maps that focus on biodiversity, and which focus on all benefits equally. Conclusions and further steps are briefly presented in Section 9.

Please note that the habitat basemap is based on existing data, and has not been extensively ground-truthed, so will be prone to some error. It does, however, provide the most comprehensive and detailed coverage that is possible at this time. Note also that the opportunity mapping identifies areas based on landscape-scale ecological principles and ecosystem services models and does not take into account local site-based factors that may impact on suitability. Any areas suggested for habitat creation will require ground-truthing before implementation. The maps should be seen as a tool to highlight key locations and to guide decision making, rather than an end in themselves.

One of the key outputs from this project are the numerous GIS maps and layers. These have been supplied to the three local authorities making up Bedfordshire. Note that this report covers the whole of Bedfordshire and includes information on background and methodology. Separate reports are available for Bedford Borough, Central Bedfordshire and Luton Borough, focussing on those areas.

2. The baseline – natural capital assets

2.1 Approach to mapping habitats

The first and key part of the whole project was to produce a detailed map of the current habitats present across Bedfordshire. This is an important component of any assessment of natural capital assets, and is required before an assessment of ecosystem services (Section 4) or habitat opportunity mapping (Section 7) can be undertaken. To do this we used Ordnance Survey MasterMap polygons as the underlying mapping unit and then a series of different data sets to classify each polygon to a detailed habitat type, and to associate a range of additional data with each polygon. The data that was used to classify habitats is shown in Box 1.

Box 1: Data used to classify habitats in the basemap:

- OS MasterMap Topography layer
- OS VectorMap District
- OS MasterMap Greenspace data
- OS Open Greenspace data
- Natural England Priority Habitats Inventory
- CEH Woody Linear Features data set (hedgerows map)
- Ancient Woodland Inventory data
- Built-up Area Boundaries data
- Digital terrain model (based on OS Terrain 5 data)

Further information on how polygons were assigned to habitats is provided in Box 2 (overleaf). Polygons were classified into Phase 1 habitat types and were also classified into broader habitat groups. The final basemap covered the whole of Bedfordshire, and covers an area of 123,543 ha or 1,235 km². It contained 1,109,436 polygons, each of which was classified to an appropriate habitat type.

Note that the basemap provides the best approximation of habitat types that can be achieved based on available data. But it has not been ground-truthed further and will inevitably contain errors. A particular challenge was classifying polygons where more than one habitat was present. Mixed habitats containing woodland and scrub, or grassland with woodland were classified in detail, but not all combinations of habitats could be accommodated. Other areas, where there was a mismatch between data sources, or land use is changing rapidly remained a challenge.

Box 2: Assigning habitats

Our approach to assigning habitats uses OS MasterMap, which is the most detailed and accurate map available across Great Britain and identifies all roads, buildings, fields and other features as individual polygons. However, information on the habitat of these features is limited. We used a series of rules and other layers to classify each polygon. For example, we used rules to assign features as houses, gardens, industrial / commercial buildings and so on.

The habitat information provided by other sources (e.g. PHI data) was then overlain and the degree of overlap calculated using zonal statistics. This does not always match precisely so, for example, if a habitat polygon marked as semi-natural broadleaved woodland (A1.1.1) overlaid houses, gardens and a polygon identified as non-coniferous trees in MasterMap, we could now assign the non-coniferous tree polygon more accurately as semi-natural broadleaved woodland, but the houses and gardens would be left unchanged.

A number of additional rules and layers were used to gradually build up as complete a picture as possible. For example, areas identified as improved grassland, but within urban areas, were classified as amenity grassland. All polygons were assigned to a Phase 1 habitat type, although areas currently undergoing development were marked as unclassified. Upon initial completion, the basemap was checked against Google and Bing maps and manual alterations were made in a number of places where miss-classifications had occurred or where habitats could be assigned with greater certainty.

2.2 Broad habitats

Figure 2 (overleaf) shows the distribution of broad habitat types across Bedfordshire and the area and percentage cover is shown in a little more detail in Table 1. Bedfordshire is dominated by cultivated (arable) land and improved grassland, making up 66% of the area (82,089 ha). The combined cover of all woodland, scrub and tree habitat types makes up a relatively low 9% of the area (11,423 ha). Woodland is found predominantly in two belts across northern and central Bedfordshire, corresponding to the Yardley Whittlewood Ridge and the Greensand Ridge respectively. Semi-natural and marshy grasslands cover 2%, while water makes up just 1%. Built-up areas, and infrastructure (roads, railways, pavements and paths) cover 8% of the land area, with gardens comprising 5%. Note that gardens are likely to include a variety of different surfaces, including lawn, hard standing, flowerbeds, shrubs, trees and so on and no attempt is made to distinguish habitats further.

Note that heathland is significantly under-represented in the basemap. We did not have access to detailed maps of heathland and it is not well captured in the publicly available data sets such as Natural England's Priority Habitats Inventory. This is something that could be captured on subsequent updates to the basemap.

Table 1 Area and percentage cover of broad habitat types across Bedfordshire and its three local authorities

Broad habitat	Bedfordshire		Bedford Borough		Central Bedfordshire		Luton	
	Area (Ha)	% cover	Area (Ha)	% cover	Area (Ha)	% cover	Area (Ha)	% cover
Cultivated / disturbed land (arable)	69,739	55.93	30,139	62.67	39,441	54.62	159	3.67
Uncertain agriculture	1,499	1.20	368	0.77	1,027	1.42	103	2.38
Improved grassland	12,350	9.91	4,184	8.70	8,147	11.28	19	0.43
Amenity grassland	5,031	4.04	1,920	3.99	2,496	3.46	615	14.17
Semi-natural grassland	2,234	1.79	282	0.59	1,866	2.58	86	1.98
Marshy grassland	207	0.17	76	0.16	131	0.18	0	0.00
Other grassland	820	0.66	392	0.81	372	0.51	56	1.29
Heathland	11	0.01	0	0.00	11	0.02	0	0.00
Fen, marsh and swamp	56	0.04	22	0.05	27	0.04	7	0.16
Scrub	322	0.26	87	0.18	221	0.31	14	0.32
Trees / Parkland	2,344	1.88	874	1.82	1,416	1.96	53	1.21
Broadleaved woodland	6,984	5.60	2,357	4.90	4,499	6.23	128	2.95
Coniferous woodland	1,281	1.03	158	0.33	1,124	1.56	0	0.00
Mixed woodland	493	0.40	187	0.39	304	0.42	2	0.04
Hedgerows	1,565	1.26	605	1.26	907	1.26	7	0.16
Water	1,616	1.30	738	1.53	870	1.21	7	0.17
Built-up areas	5,688	4.56	1,832	3.81	2,712	3.76	1,143	26.35
Infrastructure	4,313	3.46	1,375	2.86	2,292	3.17	645	14.87
Garden	6,811	5.46	2,063	4.29	3,477	4.82	1,271	29.30
Rock, exposure and waste	519	0.42	42	0.09	477	0.66	0	0.00
Unclassified (land currently under development)	732	0.59	371	0.77	338	0.47	23	0.54
Mixed / other / uncertain	66	0.05	21	0.04	48	0.07	1	0.02
TOTAL	124,681	100	48,091	100	72,205	100	4,339	100

Natural capital basemap

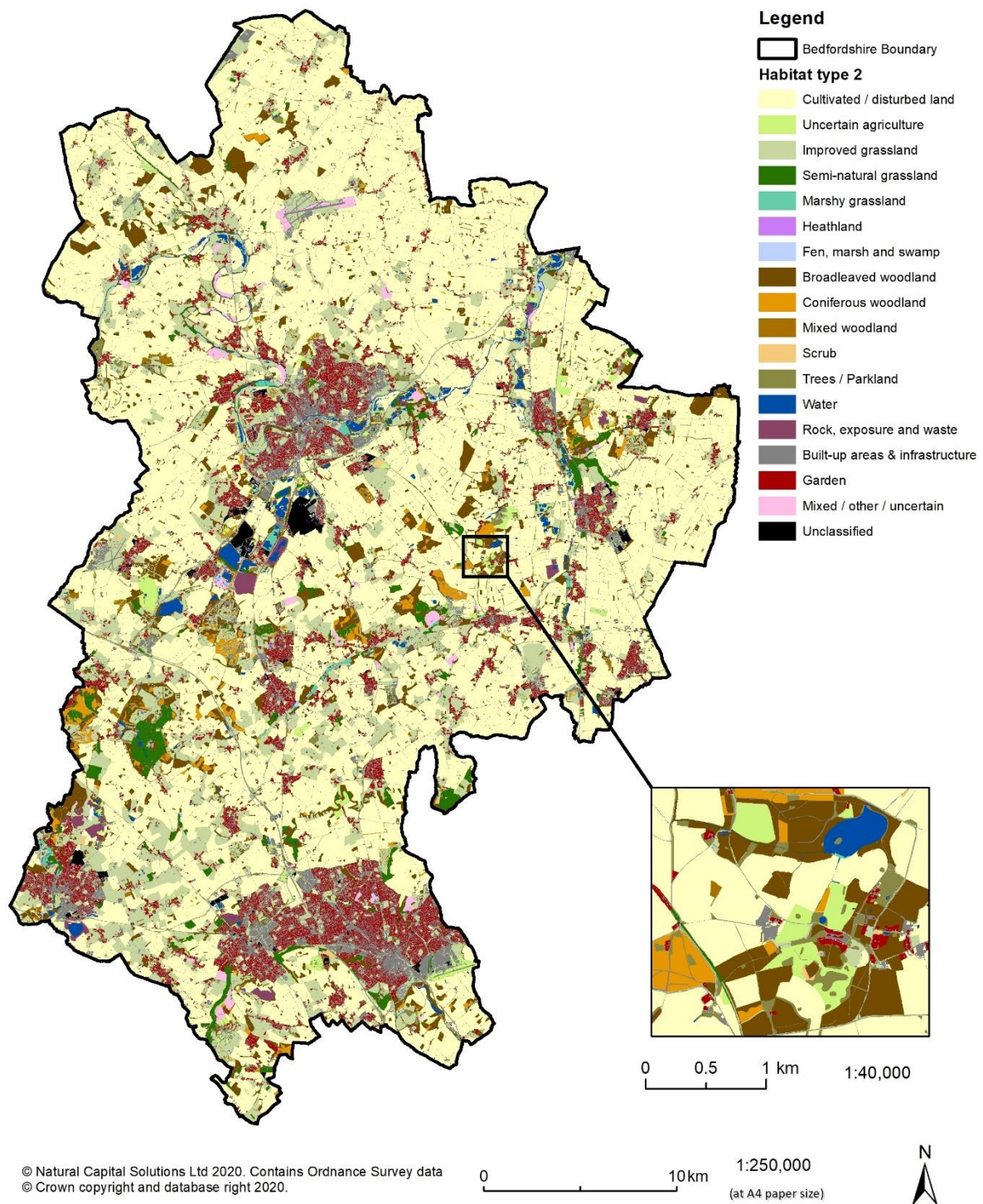


Figure 2 Broad habitats across Bedfordshire. Note that Unclassified sites are those that are currently under development.

2.3 High quality habitats

The highest quality semi-natural habitats can be identified from the basemap and are shown in Figure 3, although note that this is based on habitat type and not on condition, which was not assessed here. In total 8,412 ha, which represents 6.8% of Bedfordshire, contain these high-quality habitats. The greatest amounts are 6,980 ha of broadleaved woodland, 492 ha of mixed woodland and 317 ha of neutral grassland. However, this includes all broadleaved and mixed woodland, some of which will not have been high quality. There are also 225 ha of calcareous grassland, 178 ha of acid grassland, and 168 ha of floodplain grazing marsh and marshy grassland. Note that it was not possible to distinguish high quality parkland from any areas containing scattered trees, or higher quality rivers, streams and standing water, hence these habitat types have not been included on this map. Mixed habitats were also not included as although some of these areas are likely to be high quality habitat, not all such areas will be.

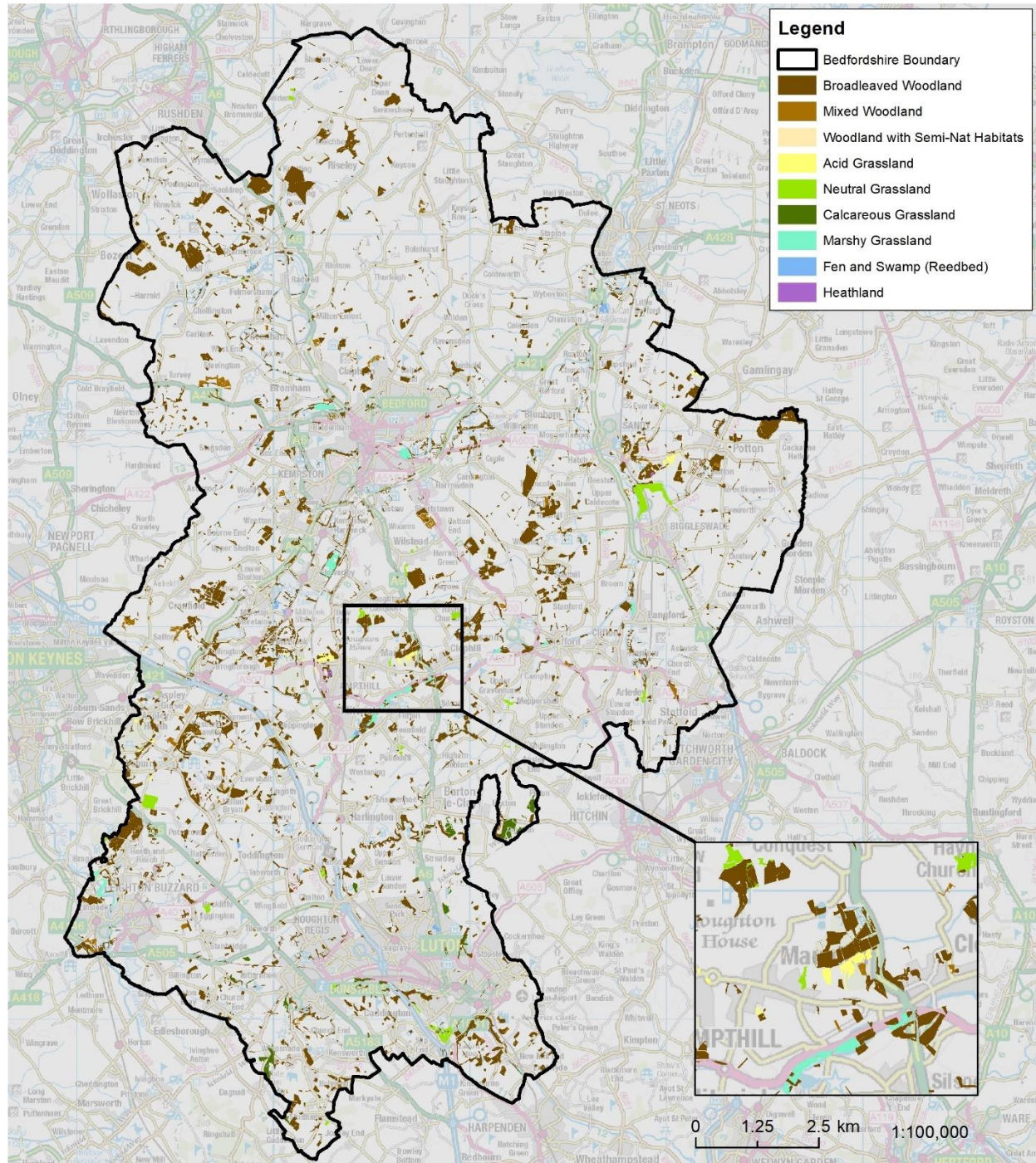
2.4 Nature conservation designations

The location of designated sites is shown on Figure 4. In total 346 ha are designated as LNRs within Bedfordshire (0.28% of the total land area). The total amount of land designated as NNRs within Bedfordshire is 173 ha (0.14% of the total area) with an additional 1,374 ha (1.11%) designated as SSSI and 6,365 ha (5.15%) designated as AONB. There was significant overlap across each of the designations, with the total amount of land receiving some level of protection amounts to 7,490 ha, or 6.06% of the total area of Bedfordshire.



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High quality habitats



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0 10km

1:250,000
(at A4 paper size)



Figure 3 High quality habitat types, identified from the basemap.



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Designated sites

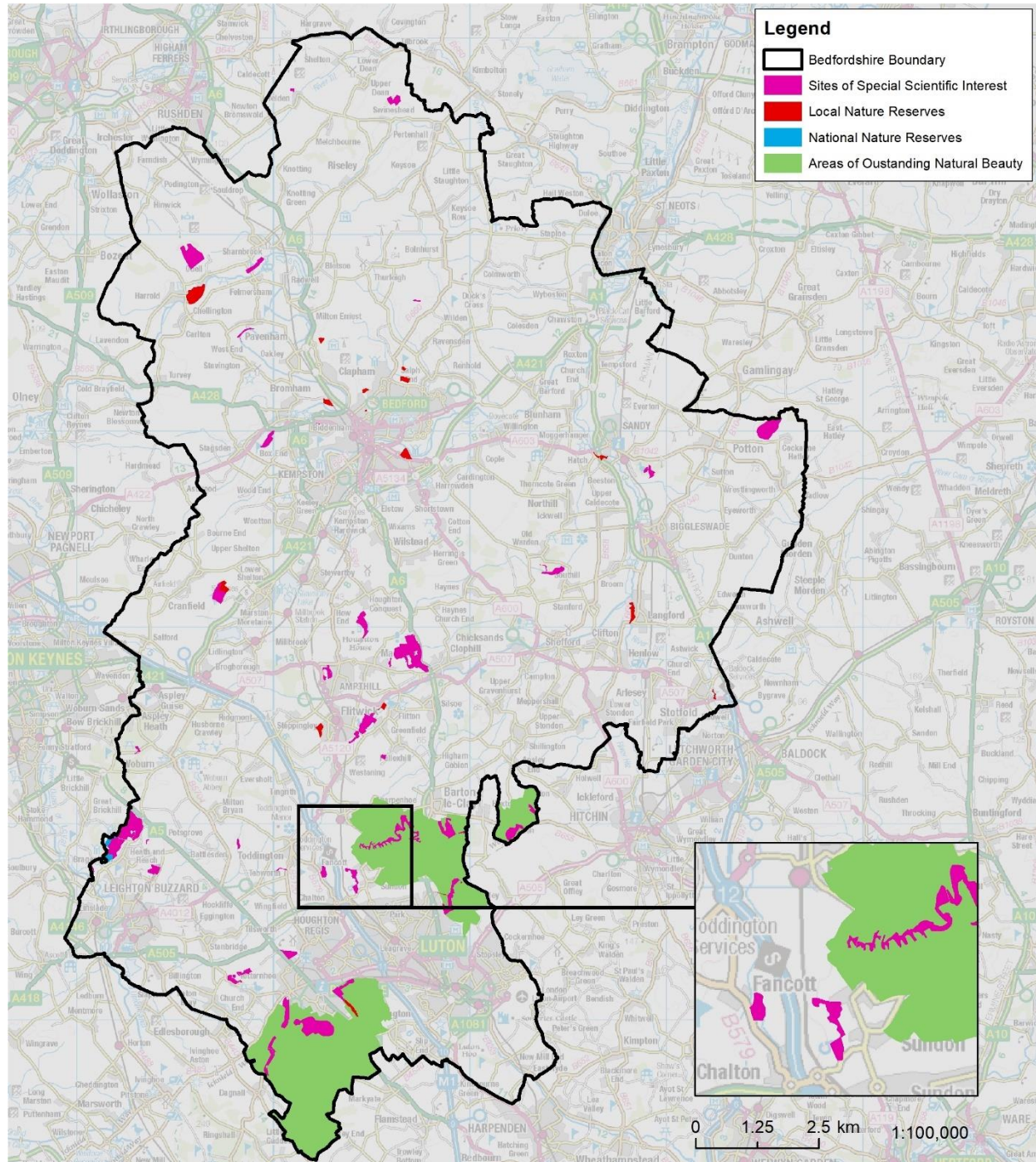


Figure 4 International, national and locally designated sites for nature conservation. Note that many SSSIs are also Local or National Nature Reserves.

2.5 Environmental quality and natural capital assets

The core component of a natural capital asset register is a map and accompanying data on the habitats present across a study area, which provides information on the type, extent and location of natural capital assets. This has been described and mapped in Section 2.2 and Figure 2 and has been used to highlight high quality habitats (Section 2.3). However, to build a more complete picture, it is helpful to include information on broader aspects of natural capital beyond habitats. This may include indicators of environmental quality across air, land and water, stocks of natural capital beyond habitats, degree of protection (Section 2.4 above) and information on public access. The focus here is on stocks of assets themselves (i.e. the amount or quality of the asset) rather than flows of benefits that are derived from the assets, or ecosystem services, which are modelled, mapped and valued in Sections 4 and 5. The following maps have been created, based on publicly available data:

- **Modelled background air pollution data** was obtained from Defra at a resolution of 1km², and was used to create a map showing PM_{2.5} (particulate matter at 2.5 µm, Figure 5a) and another showing NO_x (nitrogen oxides, Figure 5b). Both maps are fairly similar, with the M1, A421 and A1 showing up as pollution hotspots, along with Luton airport (for NO_x), Luton and Bedford.
- **Overall water body class of WFD River Waterbody Catchments** combines ecological status with chemical status to form an overall assessment of the quality of the waterbody. There are five classes (high, good, moderate, poor, or bad). This is mapped in Figure 5c and shows that waterbody catchments associated with Bedford and Luton are in bad condition, but the majority of water bodies across the county are in moderate condition.
- **Agricultural Land Classification** uses a grading system to assess and compare the quality of agricultural land at national, regional and local levels. It assesses the potential for land to support different agricultural uses, based on a combination of climate, site and soil characteristics. The map for the study area is shown in Figure 5d and shows that ALC varies from Grade 1 to 4 across the county, with most of the Grade 1 and 2 land to the east and north-east of the county.
- **Canopy cover** was mapped for each Ward across the study area based on data from the UK Ward Canopy Cover Map, co-ordinated by Forest Research. The map (Figure 6a) highlights that Wards across the Greensand Ridge have higher canopy cover of 15-25% than the rest of Bedfordshire, whilst the lowest canopy cover (Wyboston Ward at 4.5%) is in the north-east.
- **Public Rights of Way** were mapped by combining PRoW maps supplied by the three local authorities and is shown in Figure 6b. This is a key information source for determining access to the countryside and accessible nature and shows an extensive network across most of the county, although the network is thin in some places.

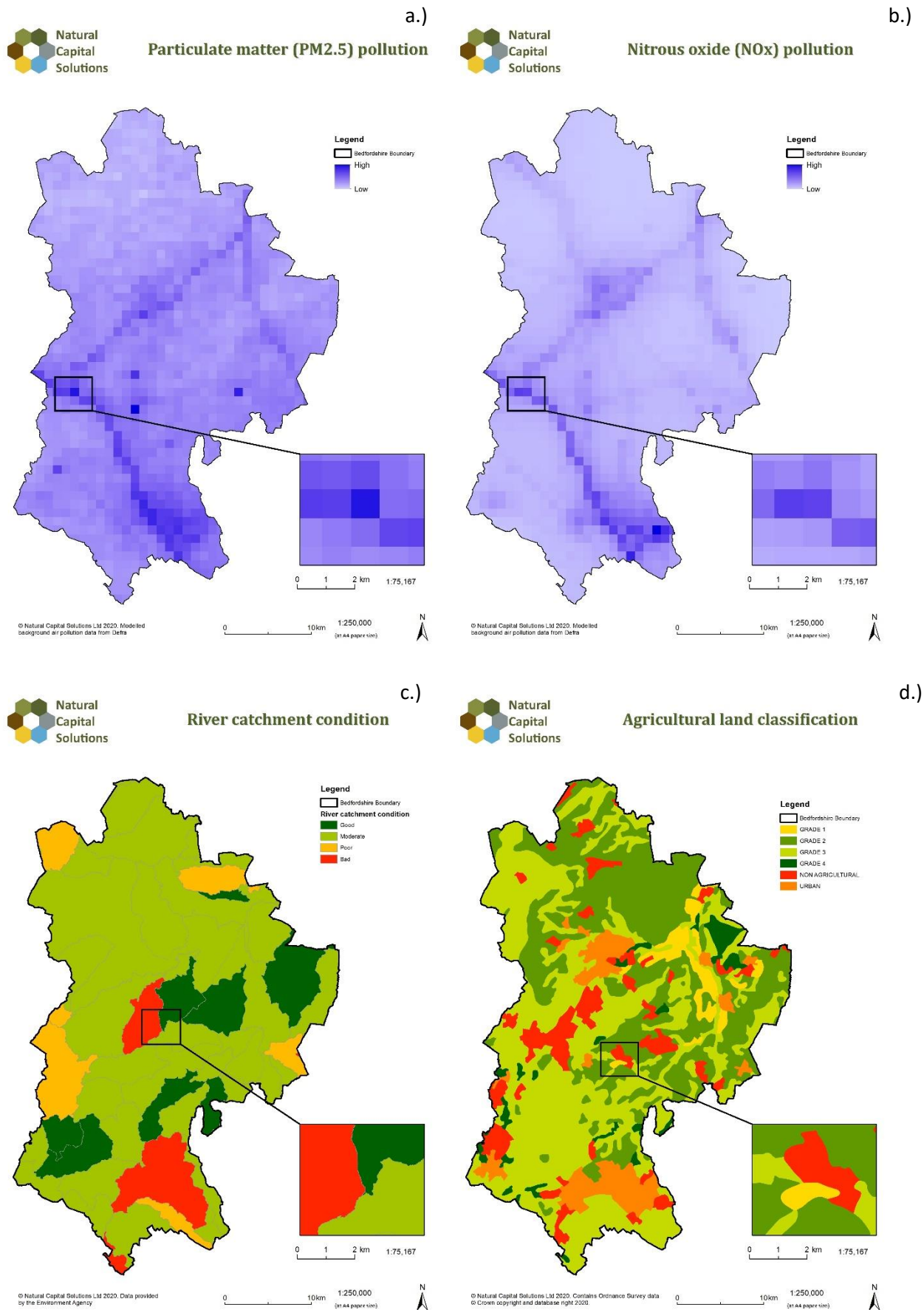


Figure 5 Environmental quality and natural capital asset maps showing a.) air quality with respect to PM_{2.5}, b.) air quality NO_x, c.) overall water body class, and d.) agricultural land classification.

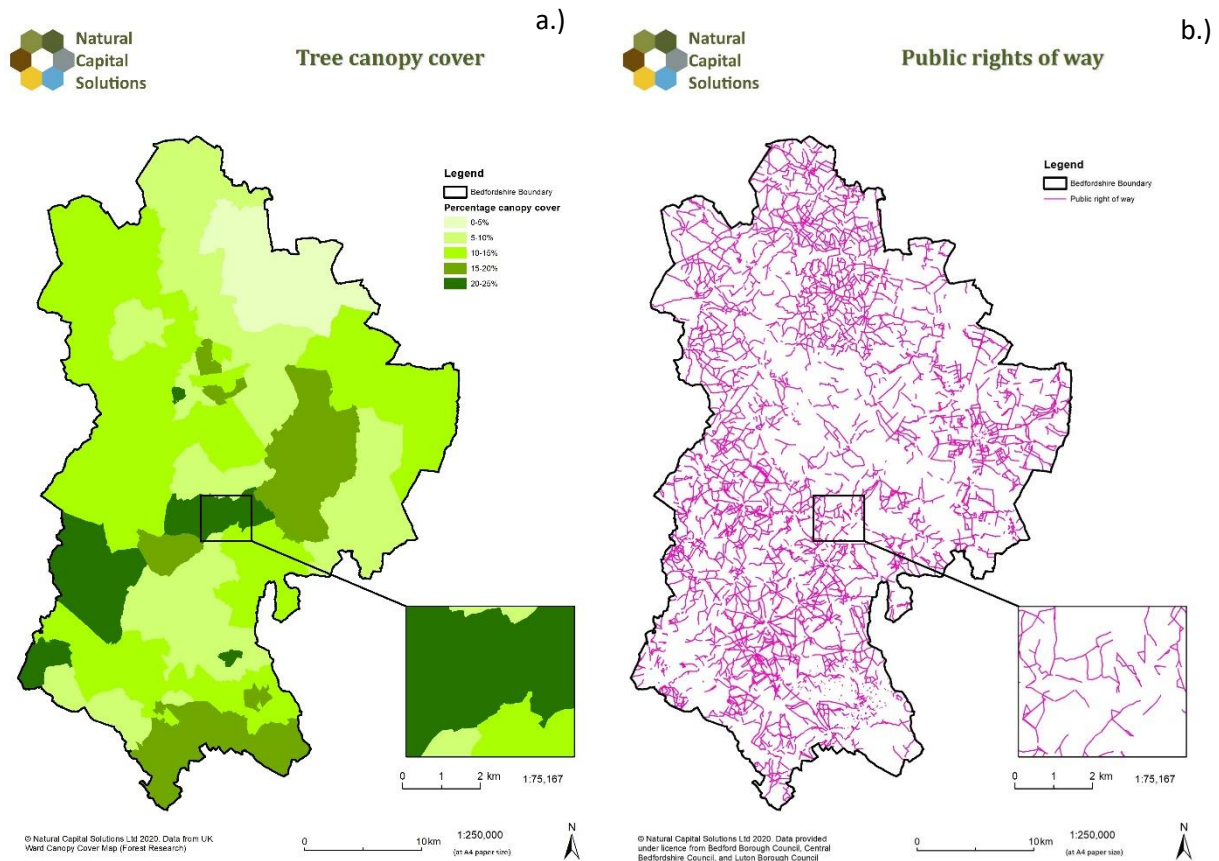


Figure 6: Environmental quality and natural capital asset maps showing a.) canopy cover for each Ward, and b.) Public Rights of Way.

3. The changing habitats of Bedfordshire: a historical perspective over 80 years

3.1 Introduction

Land-use and habitats in the UK have changed drastically since the Second World War. During this time period the countryside underwent a period of major intensification and industrialisation, with a rapid rise in the use of artificial fertilizers, pesticides, and machinery, as well as increases in field sizes, drainage of wetlands, reduction in rotations, simplification and homogenization of farm types, and altered cropping patterns from spring sown to autumn sown crops. At the same time there has been a rapid expansion of urban areas and an increase in plantation forestry. These factors taken together have led to the loss of many of the semi-natural habitats of lowland UK, and the fragmentation of remaining patches, resulting in major declines in biodiversity. It has also resulted in changes to the ecosystem services delivered by the land, with a primary focus on agricultural and timber production, but a decline in other ecosystem services.

Here, the land-use and habitats of Bedfordshire have been mapped using data from the 1930s and compared to the current situation (2020). The primary aims have been to establish how land-use has changed, and the magnitude of change across different habitats.

3.2 Approach

Although historic maps are available dating back several centuries and with newer editions appearing at regular intervals in more recent times, these do not provide any information on habitats, apart from identifying woodlands. Indeed, only one source of habitat information is available prior to the 1980s and that is The Land Utilisation Survey of Great Britain, 1933-49. These resulting maps are known as the “Dudley Stamp Maps” after the organiser and instigator of the survey. A scanned and digitised version of the survey was obtained, to represent habitats from the 1930s.

The digital version of the Land Utilisation Survey classifies habitats into eight different categories, whereas the modern basemap (Section 2) uses a large number of different habitat types. A key challenge when comparing maps from very different sources is the difficulty of matching land cover types between the different surveys. The original definitions of the Dudley Stamp categories were used and compared to the habitat types produced in the modern basemap, and matched as closely as possible. Nine final categories were chosen, and Table 2 (overleaf) describes how the habitats from both time-periods fit into these categories.

All “meadowland and permanent grass” identified in the Dudley Stamp map was classified as “semi-natural grassland” and no areas were classified in the “improved grassland” category. This is based on the assumption that no agricultural grasslands were improved at that time as they were not receiving inorganic fertilizers. This has been shown to be true in areas with detailed botanical data from the 1930s.

Urban areas presented a particular difficulty as these areas were not mapped in any detail in the Dudley Stamp survey. In the Dudley Stamp maps, dense urban areas were classified as “land agriculturally unproductive”, with suburban areas classified as “gardens”, and only large greenspaces within urban areas were marked separately. As there was no obvious way to match this with the categories on the modern map, a new category was created of “built-up areas and gardens” containing both the Dudley Stamp categories. For the present-day map, all urban and garden categories were combined, along with amenity grassland (e.g. road verges) that were less than 1 ha in size. Note that ditches between fields

were not recorded on the Dudley Stamp maps and the width of larger rivers and drainage channels was not recorded accurately, hence any change in the amount of water between the two time periods should be interpreted with caution.

Table 2: Final habitat categories chosen, and the corresponding categories from the Dudley Stamp maps (1930s) and the natural capital basemap (2020)

Final categories	Dudley Stamp categories	Basemap habitats
Woodland	Forest and woodland	Broadleaved woodland Coniferous woodland Mixed woodland Scrub Parkland
Arable	Arable land	Cultivated / disturbed land (excluding allotments)
Semi-natural grassland	Meadowland and permanent grass	Semi-natural grassland (includes neutral, acid, calcareous and rough grasslands), Floodplain grazing marsh
Improved grassland	-	Improved grassland (excluding floodplain grazing marsh), Amenity grassland > 1 ha
Heath and marsh	Heaths and moorlands	Marshy grassland, Heathland, Mire Swamp
Built-up areas and gardens	Land agriculturally unproductive (includes buildings, roads, industry) Gardens (includes allotments)	Built-up areas Infrastructure Gardens & brownfield Allotments Amenity grassland < 1 ha Railway and road verges
Orchards	Orchards	Orchards
Water	Water	Water
Other / unclassified	-	Other Uncertain Unclassified (currently under development)

Using the new categories, two maps were created representing the 1930s and 2020 and clipped to the study area boundary. Data were then extracted on the cover of each habitat in each time period and the change in habitat area was calculated.

3.3 Results

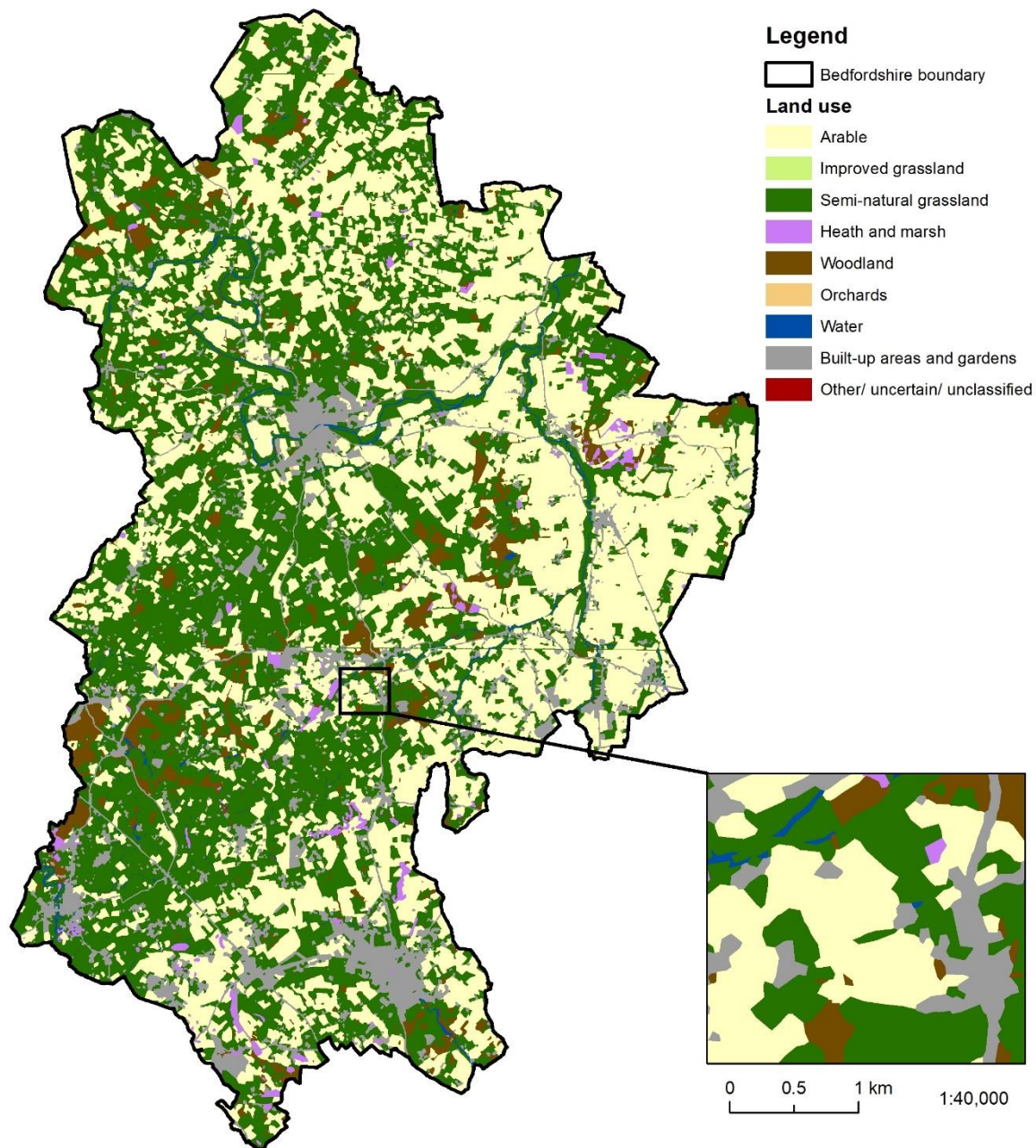
A map of habitats in the 1930s is shown as Figure 7, with the corresponding map from 2020 as Figure 8.

Semi-natural grassland and arable were the dominant habitat types in the 1930s, occupying 42.2% (52,166 ha) and 41.3% (51,081 ha) of the area of Bedfordshire respectively (Figure 9). Semi-natural grassland was dominant in the west of the county, particularly the south-west, and arable was more common in the east. Woodlands occupied only 4.9%, and was concentrated almost entirely along the Greensand Ridge and the Yardley Whittlewood Ridge. Heathland and marsh took up 1.1% of Bedfordshire, while built-up areas and gardens occupied 9.5%. There were no improved grasslands.

In contrast, by 2020, arable has increased to 56.3% of the land area (69,549 ha) and is now the single dominant land cover type, with improved grasslands occupying a further 12.4%. Semi-natural grassland has declined to just 1.9% (2,392 ha), whilst built-up areas and gardens have increased to 16.5% and woodland has increased to 9.1% of the area.

The overall change in cover between the two time periods is shown in Figure 10. This shows that there has been a loss of almost 50,000 ha of semi-natural grasslands (a 95% decline) and over 1,200 ha of heath and marsh (wetland) habitats (a 91% decline) across Bedfordshire. On the other hand, arable has increased by 18,500 ha (an increase of 36%), built-up areas and gardens by 8,700 ha (74% increase) and woodland by 5,170 ha (85% increase). Improved grassland has increased from zero to 15,300 ha. The amount of water has increased by 42%, although the exact change recorded here is unreliable, as smaller drainage ditches were not recorded in the 1930s map. Orchards increased from 48 to 181 ha (an increase of 274%).

Land use and habitats in the 1930s



Data are derived from the Land Utilisation Survey of Britain, 1933-1949, (c) Audrey N. Clark.
Contains Environment Agency information (c) Environment Agency and/or database rights.

© Natural Capital Solutions Ltd 2020. Contains Ordnance Survey data
© Crown copyright and database right 2020.

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Figure 7: Land-use and habitats in the 1930s, derived from the “Dudley Stamp” maps.

Land use and habitats in 2020

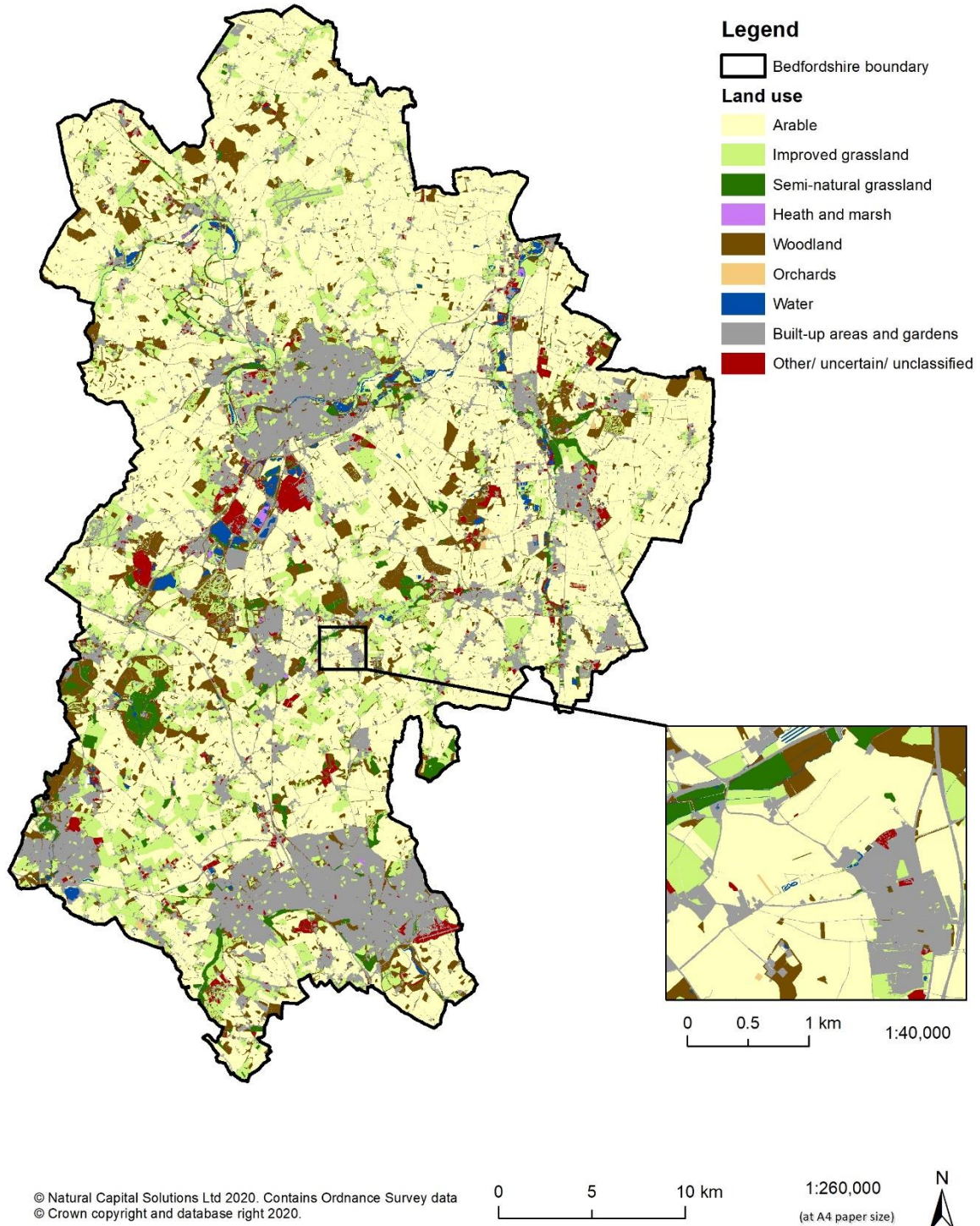


Figure 8: Land-use and habitats in 2020, derived from natural capital basemaps for each county, but with categories matched as closely as possible to the “Dudley Stamp” maps.

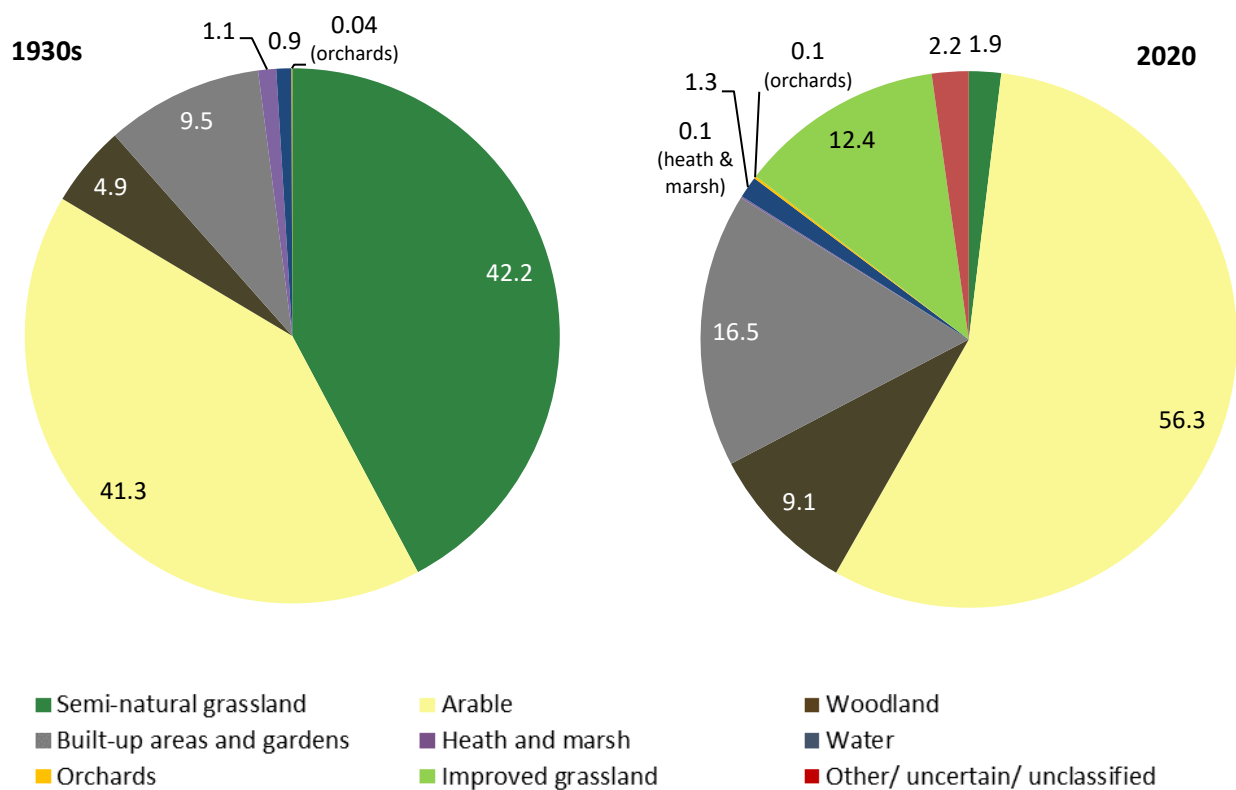


Figure 9: Percentage cover of habitat types in the 1930s (left) and 2020 (right).

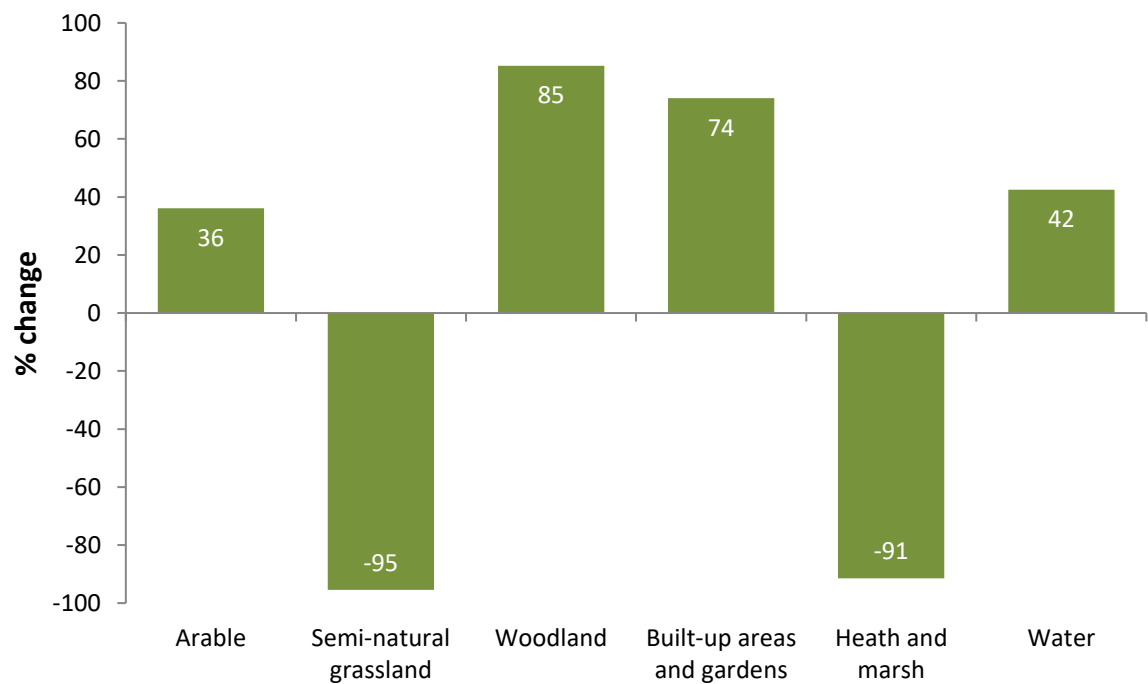


Figure 10: Percentage change in habitat types between the 1930s and 2020. Note that orchards increased by 274% (from 48 to 181 ha) in the same time period and is not shown.

3.4 Discussion

The maps and data paint a picture of profound habitat change over the last 80 years. The vast majority of semi-natural habitats have been lost, replaced predominantly by arable and improved grassland. There has also been an expansion of woodland, particularly of plantation forestry in the 1950-60s. Similar changes have been seen throughout the UK. Nationally, it has been estimated that 97% of enclosed semi-natural grasslands in England and Wales were lost between 1930 and 1984, whereas woodland in the UK increased by almost 100% over similar periods⁶, figures that are similar to the 95% decline and 85% increase seen here. The figures from Bedfordshire are almost identical to Northamptonshire, where a 95% decline in semi-natural grasslands and an 88% decline in heath and marsh were recorded, with a similar shift to arable, improved grassland and woodland. Cambridgeshire was already dominated by arable in the 1930s, but still recorded an increase in arable and a loss of 84% of semi-natural grasslands and 88% of heath and marsh.

Such significant losses of semi-natural habitats are almost certain to have had an impact on biodiversity across the county. As well as direct loss of habitat, remaining habitat patches are smaller and more fragmented with reduced connectivity between wildlife populations. This reduces dispersal between populations, and small and isolated populations are more prone to local extinction.

Efforts were made to match the habitats recorded in the 1930s to those from the present day, but there will inevitably be some discrepancies. Habitats were recorded at a much higher resolution in the present study, capturing very small habitat patches. This was not the case in the 1930s, particularly in urban areas, and water was also mapped with less accuracy. In addition, the digitization process of the Dudley Stamp maps led to some further loss of detail for small habitat patches. It is likely that both the built-up / garden and water categories will have been slightly over-simplified in the 1930s map compared to the present day, and some smaller habitats such as orchards will have been underrepresented. The exact habitat areas and percentage change reported here are therefore prone to some error. Nevertheless, the overall picture of change is accurate.

There are likely to have been major changes in the ecosystem services delivered by the natural environment over the last 80 years. Clearly agricultural production will have increased, along with timber production. However, a number of regulatory services are likely to have declined. The ability of the land to retain water will have decreased, and the positive impact of habitats filtering pollutants and enhancing water quality will also have declined. The impact on carbon storage and sequestration is more difficult to predict without a detailed assessment, as gains in carbon through increasing woodland cover will have been offset by losses due to conversion of semi-natural grasslands to arable and improved grassland, which store less carbon and give rise to emissions from agricultural activities. The supply of pollination services is likely to have declined with the loss of semi-natural habitats, but the demand for pollination will have increased considerably as oilseed rape has become a major component of the farming landscape but was not planted at all in the 1930s. Cultural services will also have been impacted although it is impossible to assess these due to cultural and other changes over the period.

Mapping and comparing land use and habitats over 80 years is a powerful way of demonstrating the changing landscape of Bedfordshire and the loss of semi-natural habitats. Additional uses of the maps could be to assess changes in the degree of fragmentation and connectivity of habitat patches, and to identify previous land-use configurations to aid with the identification of the most suitable locations for habitat restoration. This could work particularly well in combination with the opportunity mapping.

⁶ UK NEA (2011) The UK National Ecosystem Assessment. UNEP WCMC, Cambridge.

4. Modelling and mapping ecosystem services (physical flows)

Once a detailed habitat basemap had been created for Bedfordshire, it was then possible to quantify and map the benefits that these habitats (natural capital) provide to people. The following benefits (ecosystem services) have been assessed for this project:

- Carbon storage and sequestration
- Air purification
- Noise regulation
- Local climate regulation
- Water flow regulation
- Water quality regulation
- Agricultural production
- Timber production
- Accessible nature

The list of services assessed was considered to capture the most important services provided by the natural environment, supported by expert knowledge from within the project team. A variety of methods were used, and these are described for each individual ecosystem service in the sections below. In all cases the models were applied at a 10m by 10m resolution to provide fine scale mapping across the area. The models are based on the detailed habitat information determined in the basemap, together with a variety of other external data sets (e.g. digital terrain model, UK census data 2011, open space data, and many other data sets and models mentioned in the methods for each ecosystem service). Note, however, that many of the models are indicative (showing that certain areas have higher capacity or demand than other areas) and are not process-based mathematical models (e.g. hydrological models). In all cases the capacity and demand for ES is mapped relative to the values present within the study area.

For every ecosystem service listed, the capacity of the natural environment to deliver that service – or the current supply – was mapped. For air purification, noise regulation, local climate regulation, and accessible nature, it was also possible to map the local demand (the beneficiaries) for these services. The importance and value of ecosystem services can often be dependent upon its location in relation to the demand for that service, hence capturing this information provides useful additional insight. Mapping demand was not, however, possible, for the other services where there was no obvious method to apply, or local demand is not relevant, such as food or timber production (demand for food and timber production is national and does not vary by location in a meaningful way).

4.1 Carbon storage capacity

What is it and why is it important?

Carbon storage capacity indicates the amount of carbon stored naturally in soil and vegetation. Carbon storage and sequestration is seen as increasingly important as we move towards a low-carbon future. The importance of managing land as a carbon store has been recognised by the UK Government, and land use has a major role to play in national carbon accounting. Changing land use from one type to another can lead to major changes in carbon storage, as can restoration of degraded habitats. Note that carbon storage measures the stock of carbon in the natural environment, whereas carbon sequestration (Section 4.2) measures its annual flow.

How is it measured?

The EcoServ GIS carbon storage model was used. This model estimates the amount of carbon stored in the vegetation and top 30cm of soil. It applies average values for each habitat type taken from a review of a large number of previous studies in the scientific literature. As such it does not take into account habitat condition or management, which can cause variation in amounts of carbon stored. It is calculated for each 10m by 10m cell across the study area. Scores are scaled on a 0 to 100 scale, relative to values present within the mapped area.

In all the ecosystem services maps that follow, the highest amounts of service provision and demand (hotspots) are shown in red, with a gradient of colour to blue, which shows the lowest amounts (coldspots).

Results for Bedfordshire

Figure 11 (overleaf) shows baseline carbon storage capacity across the study area. The score is out of a maximum possible of 100 (given to broadleaved woodland).

Carbon storage capacity in the region is clustered in areas of habitats such as broadleaved woodland and other woodland types, which are particularly efficient at carbon storage. These are particularly prevalent in the central (Greensand Ridge) and northern (Yardley Whittlewood Ridge) part of the county. However, most green spaces in the region support some level of carbon storage, with much lower levels in urban areas dominated by buildings and sealed surfaces.

Carbon Storage Capacity

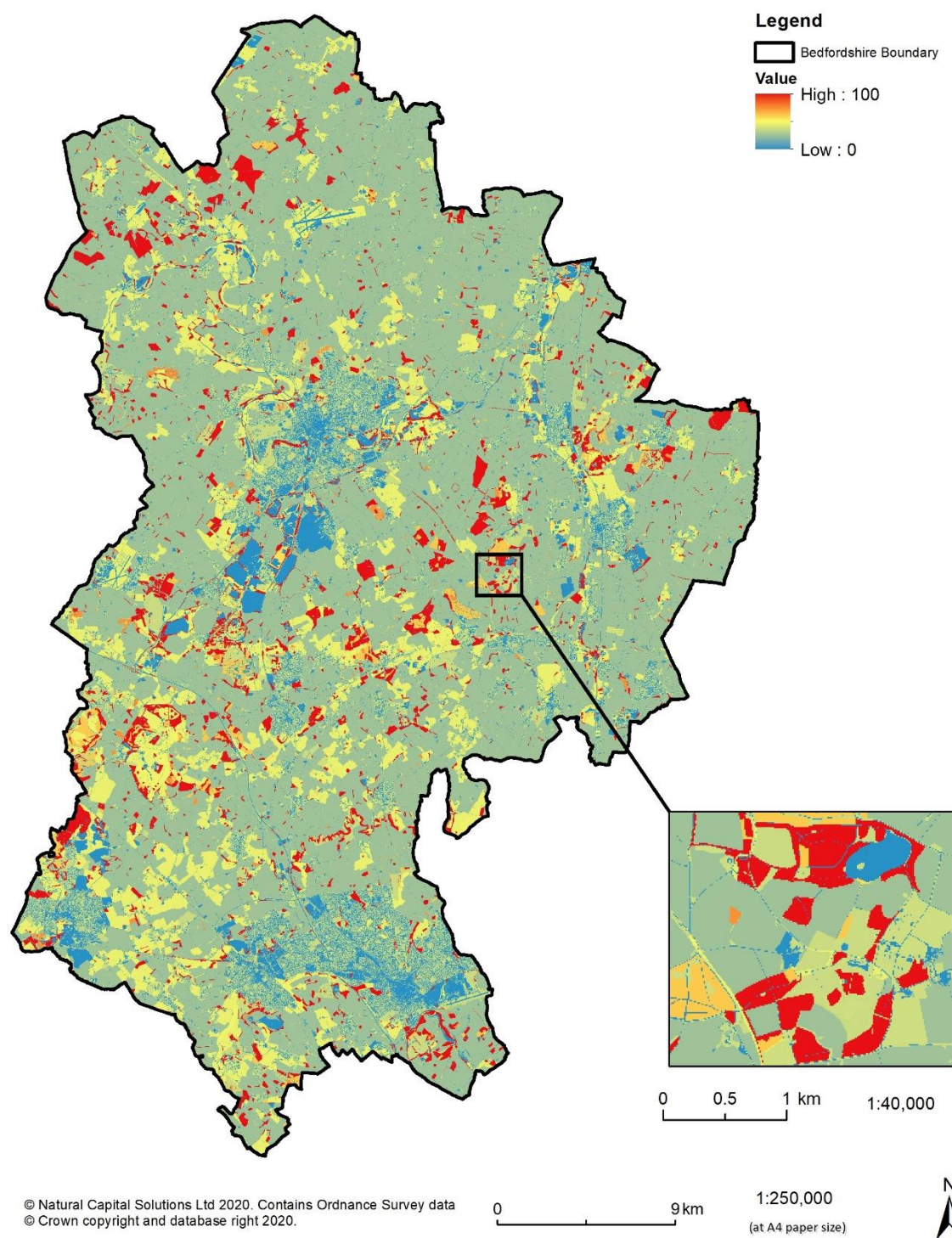


Figure 11 Carbon storage capacity across Bedfordshire. Inset map shows level of detail in the map for a representative location.

4.2 Carbon sequestration

What is it and why is it important?

Carbon is sequestered (captured) by growing plants. Plants that are harvested annually (e.g. arable crops, improved grassland) will be approximately carbon neutral over the course of a year as the sequestered carbon is immediately released. There is very little information about sequestration in other habitats (apart from woodland), but these are likely to be very low. Therefore, estimates are solely based on woodland carbon sequestration.

How is it measured?

Carbon sequestration rates for woodland and other habitats with trees were calculated following the UK Woodland Carbon Code methodology and look-up tables (Woodland Carbon Code 2018⁷). Coniferous woodland sequestration rates were averaged over a 60-year period and deciduous woodland sequestration rates were averaged over a 100-year period, as this is the length of a typical forestry cycle for these woodland types. Information on species composition was taken from the Forestry Commission's National Inventory of Woodland and Trees County Report for Bedfordshire (2002⁸). Yield classes for each tree species in Bedfordshire were derived from Forest Research's Ecological Site Classification tool (<http://www.forestdss.org.uk/geoforestdss/>). Average spacing between trees was assumed, and it was also assumed that deciduous woodland was not thinned, but coniferous areas were. The annual sequestration rate for each species was then multiplied by the proportion of each species to give the total annual sequestration estimate for each woodland type.

The calculations included areas of parkland and scrub. The former sites were assessed to, on average, have 20% tree cover with a broadleaved mix of sycamore, ash and birch. Areas of scrub were calculated at half the sequestration rates of deciduous woodland of the same species mix.

Maps of the sequestration rate were scaled from 0 to 100 for consistency with the other maps.

Results for Bedfordshire

The baseline carbon sequestration map (Figure 12) shows that the greatest areas of carbon sequestration (in red) are within the larger areas of broadleaved woodland that are predominantly in the central and northern part of the county. These are areas of mostly broadleaved woodland. Coniferous woodland plantations show up as orange, and are also reasonably good at sequestering carbon. Coniferous woodland often sequesters carbon at a faster rate than broadleaved woodland, but it is usually managed for timber, which involves regular thinning, hence reducing the accumulation of carbon.

⁷ Woodland Carbon Code (2018) Carbon calculation guidance v2. March 2018. Forestry Commission.

⁸ Forestry Commission (2002) National Inventory of Woodland and Trees County Report for Bedfordshire. Forestry Commission.

Carbon sequestration capacity

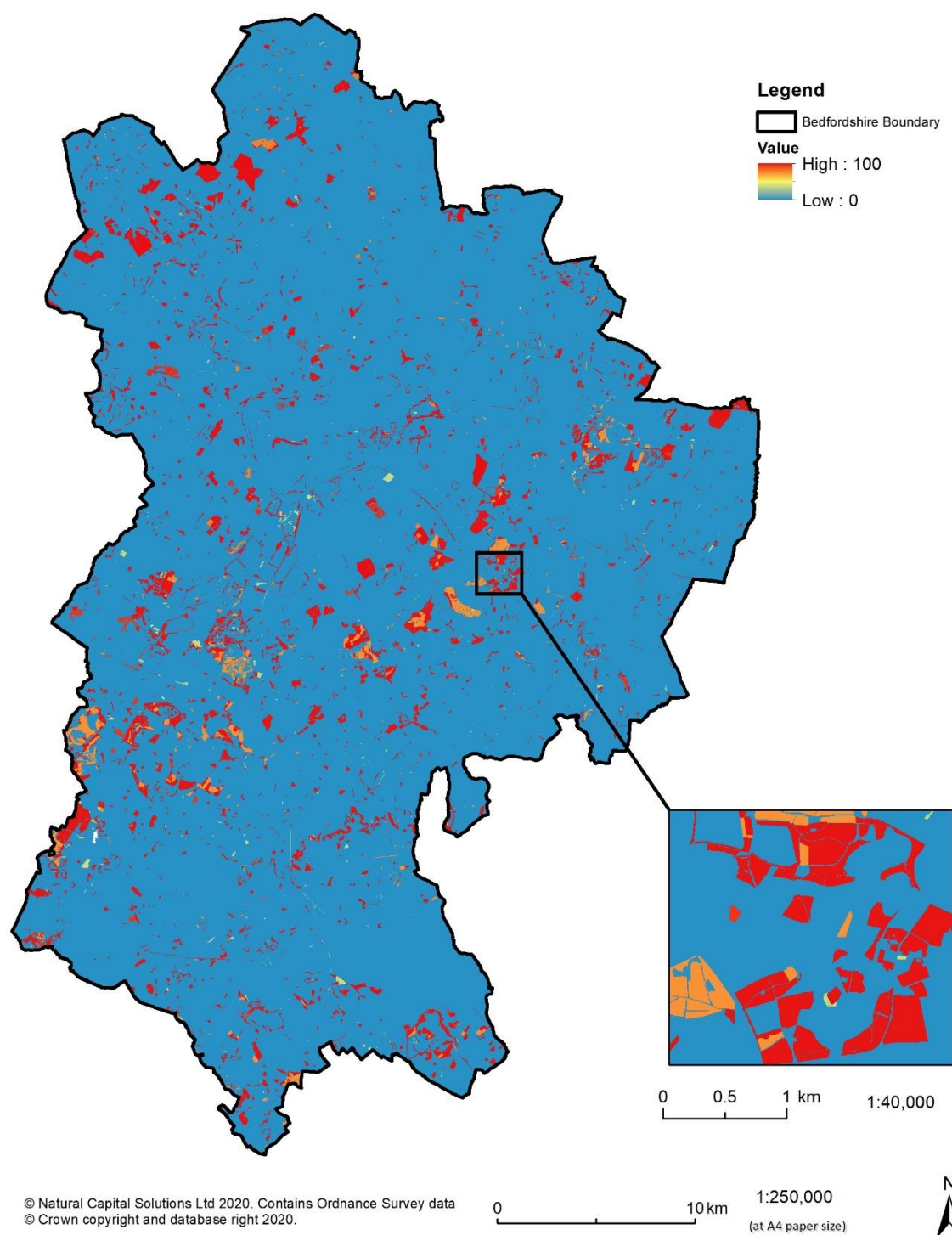


Figure 12 Carbon sequestration capacity across Bedfordshire.

4.3 Air purification capacity (air quality regulation)

What is it and why is it important?

According to the Public Health England, air pollution is the biggest environmental threat to health in the UK, with between 28,000 and 36,000 deaths a year attributed to long-term exposure, with the greatest threats from particulate matter (PM_{2.5}) and nitrous oxides (NO_x). Even small changes can make a big difference, just a 1µg/m³ reduction in PM_{2.5} concentrations could prevent 50,000 new cases of coronary heart disease and 9,000 new cases of asthma by 2035⁹. Air pollution also contributes to climate change, reduces crop yields, and damages habitats and biodiversity.

Air purification capacity estimates the relative ability of vegetation to trap airborne pollutants or ameliorate air pollution. Vegetation can be effective at mitigating the effects of air pollution, primarily by intercepting airborne particulates (especially PM₁₀ and PM_{2.5}) but also by absorbing ozone, SO₂ and NO_x. Trees provide more effective mitigation than grass or low-lying vegetation, although this varies depending on the species of plant. Coniferous trees are generally more effective than broadleaved trees due to the higher surface area of needles and because the needles are not shed during the winter.

How is it measured?

Local climate regulation capacity was mapped using a modified version of a EcoServ GIS model. The model assigns a score to each habitat type, representing the relative capacity of each habitat to ameliorate air pollution. The cumulative score in a 20m and 100m radius around each 10m by 10m pixel was then calculated and combined. The benefits of pollution reduction by trees and greenspace may continue for a distance beyond the greenspace boundary itself, with evidence that green area density within 100m can have a significant effect on air quality. Therefore, the model extends the effects of greenspace over the adjacent area, with the maximum distance of benefits set at 100m. Note that the model does not take into account seasonal differences or differences in effect due to prevailing wind direction.

The final capacity score was calculated for each 10m by 10m cell across the study area, and was scaled on a 0 to 100 scale, relative to values present within the mapped area. High values (red) indicate areas that have the highest capacity to trap airborne pollutants and ameliorate air pollution.

Results for Bedfordshire

Woodland is by far the best habitat at intercepting and absorbing air pollution, with the very highest scores from coniferous forests. The lowest scores (dark blue) are from man-made sealed surfaces and water features which effectively have zero capacity to ameliorate air pollution.

Of particular note are the densely forested areas, apparent as dark red patches of high air purification capacity in Figure 13. These include significant strips of northern and central Bedfordshire, especially in the Greensand Ridge and the Yardley Whittlewood Ridge. Urban areas display much lower levels of air purification capacity in general, although street and garden trees can be locally important.

⁹ Public Health England (2018) Estimation of costs to the NHS and social care due to the health impacts of air pollution. Crown Copyright.

Air Purification Capacity

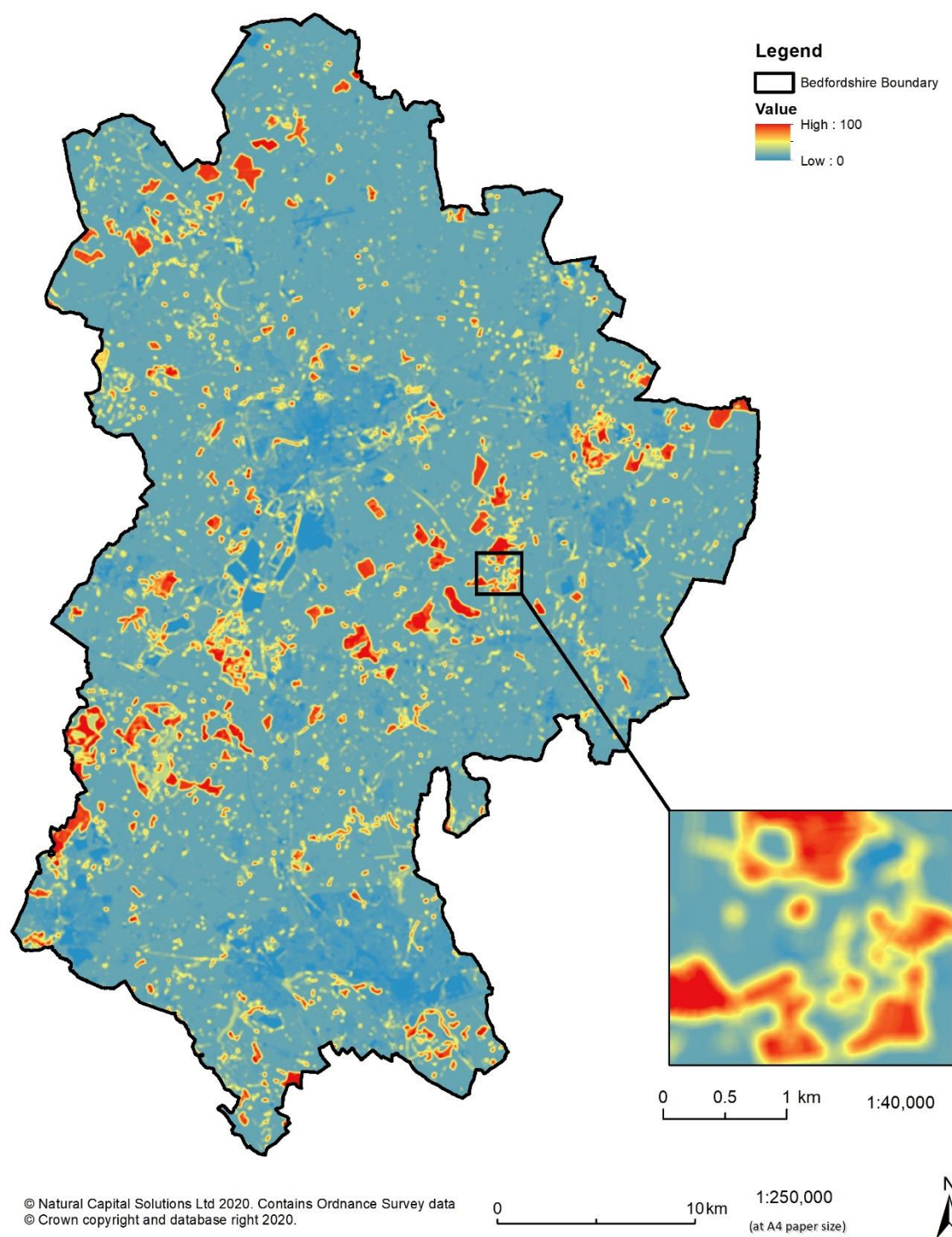


Figure 13 Air purification capacity across Bedfordshire.

4.4 Air purification demand

What is it and why is it important?

Air purification demand estimates societal and environmental need for ecosystems that can absorb and ameliorate air pollution. Demand is assumed to be highest in areas where there are likely to be high air pollution levels and where there are lots of people who could benefit from the air purification service.

How is it measured?

Air purification demand was mapped using a model from EcoServ GIS. The model combines two indicators of air pollution sources (log distance to roads, and % cover of sealed surfaces) and two indicators of societal need for air purification (population density, and Index of Multiple Deprivation health score).

The scores for each indicator were normalised and combined with equal weighting. The final score was then projected on a 0 to 100 scale, relative to values present within the study area. High values (red) denote areas with the greatest demand for air purification as a service.

Results for Bedfordshire

Air purification demand is highest in urban centres as these have both higher air pollution levels and higher populations that would benefit from better air quality. The main road network is also clearly visible as a major pollution source, and where these main roads pass through built up areas, there is increased demand for air purification, for example along the A5 as it passes through Dunstable. On Figure 14, the areas of highest demand are clustered around major towns in the region, particularly in Bedford and Luton, but also in the minor towns such as Leighton Buzzard, Flitwick, Biggleswade and Sandy. Outside of these clusters, demand is relatively low across the study region.

Balancing supply and demand for air purification services

By considering both the air purification capacity and demand maps (Figures 13 and 14), it is clear that there is a significant spatial disparity in air purification capacity and demand, with the former being higher in rural areas and the latter higher in urban areas. Planting (or maintaining) trees and woodland close to main roads and other pollution sources in built-up areas would be highly beneficial, with considerable benefits to society. Air pollution can be very localised, hence it is important to consider the specific location of trees to gain the maximum benefit of this service.

Trees are very effective at mitigating the effects of air pollution. However, there are major differences in the ability of different species to intercept pollution. The location of trees relative to pollution sources also determines how effective they are at removing pollutants, with trees close to sources being the most effective. Urban woodland is particularly effective as it has high capacity to absorb pollution and is also situated in locations likely to have high demand for the service.

Air Purification Demand

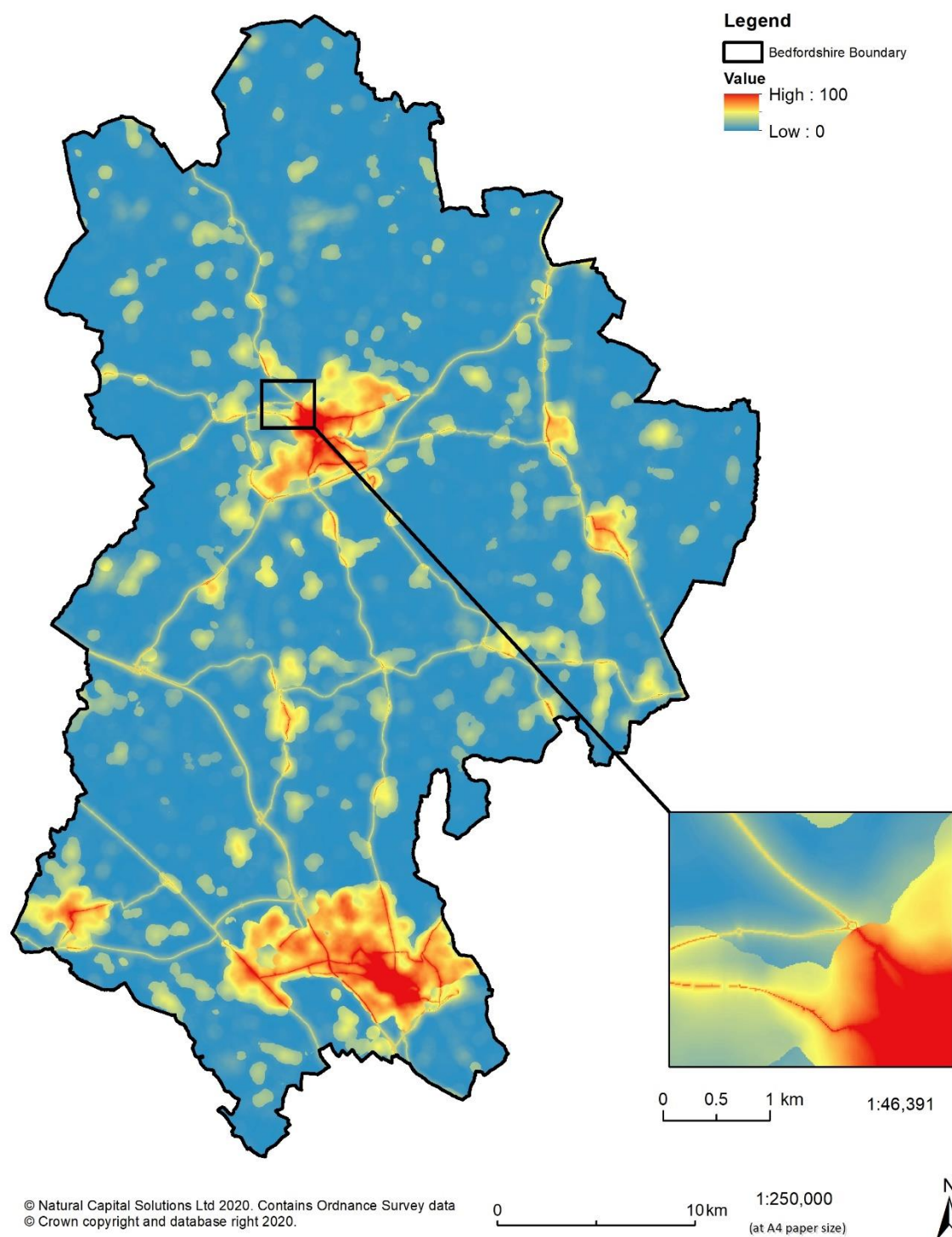


Figure 14 Air purification demand across Bedfordshire.

4.5 Noise regulation capacity

What is it and why is it important?

Noise regulation capacity is the capacity of the land to diffuse and absorb noise pollution. Noise can impact on health, wellbeing, productivity and the natural environment and the World Health Organisation (WHO) have identified environmental noise as the second largest environmental health risk in Western Europe (after air pollution). It is estimated that the annual social cost of urban road noise in England is £7 to £10 billion (Defra 2013¹⁰). Major roads, railways, airports and industrial areas can be sources of considerable noise, but use of vegetation can screen and reduce the effects on surrounding neighbourhoods. Complex vegetation cover, such as woodland, trees and scrub, is considered to be most effective, although any vegetation cover is more effective than artificial sealed surfaces, and the effectiveness of vegetation increases with width.

How is it measured?

The EcoServ GIS noise regulation model was used, with some modifications. First, the capacity of the natural environment was mapped by assigning a noise regulation score to vegetation types based on height, density, permeability and year-round cover. Next, the noise absorption score in 30m and 100m radii around each point was modelled and the scores combined, which results in wider belts of vegetation receiving a higher score. The score was calculated for each 10 m by 10m cell across the study area, and is scaled on a 0 to 100 scale, relative to values present within the mapped area. High values (red) indicate areas that have the highest capacity to absorb noise pollution.

Results for Bedfordshire

This model is similar to the air purification capacity model and similarly to that, woodland is by far the most effective habitat at absorbing noise. However, the effects are modest, with reductions of 2-4 dB typically recorded across dense tree belts. Figure 15 shows a broadly similar spatial pattern to Figure 13, air purification capacity. Noise regulation capacity is relatively low in urban areas, and highest in forested areas, concentrated in the central and northern parts of the county. Outside of this area, noise regulation capacity is variable and occurs mainly in clusters around green spaces across the region.

¹⁰ Defra (2013) Noise pollution: economic analysis. Crown Copyright.

Noise regulation capacity

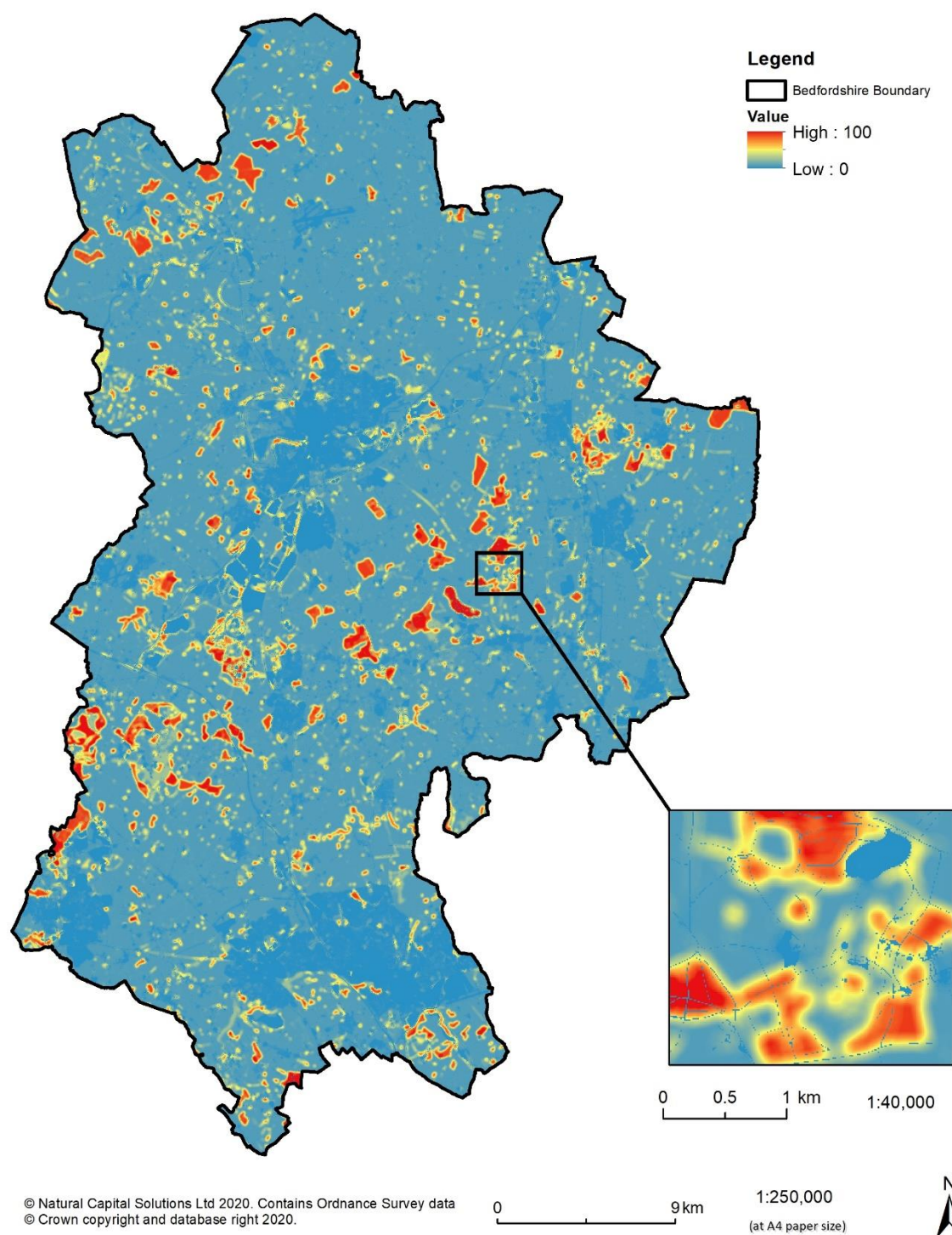


Figure 15 Noise regulation capacity across Bedfordshire.

4.6 Noise regulation demand

What is it and why is it important?

Noise regulation demand estimates societal and environmental need for ecosystems that can absorb and reflect anthropogenic noise.

How is it measured?

Noise regulation demand was mapped using a modified version on an EcoServ GIS model. The model combines one indicator that maps noise sources (inverse log distance to different road classes and railways, custom built for the study area based on Defra noise modelling) and two indicators of societal demand for noise abatement (population density, and Index of Multiple Deprivation health scores).

Scores are on a 1 to 100 scale, relative to values present within the study area. High values (red) indicate areas that have the highest demand for noise regulation as a service.

Results for Bedfordshire

Figure 16 shows noise regulation demand across the Bedfordshire region. Demand is greatest in urban areas close to major roads, as these contain large populations, with potentially poor health scores, that would benefit from noise abatement from the main roads. The greatest demand occurs in Bedford and Luton, but there is also relatively high demand in Leighton Buzzard, Flitwick, Biggleswade, Sandy and Brogborough. Luton Airport is also included, although most of the noise is focussed away from residential areas, hence demand is reduced in our model.

Balancing supply and demand for noise regulation services

The pattern of supply and demand for this service is rather similar to that of air purification, with a spatial disparity between capacity and demand - capacity is concentrated in more rural areas and demand is clustered around urban areas, as well as roads and railways. Again, planting trees close to main roads and other noise sources would be the most effective mitigation.

Studies in many countries have shown that densely planted tree belts can reduce noise levels, but the effects are modest, with reductions of 2-4 dB typically recorded. Note however, that there is some evidence to suggest that the presence of vegetation blocking views of a noise source such as a road can enhance the perception of noise reduction. Densely planted and complex vegetation cover such as trees mixed with scrub is considered to be most effective, although any vegetation cover is more effective than artificial sealed surfaces.

Noise Regulation Demand

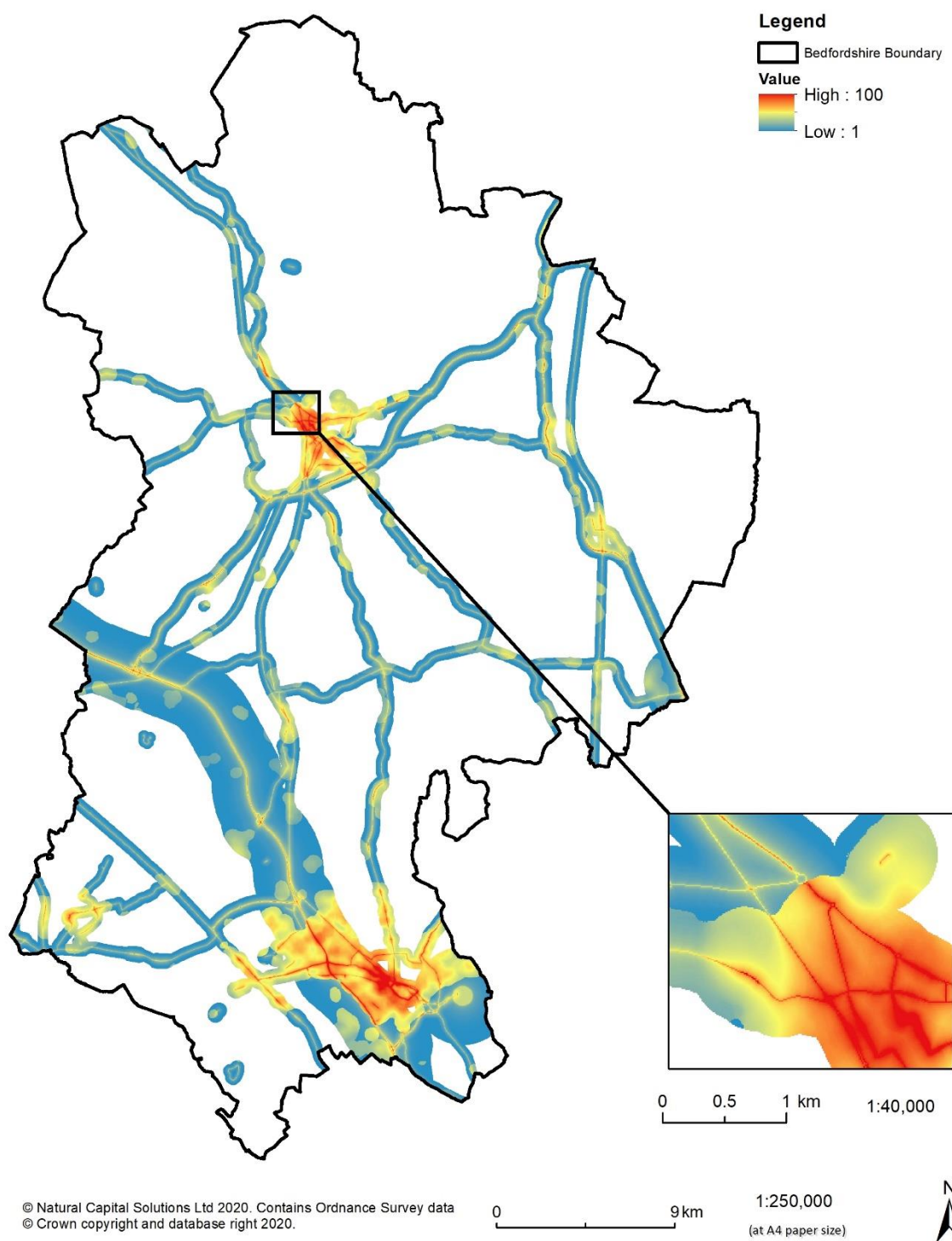


Figure 16 Noise regulation demand across Bedfordshire. Areas with zero demand have been excluded to improve map legibility.

4.7 Local climate regulation capacity

What is it and why is it important?

Land use can have a significant effect on local temperatures. Urban areas tend to be warmer than surrounding rural land due to a process known as the “urban heat island effect”. This is caused by urban hard surfaces absorbing more heat, which is then released back into the environment, coupled with energy released by human activity such as lighting, heating, vehicles and industry. Climate change impacts are predicted to make the overheating of urban areas and urban buildings a major environmental, health and economic issue over the coming years. Natural vegetation, especially trees / woodland and rivers, are able to have a moderating effect on local climate, making nearby areas cooler in summer and warmer in winter. Local climate regulation capacity estimates the capacity of an ecosystem to cool the local environment and cause a reduction in urban heat maxima.

How is it measured?

Local climate regulation capacity was mapped using an EcoServ GIS model. The model calculates the proportion of the landscape that is covered by woodland / scrub and water features within a 200m radius around each 10m by 10m cell across the study area. However, temperature regulating effects of woodland and water will also occur in nearby adjacent areas, with the distance of the effect dependent on the patch size of the natural area. To incorporate this effect, a buffer was applied around each woodland / water patch, with wider buffers modelled around larger natural sites. Note that this model only includes woodland / scrub and water features which provide the most significant effects. All green space is beneficial compared to artificial sealed surfaces, so a future iteration of the model could include all natural surfaces.

The final capacity score was calculated for each 10m by 10m cell across the study area, and was scaled from 0 to 100, relative to values present within the mapped area. High values (red) indicate areas that have the highest capacity to regulate temperatures, keeping them cool in the summer and warmer in the winter.

Results for Bedfordshire

Figure 17 shows local climate regulation capacity across Bedfordshire. In the absence of large bodies of water, larger areas of woodland in the central and northern parts of the county provide the highest local climate regulation capacity in the region. For this reason, Figure 17 shows a similar capacity pattern to Figures 13 and 15. In much of the remaining region, away from woodland and water bodies, capacity is significantly lower.

Local climate capacity

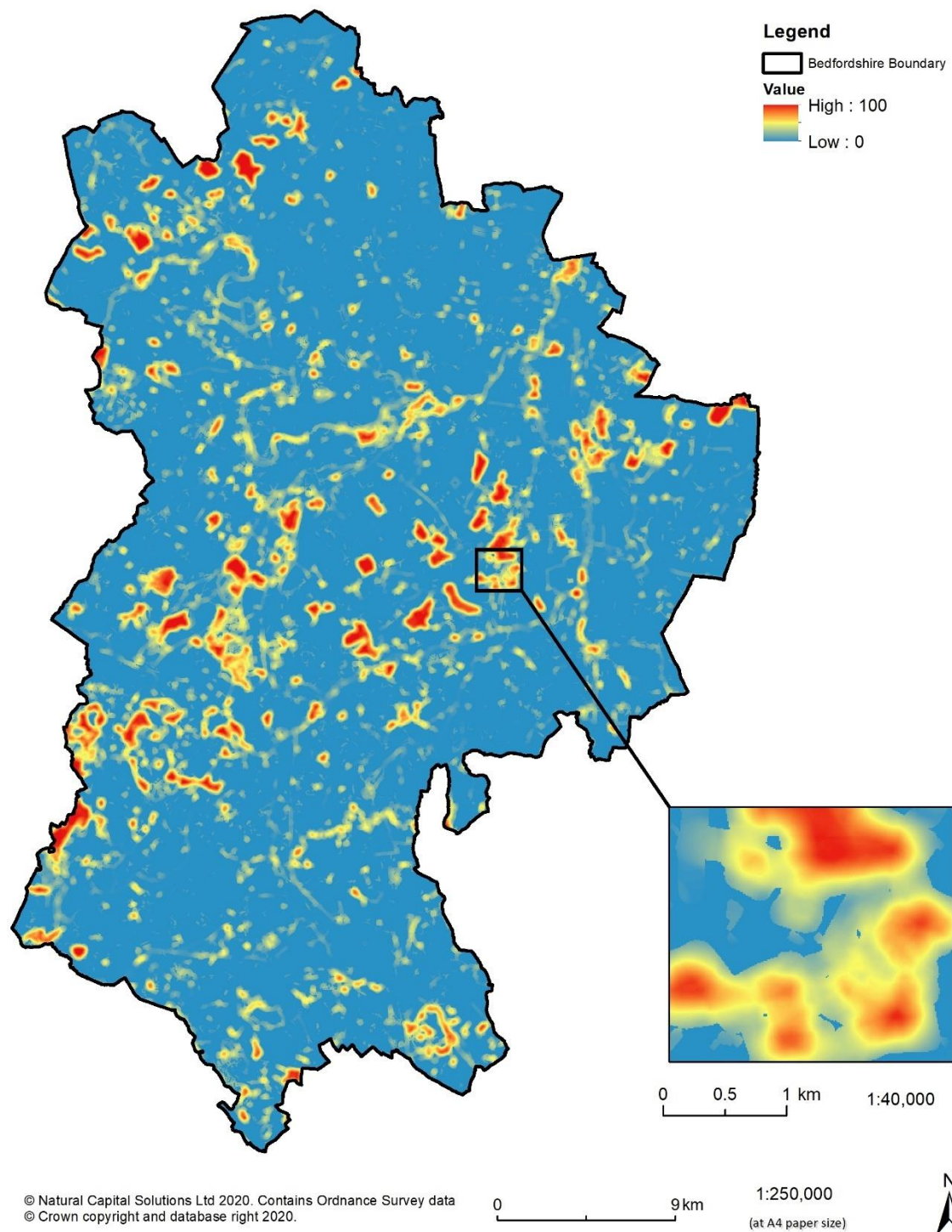


Figure 17 Local climate regulation capacity across Bedfordshire.

4.8 Local climate regulation demand

What is it and why is it important?

Local climate regulation demand estimates societal and environmental need for ecosystems that can regulate local temperatures and reduce the effects of the urban heat island.

How is it measured?

Local climate regulation demand was mapped using an adapted version of an EcoServ GIS model. The model combines one indicator showing the location of areas suffering from the urban heat island effect (the proportion of sealed surfaces), with two indicators showing societal need for local climate abatement (population density, and proportion of the population in the highest risk age categories – defined as under 10 and over 65).

Scores are on a 0 to 100 scale, relative to values present within the study area. High values (red) indicate areas that have the highest demand for local climate regulation as a service.

Results for Bedfordshire

Figure 18 shows local climate regulation demand across the Bedfordshire region. By removing areas of zero demand, it is immediately clear that demand is heavily clustered around urban centres, Bedford and Luton, but also in the minor towns such as Leighton Buzzard, Flitwick, Biggleswade and Sandy. Demand for local climate regulation is effectively zero outside of these centres, and so interventions looking to reduce the disparity between capacity and demand in this service would benefit heavily from investing in capacity in urban areas to meet this concentrated demand.

Balancing supply and demand for local climate regulation services

Demand for this service is focussed around the larger, more densely populated communities. The large areas of woodland adjacent to towns in the south of the county, and especially those that extend into urban areas, are particularly beneficial with respect to local climate regulating services as they are able to bring moderating conditions into the heart of these urban areas. Installing water features and planting trees would be the most effective way to extend these benefits to other areas, particularly when these are installed close to or within built-up areas.

Although regulating local climate and moderating the impacts of the urban heat island effect may be considered to be a relatively low priority at present, its importance is likely to increase over time due to climate change and an increasing (and ageing) population.

Local climate demand

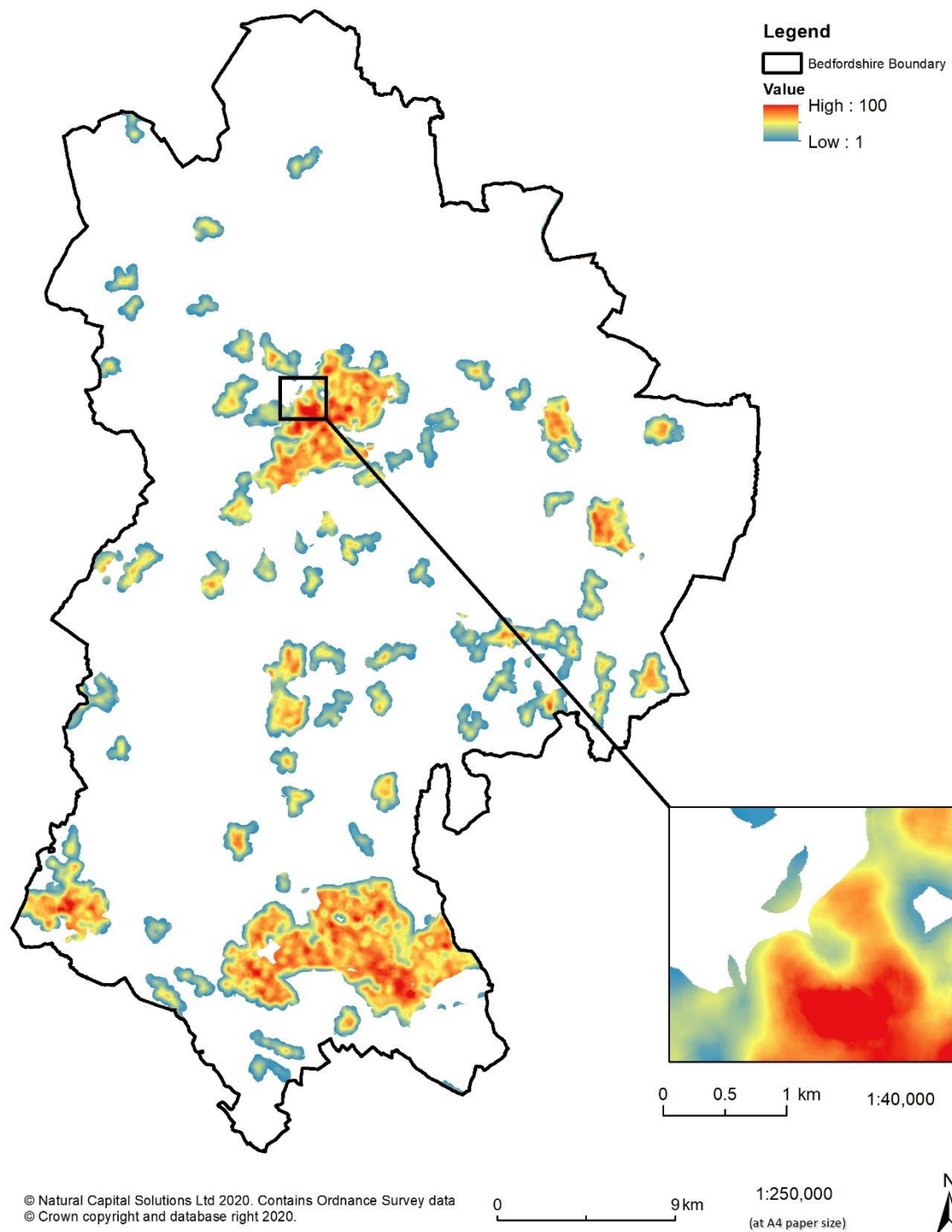


Figure 18 Local climate regulation demand across Bedfordshire. Areas with zero demand have been excluded to improve map legibility.

4.9 Water flow capacity

What is it and why is it important?

Water flow capacity is the capacity of the land to slow water runoff and thereby potentially reduce flood risk downstream. Following a number of recent flooding events in the UK and the expectation that these will become more frequent over the coming years due to climate change, there is growing interest in working with natural process to reduce downstream flood risk. These projects aim to “slow the flow” and retain water in the upper catchments for as long as possible. Maps of water flow capacity can be used to assess relative risk and help identify areas where land use can be changed.

How is it measured?

A bespoke model was developed, building on an existing EcoServ GIS model and incorporating many of the features used in the Environment Agency’s catchment runoff models used to identify areas suitable for natural flood management. Runoff was assessed based on the following two factors:

Roughness score – Manning’s Roughness Coefficient provides a score for each land use type based on how much the land use will slow overland flow.

Slope score – based on a detailed digital terrain model, slope was re-classified into a number of classes based on the British Land Capability Classification and others.

Each indicator was normalised from 0-1, then added together and projected on a 0 to 100 scale, as for the other ecosystem services. Note that this is an indicative map, showing areas that have generally high or low capacity and is not a hydrological model. High values (dark orange and red) indicate areas that have the highest capacity to slow water runoff.

Results for Bedfordshire

The best locations for slowing water runoff are areas of woodland on flat land. The worst areas (blue on the map, Figure 19) are areas of impermeable surface and slopes. Though not particularly visible at a regional scale, impermeable sealed surfaces are prominent in urban areas, where water flow regulation capacity is quite poor.

In comparison, the best areas for water flow regulation capacity are woodland patches with gentle slopes (red on the map, Figure 19). This is because woodland and low gradient slopes both help to slow the surface water flow.

Note that it would be possible to incorporate information on soil type and permeability into the model, which is another important aspect of runoff, so would improve the model further.

Water flow capacity

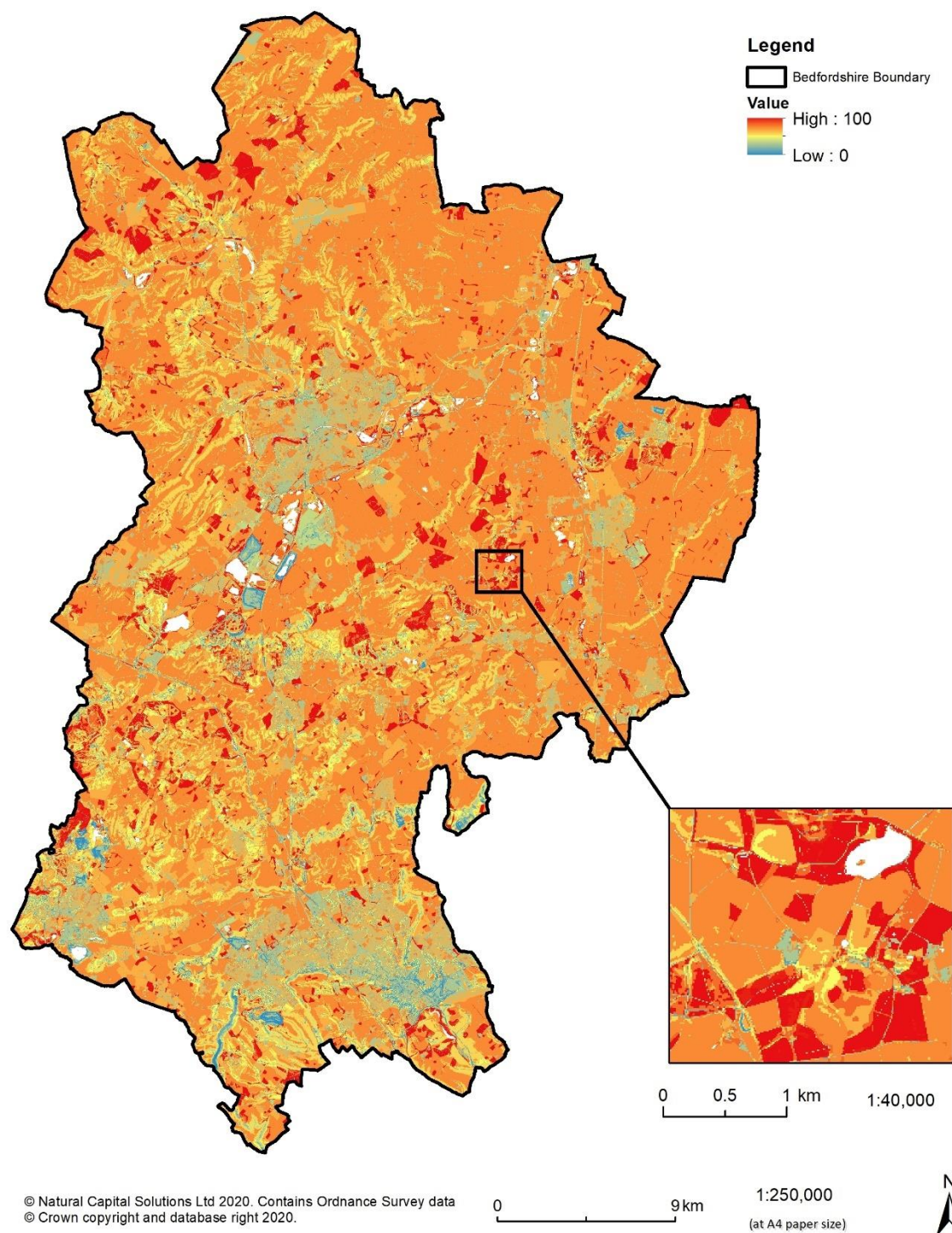


Figure 19 Water flow regulation capacity across Bedfordshire. Note that areas of water are shown as blank (white) on this map.

4.10 Water quality capacity (soil erosion reduction)

What is it and why is it important?

Water quality capacity maps the risk of surface runoff becoming contaminated with high sediment loads before entering a watercourse, with a higher water quality capacity indicating that water is likely to be less contaminated. Sedimentation causes direct impacts on river substrates, fish and aquatic invertebrates, and on flood risk, but also causes indirect impacts through pollutants that are adsorbed onto sediment, and then washed into watercourses. Note that although urban diffuse pollution is partially captured in the model at catchment scale, the focus is on sedimentation risk (soil erosion) from agricultural land, hence built-up areas are not particularly well accounted for in the existing model.

How is it measured?

A modified version of an EcoServ GIS model was developed, which combines a coarse and fine-scale assessment of pollutant risk.

At a coarse scale, catchment land use characteristics were used to determine the overall level of risk. The percentage cover of sealed surfaces and arable farmland in each sub-catchment (EA Waterbody catchment) was calculated and the values were re-classified into a number of risk classes. There is a strong link between the percentage cover of these land uses and pollution levels, with water quality particularly sensitive to the percentage of sealed surfaces in the catchment¹¹.

At a fine scale, a modification of the Universal Soil Loss Equation (USLE) was used to determine the rate of soil loss for each cell. This is based on the following three factors:

- **Distance to watercourse** – using a least cost distance analysis, taking topography into account.
- **Slope length** – using a flow accumulation grid and equations from the scientific literature. Longer slopes lead to greater amounts of runoff.
- **Land use erosion risk** – certain land uses have a higher susceptibility to erosion and standard risk factors were applied from the literature. Bare soil is particularly prone to erosion.

Each of the three fine scale indicators and the catchment-scale indicator were normalised from 0-1, then added together and projected on a 0 to 100 scale. As previously, this is an indicative map, showing areas that have generally high or low capacity and is not a process-based model. High values (red) indicate areas that have the greatest capacity to deliver high water quality (least sedimentation risk).

Results for Bedfordshire

Water quality capacity across Bedfordshire tends to be lower in agricultural areas (blue on the map, Figure 20). Whereas, water quality capacity is highest within the urban areas across the county (red on the map, Figure 20). However, as highlighted above, the water quality model does not fully account for urban diffuse pollution as it focuses on sedimentation risk from agricultural diffuse pollution.

¹¹ Walsh, C J, Roy, A H, Feminella, J W, Cottingham, P D, Groffman, P M & Morgan, R P 2005 The urban stream syndrome: current knowledge and the search for a cure. *Journal of the North American Benthological Society* 24 706-23.

Water quality capacity

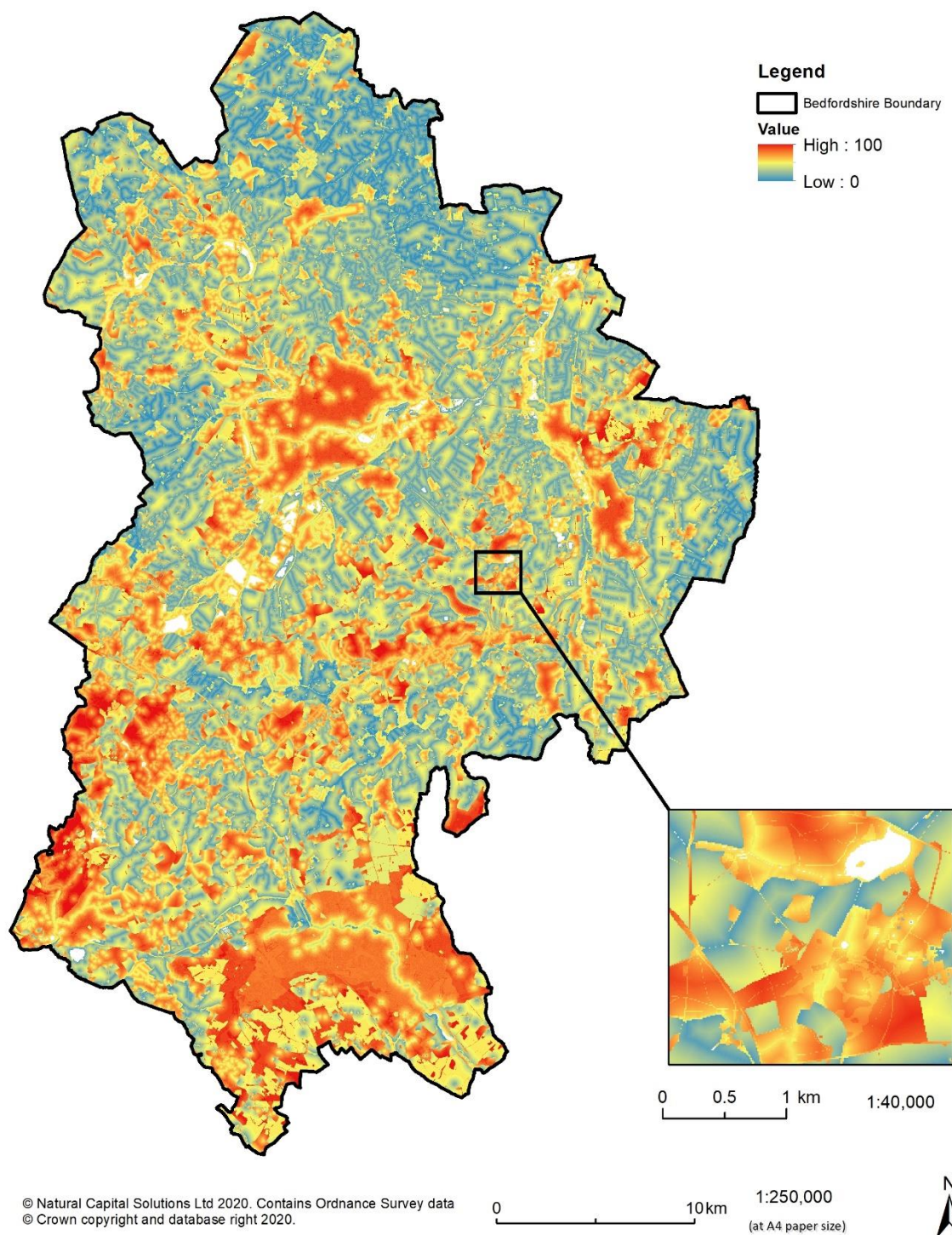


Figure 20 Water quality regulation capacity across Bedfordshire. Note that areas of water are shown as blank (white) on this map.

4.11 Food production capacity

What is it and why is it important?

Food production models the capacity of the land to produce food under current farming practices. Farming is the dominant land-use in Bedfordshire, with arable being much more dominant than grassland for livestock. These land covers provide the largest proportion of food, however, food is produced from a range of other habitats, albeit to a lesser extent. The ability of habitats to provide food, accounting for Agricultural Land Classification, was mapped.

How is it measured?

The methodology follows that outlined in Smith (2020)¹² and was developed for the Ecometric tool. Broad habitats in Bedfordshire were assigned a score based their relative ability to provide food:

- Arable, improved grassland – 10
- Orchards, allotments – 7
- Semi-natural and rough grasslands – 6
- Marshy grassland – 4
- Wood pasture and parkland – 3
- Bog/heath, domestic gardens, broadleaved and mixed woodlands - 1

This was mapped in GIS and then weighted by the Agricultural Land Class in which it occurred. The weighting was based on typical dry yield and an additional multiplier for versatility, following Smith (2020):

Grade 1 – 3.03
 Grade 2 – 2.40
 Grade 3 – 1.33
 Grade 4 – 0.67
 Grade 5 – 0.50

To maintain compatibility with the other ecosystem services maps, the weighted scores were scaled on a 0 to 100 scale, relative to values present within the mapped area.

Results for Bedfordshire

While the majority of Bedfordshire has a medium to low food production capacity (yellow/light blue in Figure 21), there are significant areas of high food production capacity (red to orange in Figure 21). The low to medium food production areas have an Agricultural Land Classification of Grade 3 and Grade 4. The high food production areas are areas of Grade 2 and 1 land, which is predominantly down to horticulture and likely to be highly productive. Urban areas have a very low production capacity reflecting the limited production resulting from gardens (clearly this can be high in some cases, but it is beyond the scope of this project to consider this).

¹² Smith, A. (2020) Natural Capital in Oxfordshire: Short report. Environmental Change Institute, University of Oxford.

Food production capacity

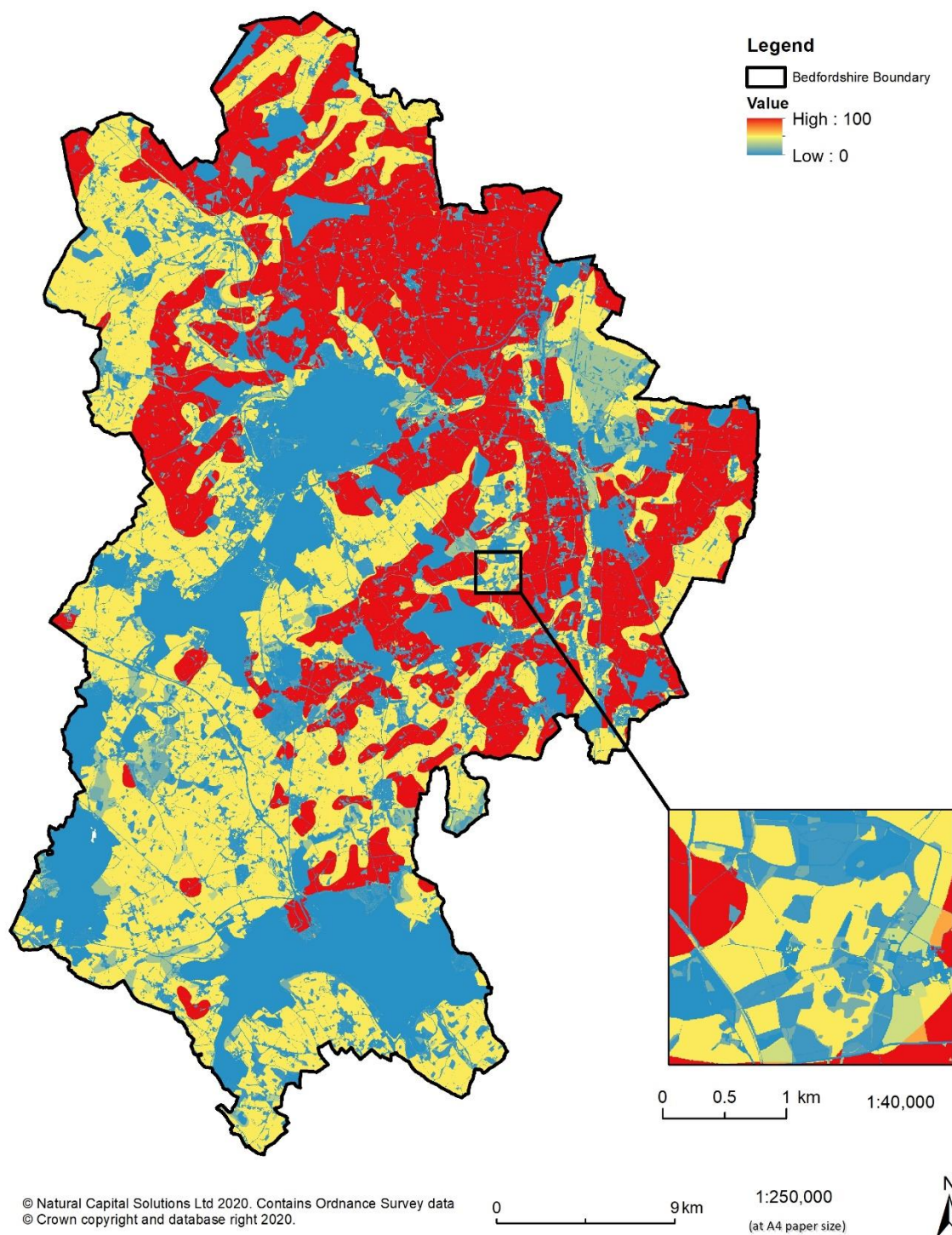


Figure 21 Food production capacity across Bedfordshire.

4.12 Timber / woodfuel capacity

What is it and why is it important?

Forestry remains an important component of the rural economy and many areas of woodland are still valued primarily on their timber value. Timber is an important product of woodlands and is the raw resource of the timber industry. Sustainably managed woodland produces timber that is important in contributing to processing mills and factories that produce wood-based products, and also produces wood fuel for the generation of renewable heat and electricity.

How is it measured?

Information on the species mix and yield class was obtained from the Forestry Commission's National Inventory of Woodland and Trees Regional Report for Bedfordshire (2002), and Forest Research's Ecological Site Classification tool (<http://www.forestdss.org.uk/geoforestdss/>). This was used to determine the average yield of timber (m³) per hectare per year. This was then mapped in GIS and, to maintain compatibility with the other ecosystem services maps, the scores were scaled on a 0 to 100 scale, relative to values present within the mapped area.

Results for Bedfordshire

The largest patches of high timber and woodfuel production capacity predominantly scattered throughout the central and northern part of the county (Figure 22). Coniferous woodland gives the highest capacity and is shown in red whereas broadleaved woodland produces medium levels of timber / woodfuel and is shown in yellow / green. Broadleaved woodland is the dominant woodland cover type in Bedfordshire, although small pockets of coniferous woodland are scattered throughout the area.

Timber capacity

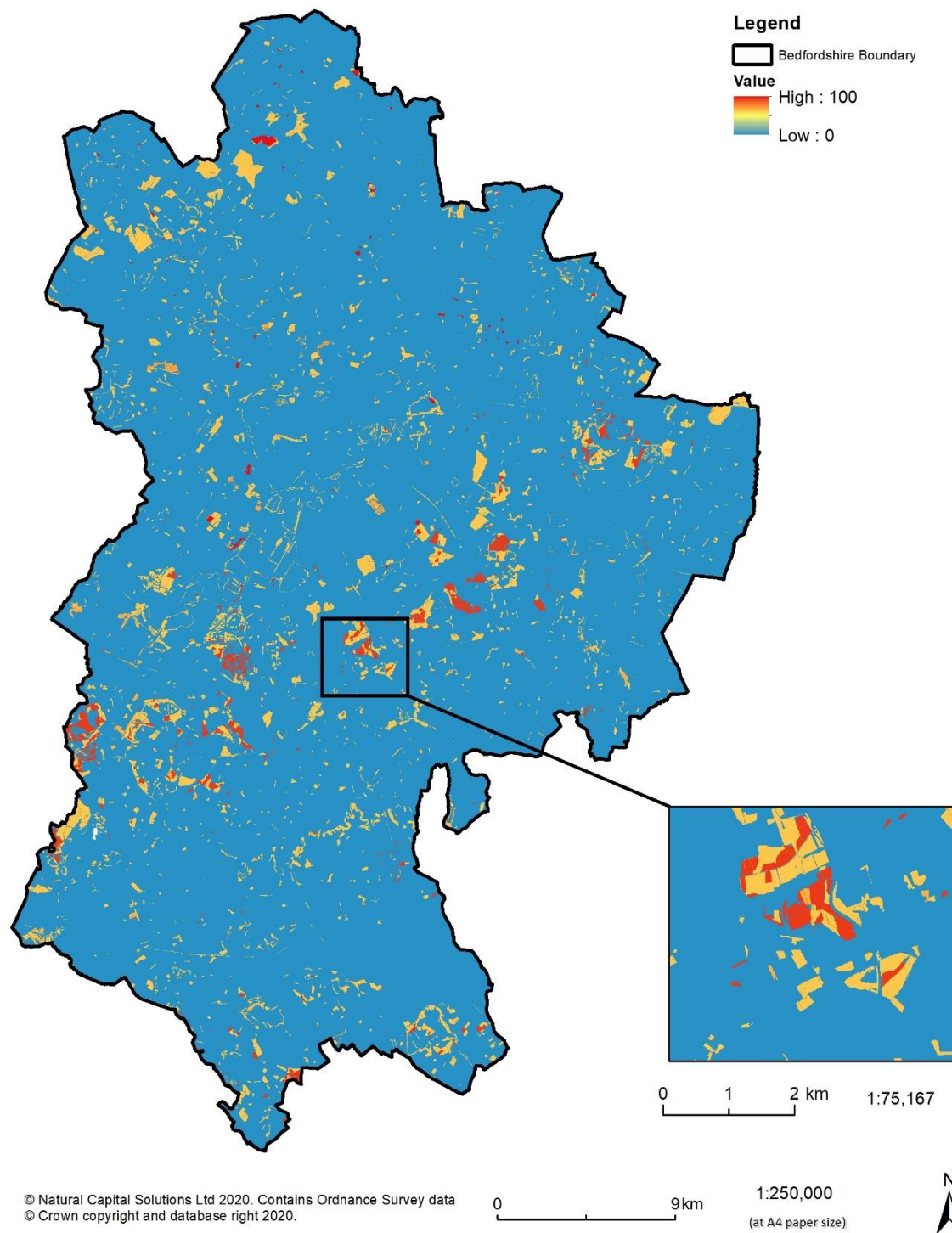


Figure 22 Timber / woodfuel capacity across Bedfordshire.

4.13 Accessible nature capacity

What is it and why is it important?

The importance of access to greenspace is being increasingly recognised due to the multiple benefits that it can provide to people. In particular there is strong evidence linking access to greenspace to a variety of health and wellbeing measures. Research has also shown that there is a link between wellbeing and perceptions of biodiversity and naturalness. Natural England and others have published guidelines that promote the enhancement of access, naturalness and connectivity of greenspaces.

The two key components of accessible nature capacity are therefore public access and perceived naturalness. Both of these components are captured in the model, which maps the availability of natural areas and scores them by their perceived level of “naturalness”. Note that the model does not take into account the number of visitors to a site, only whether it is publicly accessible, and habitat sensitivity or carrying capacity is not considered. Hence further, more detailed study would be required before increased visitor numbers were encouraged at any identified sites.

How is it measured?

Accessible nature capacity was mapped using an EcoServ GIS model. In the first step, accessible areas are mapped. These are defined as:

- Areas 10m either side of linear routes such as Public Rights of Way, pavements and Sustrans routes.
- Publicly accessible areas such as country parks, CRoW access land, local nature reserves and accessible woodlands.
- Areas of green infrastructure marked as accessible, including parks, playgrounds, and other amenity greenspaces.

These areas were then scored for their perceived level of naturalness, with scores taken from the scientific literature. Naturalness was scored in a 300m radius around each point, representing the visitors experience within a short walk of each point.

The resulting map shows accessible areas, with high values representing areas where habitats have a higher perceived naturalness score. Scores are on a 1 to 100 scale, relative to values present within the study area. White space shows built areas or areas with no public access.

Larger continuous blocks of more natural habitat types will have higher scores than smaller isolated sites of the same habitat type. One consequence is that linear routes, such as footpaths, that pass through land with no other access will not score highly.

Results for Bedfordshire

Figure 23 shows accessible nature capacity for publicly accessible land only. Accessible nature capacity is highest in Aspley Heath, Maulden Wood, Potton Wood, Fenlake, Knotting Green, Stewartby Lake / Millennium Country Park, and Priory County Park.

Accessible nature capacity is moderate around the outskirts of major urban centres, especially Bedford and Luton, which has a number of accessible greenspaces nearby. Access is lowest in more rural areas in the northern and eastern part of the county, where public footpaths provide the only access in predominantly agricultural areas.

Accessible nature capacity

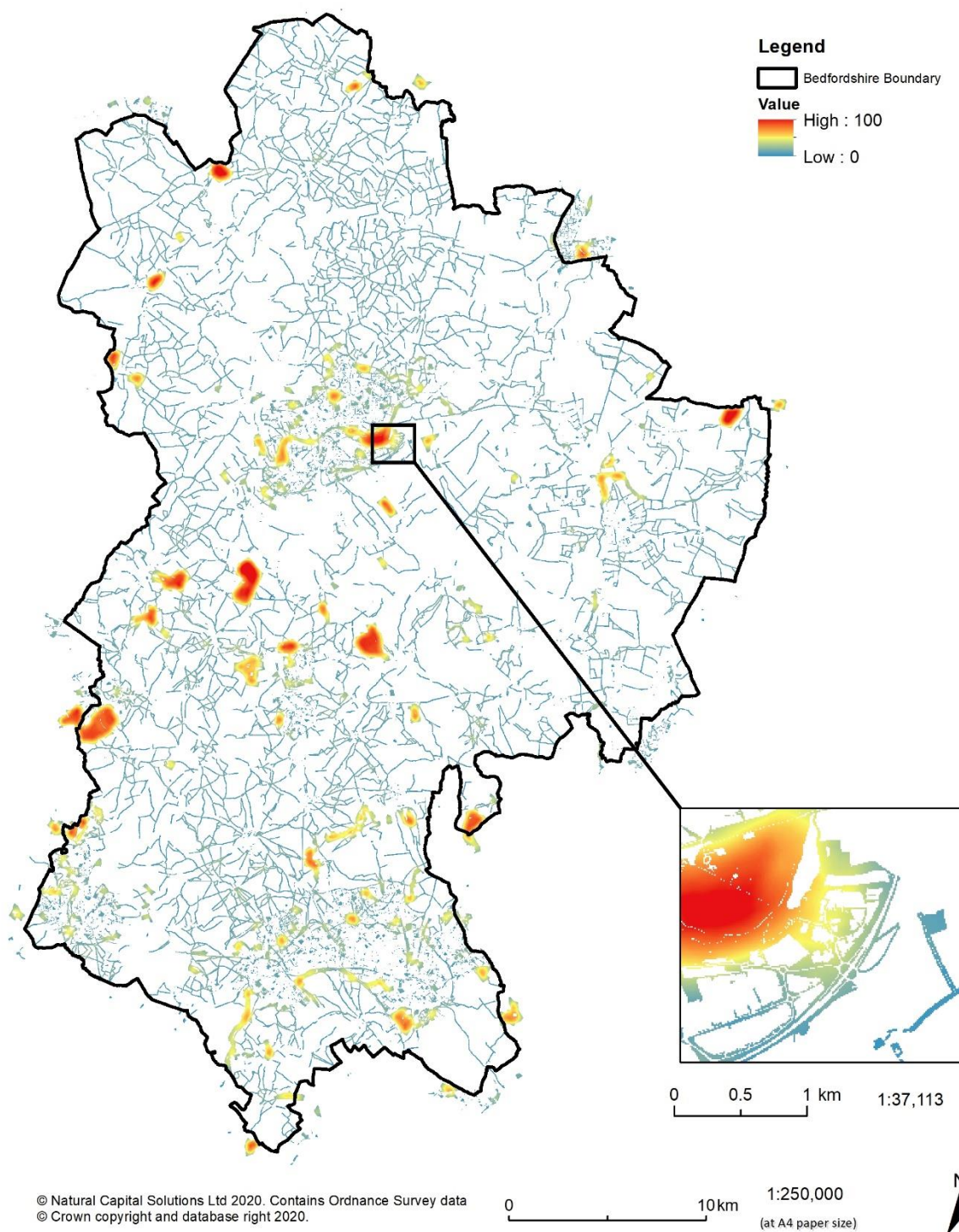


Figure 23 Accessible nature capacity across Bedfordshire. Areas with zero capacity have been excluded to improve map legibility.

4.14 Accessible nature demand

What is it and why is it important?

This indicates where there is greatest demand for accessible nature, which is strongly related to where people live. Research, including large surveys such as the Monitor of Engagement with the Natural Environment (MENE), have shown that there is greatest demand for accessible greenspace close to people's homes, especially for sites within walking distance.

How is it measured?

This model maps sources of demand, taking no account of habitat, based on three indicators: population density (based on 2011 census data), health scores (from the Index of Multiple Deprivation), and distance to footpaths and access points. The three indicators are calculated at three different scales as demand is strongly related to distance. The Monitor of Engagement with the Natural Environment (MENE) survey and other literature on visit distance was used to determine appropriate distances. The distances chosen (and rationale) were: 600m (10 minutes walking distance), 3.2 Km (67% of all visits and 90% of visits by foot occur within this distance), and 16 Km (90% of all visits travelled less than this distance).

The three indicators were normalised from 0-1, then combined with equal weighting at each scale and then the three different scales of analysis were combined and projected on a 0 to 100 scale. High values (red) indicate areas (sources) that generate the greatest demand for accessible nature.

Results for Bedfordshire

Demand for accessible nature (see Figure 24) is focussed around where people live, hence Bedford and Luton provide the largest demand across the county. There is also significant demand from the numerous other urban areas across the county, with lowest demand in the north and east.

Balancing supply and demand for accessible nature

Numerous researchers have shown that people travel most frequently to greenspaces very close to their homes and Natural England recommend that everyone should have access to at least some greenspace within 300m (5 minutes walk) and larger sites within 2 km. Furthermore, surveys have shown that the majority of people will typically travel less than 3.2 km to visit greenspace. Any new accessible greenspace being created should therefore be close to housing areas. New housing areas will also create increased demand for accessible greenspace, so it is important that this demand is met on-site.

There is now a vast amount of evidence showing the benefits of greenspace, particularly in built-up areas. Furthermore, research has shown that people gain greater well-being from visiting sites that they perceive to be more natural and richer in biodiversity. This shows that as well as providing access to greenspace, it is important that the greenspace is of a high quality and as natural as possible.

Accessible nature demand

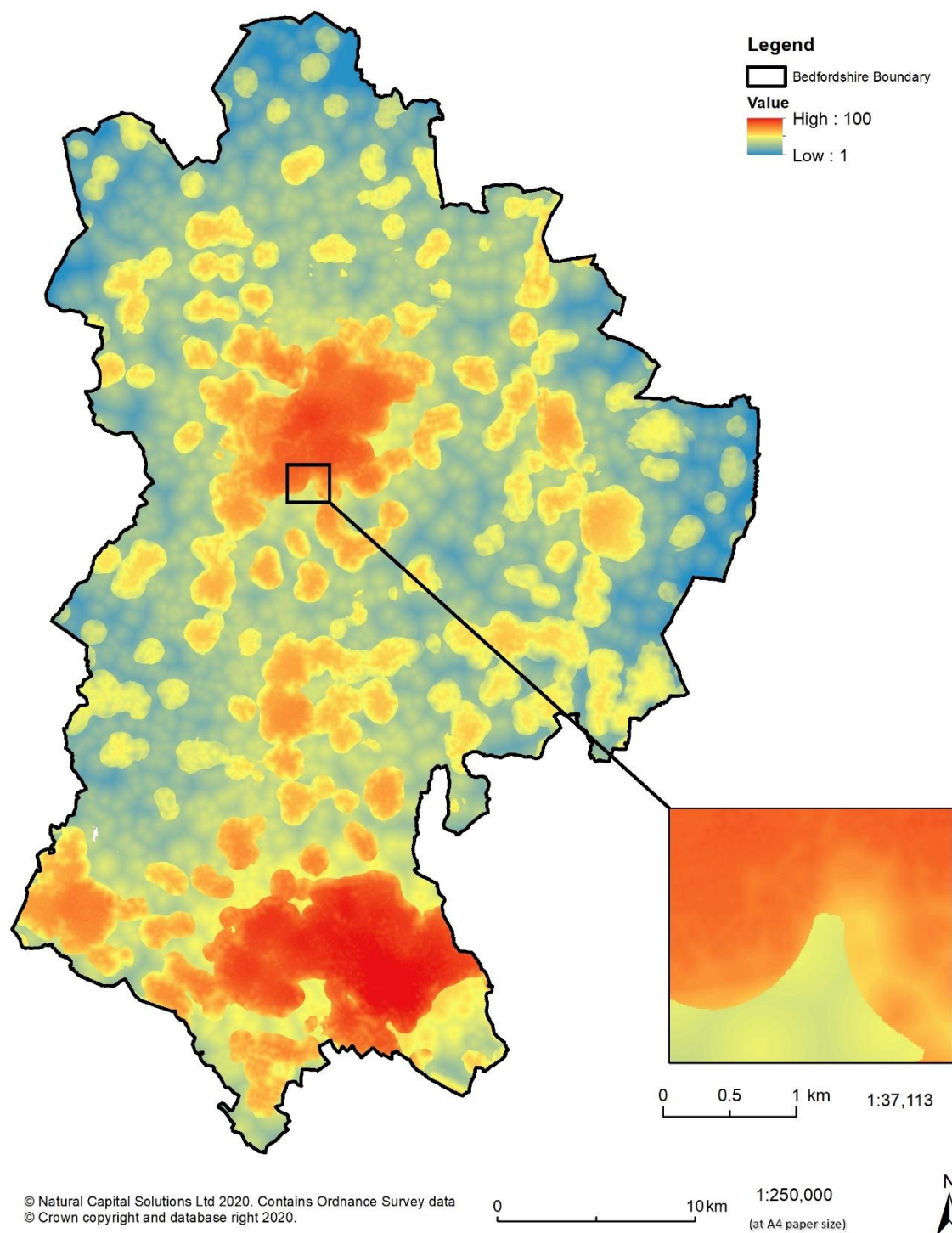


Figure 24 Accessible nature demand across Bedfordshire.

5. Baseline ecosystem service valuation (monetary flows)

We estimated the annual monetary flow of the following ecosystem services: air quality regulation, carbon sequestration, GHG emissions from agriculture, recreation, physical health, agricultural production and timber production. Table 3 outlines the indicators used to quantify both the physical and monetary flows of these services.

Table 3 Ecosystem services and indicators for physical and monetary measurement.

Ecosystem service	Physical flow	Valuation
Air quality regulation	Tonnes of PM _{2.5} and SO ₂ absorbed	Costs avoided £/tonne of PM _{2.5} and SO ₂ /year
Carbon sequestration	Quantity of CO ₂ sequestered	£/tonne of CO ₂
Greenhouse gas emissions from agriculture	GHG/ha	£/ha/year
Recreation	Number of visits	Welfare value/visit/year
Physical health	Active visits	£/QUALY/year
Agricultural production	ha	£/ha/year
Timber/woodfuel production	m ³ /ha	£/m ³ /year

Annual monetary flows of ecosystem services have been calculated based on the latest valuation techniques available in the scientific literature and approaches adopted by the Office for National Statistics (ONS 2017¹³), and recent Defra guidance to standardise approaches to the valuation of ecosystem services¹⁴. The physical and monetary flows of the ecosystem services are presented below for Bedfordshire as a whole. The methods used to calculate these are described in more detail in the Technical Appendix at the end of the report (Annex 2).

Vegetation can be effective at contributing to **air quality regulation**, with surface area being the most important determinant of capacity. Trees are much more effective than grass at this, and capacity increases significantly as trees grow and their surface area increases. The woodland and grass vegetation across Bedfordshire is estimated to absorb 878 tonnes of PM_{2.5} (particulate matter 2.5 micrometres or less in diameter) annually, at an annual value of £90.4 million with a present value (over 50 years) of £3.3 billion (Tables 4 & 5).

¹³ ONS (2017) Principles of Natural Capital Accounting. Office for National Statistics

¹⁴ Defra (2020). [Enabling a Natural Capital Approach \(ENCA\)](#).

Carbon sequestration is the uptake of carbon by plants as they grow, with woodlands being much the most effective habitat at this in Bedfordshire. In total, the average annual carbon sequestration in Bedfordshire is of 79,950 tonnes of carbon per year (tCO₂e) at an annual value of £5.5 million and a present value (over 50 years) of £323 million. The overall carbon budget is simply the balance between greenhouse gas emissions from the land and carbon sequestration from woodland. The greenhouse gas balance reported here represents the agriculture and land use, land use change and forestry (LULUCF) sectors for which national emissions information is collected. Overall, **agricultural GHG emissions** outweigh carbon sequestration within Bedfordshire as agriculture emits 113,000 tCO₂e per year, at a **cost** of £7.8 million annually, and a present value of £457 million (Table 4). Therefore, land use and agriculture across Bedfordshire produces net emissions of approximately 33,000 tCO₂e per year. To move towards net zero (assuming no changes in agriculture) would require the planting of approximately 3,750 ha of broadleaved woodland, occupying about 3.0% of the land area of Bedfordshire. Note that soil and vegetation also act as a **stock of carbon**, currently storing 10.58 M tonnes of carbon. As a stock, we do not place a monetary value on this, but if habits were changed, over time this would change the stock of carbon and this change of stock can be valued.

Table 4 Annual physical flows, annual monetary flows (2020, £M) and present value over 50 years (£M) of ecosystem services for Bedfordshire.

Ecosystem service	Annual physical flow	Annual monetary flow (£M)	Present value over 50 years (£M)
Air quality regulation	878	£90.4	£3,340
<i>tPM_{2.5}</i>			
Carbon sequestration	80,000	£5.54	£323
<i>tCO₂e</i>			
GHG emissions from agriculture	-113,000	-£7.83	-£457
<i>tCO₂e</i>			
Recreation	28,30,000	£84.3	£2,150
<i>Visits</i>			
Physical health	2120	£31.6	£1,170
<i>QALY</i>			
Agricultural production	83,100	£2.75	£70.2
<i>Hectares</i>			
Timber/woodfuel production	87,800	£1.61	£41.2
<i>m³</i>			
Total values:	NA	£208	£6,640

NB. Figures shown to 3 significant figures. Any discrepancies due to rounding.

The Bedfordshire region has high recreational value. Using the ORVal tool (see Technical Appendix) we were able to estimate the number of **recreational visits** made to publicly accessible greenspaces in Bedfordshire (Table 4). Across the Bedfordshire region there are an estimated 28.3M recreational visits per year. The same tool estimates the welfare value derived from these visits, and these are valued at £84.3 million annually, with a present value (over 50 years) of £2.15 billion. A subset of these visitors will also receive **physical health benefits** through making regular active visits that meet national physical activity guidelines (20 minutes of moderate intensity exercise every day). It is estimated that there are 62,100 active visitors every year to publicly accessible greenspaces in Bedfordshire, which is equivalent

to 2,120 Quality Adjusted Life Years (QALY). This delivers an annual value of £31.6 million, and a present value of £1.2 billion (Table 4).

The total area of land in **agricultural production** in Bedfordshire is 83,115 ha (Table 4). This is predominantly arable (69,739 ha), with 13,376 ha improved and rough grasslands for grazing livestock (mainly cattle). This produces an annual gross margin of £53.8 million averaged over the last 5 years. However, when all costs and subsidies (including the Basic Payment Scheme) are excluded, the annual value of agricultural production in the Bedfordshire region is only £2.75 million, with a present value (over 50 years) of £70.2 million.

We have also looked at the woodland asset from a **timber and woodfuel** production perspective. This does not mean that the woodland is necessarily being harvested for these purposes, rather it is another way of exploring the value of woodland in the region. If the woodlands in Bedfordshire were to be managed for timber and woodfuel production, they would be able to produce approximately 87,800 m³ per year under their current management and averaged over a full woodland production cycle (Table 4). This has an annual value of £1.61 million, and a present value of £41.2 million (Table 4).

In total, the value of the benefits delivered by the natural capital assets that we quantified across Bedfordshire is £208.3 million annually, with a present value of £6.64 billion over 50 years. The values were also calculated separately for each of the three local Authorities and these results are shown in Table 5 (below). Results are reasonably similar for Bedford Borough and Central Bedfordshire. Being almost entirely urban, Luton has lower values for many of the services, but the value of recreation and physical health benefits are still high. When the results are re-calculated on a per hectare basis (Table 6), the per hectare values are actually considerably higher in Luton than elsewhere.

Table 5 Annual monetary flows (2020) of ecosystem services, showing the values for each of the Local Authorities in Bedfordshire.

Ecosystem service	Annual monetary flow (£)			
	Luton	Beds Borough	Central Beds	Full region
Air quality regulation	3.41 M	44.1 M	42.8 M	90.4 M
Carbon sequestration	90,000	1.77 M	3.68 M	5.54 M
GHG emissions from agriculture	-29,000	-3.24 M	-4.55 M	-7.83 M
Recreation	17.3 M	26.7 M	40.3 M	84.3 M
Physical health	6.42 M	9.65 M	15.5 M	31.6 M
Agricultural production	10,000	1.14 M	1.60 M	2.75 M
Timber/woodfuel production	20,000	0.459 M	1.13 M	1.61 M
Total value:	27.2 M	80.6 M	100 M	208 M

Table 6 Annual monetary flows (2020) per hectare for each Local Authority.

Ecosystem service	Annual monetary flow (£ per ha)			
	Luton	Beds Borough	Central Beds	Full region
Area / ha	4,335	47,641	71,553	123,529
Air quality regulation	787	926	598	732
Carbon sequestration	21	37	51	45
GHG emissions from agriculture	-7	-68	-64	-63
Recreation	3,990	560	563	682
Physical health	1,480	203	217	256
Agricultural production	2	24	22	22
Timber/woodfuel production	5	10	16	13
Total value:	6,274	1,692	1,398	1,684

5.1 Sensitivity analysis

A sensitivity analysis examined the low, central and high estimates of all the benefits we valued (Table 7). This demonstrates the overall sensitivity of the natural capital values. The overall natural capital value ranges from a present value (over 50 years) of £2.9 billion under the lowest benefits estimates up to £17.9 billion under the highest benefits estimates. This large difference highlights the challenges of placing a monetary value on some services. A key point, however, is that even under the low benefit estimate, the natural capital assets of the region will deliver a substantial benefit worth at least £97.9 million annually, which is £2.9 billion in present value terms.

Table 7 Sensitivity analysis showing low, central and high estimates of the benefits provided by the natural capital assets of Bedfordshire.

Ecosystem service	Annual values (2020)			Present value (over 50 years)		
	(£M)			(£M)		
	Low	Central	High	Low	Central	High
Air quality regulation	19.3	90.4	277	714	3,340	10,300
Carbon sequestration	2.77	5.54	8.31	154	323	492
GHG emissions from agriculture	-3.91	-7.83	-11.7	-218	-457	-695
Recreation	63.2	84.3	105	1,610	2,150	2,690
Physical health	15.9	31.6	127	587	1,170	4,700
Agricultural production	-0.567	2.75	14.5	-14.5	70.2	371
Timber/woodfuel production	1.21	1.61	2.02	30.9	41.1	51.4
Total value:	97.9	208	523	2,870	6,640	17,900

NB. Figures shown to 3 significant figures. Any discrepancies due to rounding.

This analysis shows the high levels of uncertainty inherent in valuing ecosystem service benefits. Valuation of ecosystem services should be seen as appropriate at indicating the approximate magnitude of benefits, but not their exact values. It has allowed the comparison of values for a broad suite of services to be compared across Bedfordshire. It also demonstrates the range of benefits that the natural environment can provide. However, these results need to be interpreted with care, and in the knowledge that whilst the highest quality and most readily available data and methods were used, there are limitations and assumptions that need to be borne in mind.

Work is progressing rapidly on the calculation of physical and monetary flows of ecosystem services from natural capital assets, but it remains a developing area. A number of ecosystem services remain difficult to quantify and value. Some are highly location specific, for example water flow and impact on downstream flood risk. This can be quantified and valued by running detailed hydrological and flood risk modelling, but it is difficult to generalise. Others, such as water quality can be modelled, but are very difficult to value, while there are additional cultural services, such as aesthetic experiences, cultural heritage, spiritual experience and sense of place that are difficult to even quantify. It should, therefore, be borne in mind that the valuations presented in this section place values on several key benefits, but these are necessarily incomplete.

Table 8 Summary of uncertainties in the calculation of physical flows and monetary values of each natural capital benefit, and an overall assessment of confidence, using a red, amber, green (RAG) rating.

Natural capital benefits	Assessment of uncertainties	RAG rating
Air quality regulation	Biophysical estimates based on averages for broadleaved and coniferous trees and grassland. Valuation follows ONS guidance.	
Carbon sequestration	Well studied. standardised carbon lookup tables available. Valuation uses UK Government non-traded carbon price.	
Agricultural emissions	Receiving increasing attention as part of climate change accounting. Valuation uses UK Government non-traded carbon price.	
Recreation	Welfare values from a welfare function model from the ORVal tool. This is a good model and based on a travel cost method. but it is nonetheless a model.	
Physical health	The most uncertain of the services measured. High uncertainty over who would make frequent and active visits to the green spaces and the monetary value of these benefits.	
Agricultural production	Based on extensive data collected by Defra annually and market prices.	
Timber production	Well studied over many years as part of forestry management. Valuation uses market prices.	

For the services that have been included here, a range of assumptions have been made, and these are outlined when describing the methodology (see Technical Appendix in Annex 2). In addition, a summary of the main uncertainties is provided for each service in Table 8 (above), along with a RAG rating highlighting the overall confidence in each estimate. For most ecosystem services these assumptions are minimal, as established production functions exist linking natural capital to ecosystem service production, and levels of production to monetary value. For some services, despite fast developing research in relevant areas, broad assumptions have to be made because these links are not clear. This is particularly the case for physical health, and this estimate should, therefore, be used with care.

6. Accessible natural greenspace

6.1. Introduction

Accessible greenspaces are “Places that are available for the general public to use free of charge and without time restrictions (although some sites may be closed to the public overnight and there may be fees for parking a vehicle)”¹⁵. Natural greenspaces are “Places where human control and activities are not intensive so that a feeling of naturalness is allowed to predominate”¹³. Accessible natural greenspace allows people to connect with nature, improves mental and physical wellbeing, strengthens social bonds and promotes sustainable communities, increases air quality and biodiversity, and reduces flood risk, heatwaves and noise pollution¹⁶.

We assessed access to natural greenspace within Bedfordshire using Natural England’s Accessible Natural Greenspace Standards (ANGSt). These standards stipulate that everyone should have an accessible natural greenspace:

- Of at least 2 ha in size, no more than 300 m from home.
- At least one accessible 20 ha site within 2 km of home.
- One accessible 100 ha site within 5 km of home.
- One accessible 500 ha site within 10 km of home.

Accessible natural greenspaces within and just outside Bedfordshire were identified in conjunction with each of the three local authorities. Initially, the OS Mastermap Greenspace layer and the OS Open Greenspace layer were used, but this proved to be highly inaccurate. A layer was therefore created based on open space data supplied by each of the LAs, combined with layers showing Forest of Marston Vale sites, Bedfordshire Wildlife Trust accessible sites, Accessible woodlands, CROW (Countryside and Rights of Way Act) land, Local Nature Reserves, accessible wildlife sites, along with notes from project partners. The combined layer was then extensively checked by project partners in each LA area to create the final accessible greenspace layer that formed the basis of our ANGSt analysis.

Adjacent sites were merged, and buffers were then created around each of the accessible sites, based on the threshold and distances outlined above. Then, using Ordnance Survey MasterMap residential polygons, household population data and Index of Multiple Deprivation (IMD) data, we calculated:

- The number and percentage of Bedfordshire residents that met ANGSt criteria.
- The average level of deprivation (based on IMD scores) for areas that met and did not meet the different ANGSt criteria.

6.2. Accessible natural greenspace in Bedfordshire

Figure 25 displays the accessible natural greenspace within or just outside Bedfordshire. This amounts to an area of 5,738 ha spread across 566 sites, with 5,123 ha lying within Bedfordshire and 615 ha lying just outside the Bedfordshire boundary.

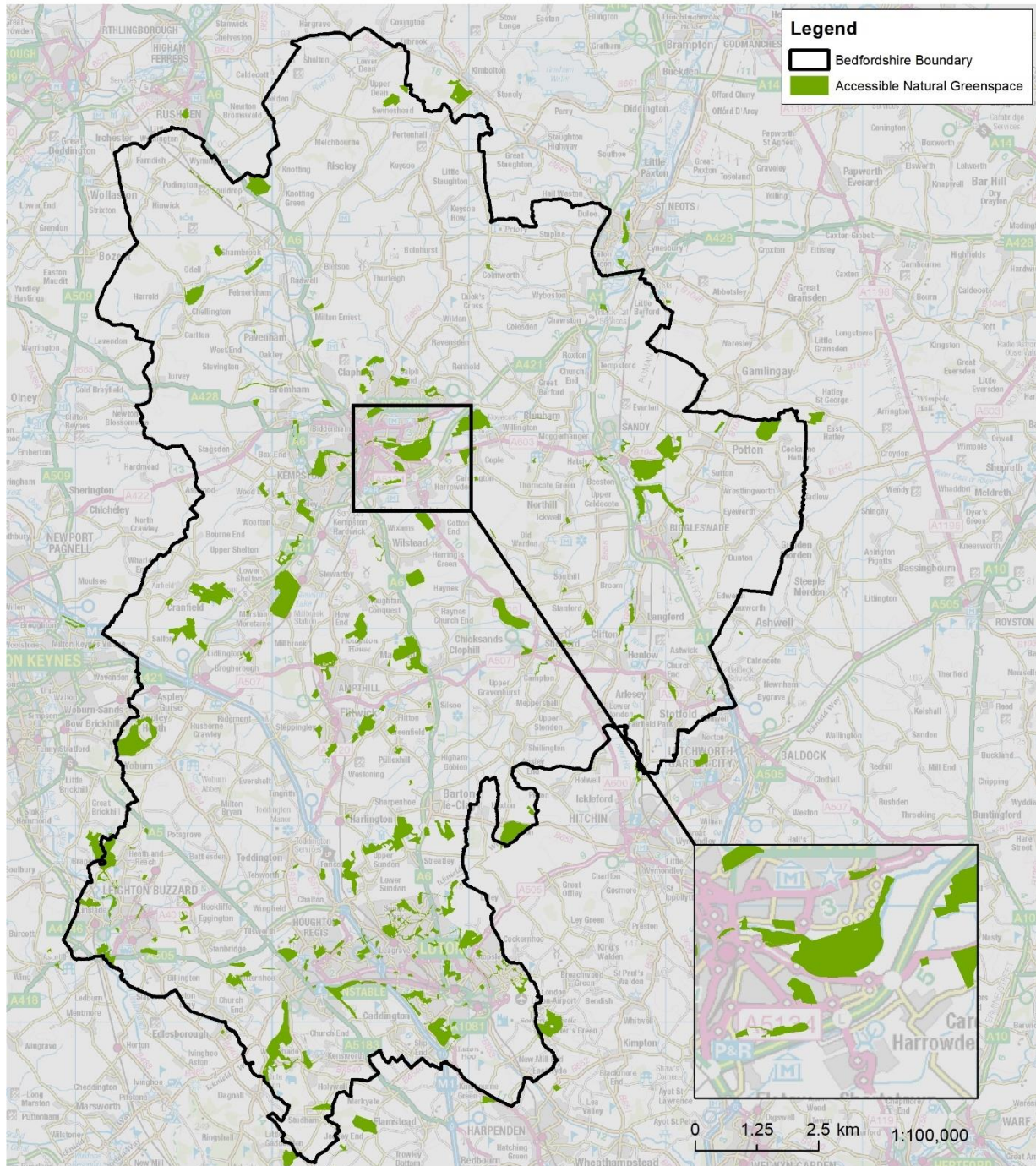
¹⁵ Natural England (2010). ‘Nature Nearby’: Accessible Natural Greenspace Guidance. Natural England

¹⁶ Public Health England (2020). Improving access to greenspace: A new review for 2020. Public Health England



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Accessible natural greenspace



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Figure 25 Accessible natural greenspace within and just outside Bedfordshire.

Accessible natural greenspace buffers

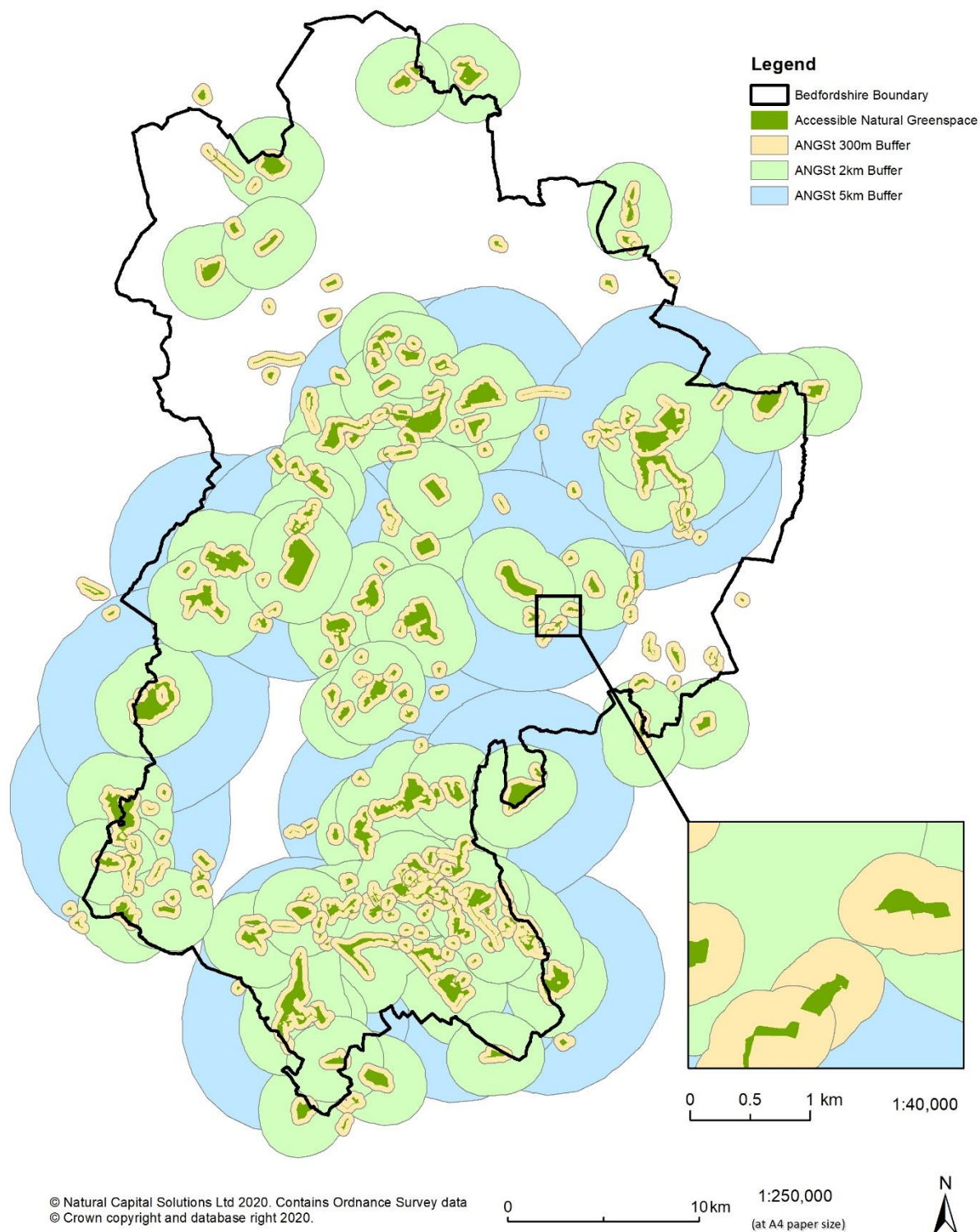


Figure 26 The buffers used during ANGSt analysis

In total, 281 of the 566 accessible natural greenspace sites were at least 2 ha in size (amounting to an area of 5,567 ha). The largest accessible natural greenspace site was 235 ha. Figure 26 displays the buffers used during the ANGSt analysis. Only 42.01% of Bedfordshire residents live within 300m of accessible natural greenspace ≥ 2 hectares in size (see Table 9). However, 86.3% of Bedfordshire residents live within 2 km of accessible natural greenspace ≥ 20 hectares in size and 90.9% of Bedfordshire residents live within 5 km of accessible natural greenspace ≥ 100 hectares in size. Unfortunately, there are no accessible greenspace sites ≥ 500 hectares in size within 10 km of Bedfordshire residents. There are also a small percentage (5.93%) of Bedfordshire residents who fall outside all of the ANGSt criteria. Finally, areas that failed the ANGSt criteria tended to be less deprived than areas that passed, indicating that most of these areas were rural locations where deprivation is generally lower.

Table 9 The number and percentage of residents within Bedfordshire and its three local authorities passing or failing each of Accessible Natural Greenspace Standards (ANGSt). Also shown are the mean IMD scores for those areas within Bedfordshire that pass or fail Accessible Natural Greenspace Standards (ANGSt). Higher IMD scores are indicative of higher levels of deprivation.

ANGSt	Area	No Residents		% Residents		Mean IMD score	
		Pass	Fail	Pass	Fail	Pass	Fail
Within 300m of ≥ 2 ha site	Bedfordshire	279,116	385,331	42.0	58.0	17.9	14.0
Within 2km of ≥ 20 ha site		573,223	91,224	86.3	13.7	16.8	8.9
Within 5km of ≥ 100 ha site		603,865	60,582	90.9	9.1	16.4	8.6
Meets at least one access to greenspace standard		625,069	39,378	94.1	5.9	16.1	9.3
Within 300m of ≥ 2 ha site	Bedford Borough	56,295	120,101	31.9	68.1	17.5	14.8
Within 2km of ≥ 20 ha site		144,313	32,083	81.8	18.2	16.8	10.6
Within 5km of ≥ 100 ha site		148,198	28,198	84.0	16.0	16.7	10.1
Meets at least one access to greenspace standard		157,638	18,758	89.4	10.6	16.2	11.1
Within 300m of ≥ 2 ha site	Central Bedfordshire	90,548	201,825	31.0	69.0	10.7	10.3
Within 2km of ≥ 20 ha site		233,233	59,140	79.8	20.2	11.0	8.1
Within 5km of ≥ 100 ha site		259,990	32,384	88.9	11.1	10.8	7.2
Meets at least one access to greenspace standard		271,754	20,619	93.0	7.0	10.6	7.6
Within 300m of ≥ 2 ha site	Luton	132,273	63,404	67.6	32.4	23.6	26.9
Within 2km of ≥ 20 ha site		195,677	0	100	0	24.6	0
Within 5km of ≥ 100 ha site		195,677	0	100	0	24.6	0
Meets at least one access to greenspace standard		195,677	0	100	0	24.6	0

7. Habitat opportunity mapping

7.1 Introduction

Habitat opportunity mapping is a Geographic Information System (GIS) based approach used to identify potential areas for the expansion of key habitats. It aims to identify possible locations where new habitat can be created that will be able to deliver particular benefits, whilst taking constraints (such as existing land uses or historic sites) into account. In this project, opportunities for new habitats across a range of different benefits have been mapped. This has included mapping opportunities for the following:

- 1) To enhance biodiversity
- 2) To reduce surface runoff
- 3) To reduce soil erosion and improve water quality
- 4) To ameliorate air pollution
- 5) To reduce noise pollution
- 6) To regulate local climate (reduce urban heat)
- 7) To increase access to natural greenspace

The approach taken, and results obtained for each of these potential services are described in turn below. Maps have also been combined to show areas that could deliver multiple benefits, and this is described in Section 8.

Please note that the mapping identifies areas based on landscape-scale ecological principles or indicative ecosystem services models and does not take into account local site-based factors that may impact on suitability. Any areas suggested for habitat creation will require ground-truthing before implementation. The maps should be seen as a tool to highlight key locations and to guide decision making, rather than an end in themselves. Further steps are highlighted at the end of this report (Section 9), which would move towards identifying specific projects to take forward.

7.2 Opportunity mapping for biodiversity enhancement

The importance of landscape-scale conservation and ecological networks has become increasingly recognised over recent years. Many wildlife sites have become isolated in a landscape of unsuitable habitats and efforts are now being directed towards linking existing habitat patches and increasing connectivity. Species are more likely to survive in larger habitat networks, are able to move and colonise new sites, and are more resilient to climate change and other detrimental impacts.

Habitat opportunity mapping to enhance biodiversity follows this ethos by using ecological networks to identify potential areas for new habitats. Identified areas will be ecologically connected to existing habitats, thereby expanding the size of the existing network, increasing connectivity and resilience, and potentially increasing the ecological quality of the new site. It was performed for three key habitat groupings, incorporating the main semi-natural habitats found in Bedfordshire. The broad habitats and their constituent types are shown in the table overleaf:

Broad habitat	Specific habitats included
Semi-natural grassland	Acid, neutral, calcareous, rough and semi-improved grasslands
Wet grassland & wetlands	Marshy grassland, floodplain grazing marsh, lowland fen and swamp (reedbed)
Woodland	Broadleaved and mixed woodland types (excludes coniferous woodland, parkland or individual trees)

Note that it would also be possible to map opportunities for heathland creation, but we did not do so on this occasion as heathland is significantly under-represented in the basemap, hence any opportunity map produced would be misleading and would miss a number of key opportunities. It is recommended that a heathland opportunity map is produced following an update of the basemap.

Biodiversity opportunity mapping followed a four-step process, as explained below, and was based on the approach developed by Catchpole (2006)¹⁷ and Watts et al. (2010)¹⁸. Note that opportunity areas for the three broad habitats often overlap, and no attempt has been made to ascertain the most suitable habitat at a particular location.

7.2.1 Method

1. *Landscape permeability*

This step involves assessing the permeability of the landscape to typical species from each habitat type and builds on work carried out by JNCC, Forest Research and others. Generic focal species are assessed for each habitat type as there is a lack of ecological knowledge to be able to repeat the process for multiple different individual species, and generic species provide an average assessment for species typical of each habitat type.

It is assumed that a species will have optimal dispersal capabilities in the habitat in which it is associated and hence the landscape is fully permeable if it consists only of this primary habitat. Each of the remaining habitat types is then assigned a permeability score that shows how likely and how far the species will travel through that habitat. Habitats are scored on a scale from 1 (most permeable) to 50 (least permeable). Permeability scores were based on expert scores compiled by JNCC and then adjusted by Natural Capital Solutions for Bedfordshire for each habitat type. Once tables had been compiled showing permeability scores for each habitat, high (10m) resolution maps were then produced using bespoke modelling, showing the permeability of the landscape for generic species from each broad habitat type.

2. *Habitat networks*

Step 2 uses the permeability map created above, along with information on average dispersal distances, to map which habitat patches are ecologically connected and which are ecologically isolated from each other. Dispersal distances were obtained from JNCC, which had performed a review of the scientific literature to ascertain the dispersal distances of a range of species for each habitat type. These were

¹⁷ Catchpole, R.D.J. (2006). Planning for Biodiversity – opportunity mapping and habitat networks in practice: a technical guide. *English Nature Research Reports*, No 687

¹⁸ Watts, K., Eycott, A.E., Handley, P., Ray, D., Humphrey, J.W. & Quine, C.P (2010). Targeting and evaluating biodiversity conservation action within fragmented landscapes: an approach based on generic focal species and least-cost networks. *Landscape Ecology*, 25: 1305–1318.

typically species of small mammals, smaller birds, butterflies, and plants. The average dispersal distance for each habitat is shown in the table below:

Dispersal distance in optimal habitat:	
Semi-natural grassland	2.0 km
Wet grassland & wetlands	2.0 km
Broadleaved and mixed woodland	3.0 km

3. *Identifying constraints*

The habitat network map created in Step 2 can be used to indicate where new habitat could be created; any habitat created within the existing network would be ecologically connected to existing patches. However, in reality a number of constraints exist that need to be taken into account when producing opportunity maps. The aim of this step, therefore, is to produce a series of maps of constraints that can be used to show where habitat cannot or should not be created. The following constraints were mapped and are shown on Figure 27 (overleaf):

- Land-use constraints – infrastructure (roads, railways, and paths), urban (all buildings), gardens, and water (standing and running), as it is highly unlikely that these would be available for habitat creation.
- High quality habitats – all existing habitats of high nature conservation interest were identified from the basemap (as described in Section 2.3), as it would not make sense to destroy existing high-quality habitat to create new habitat of a different type. A full list of these habitats is shown in Box 3 (below).
- Historic sites – data were obtained from Historic England on the location of Scheduled Monuments, Registered Parks and Gardens, and Registered Battlefields across the study area and a 30m buffer was applied around each individual site, as recommended by Historic England.
- National Grid gas pipelines, overhead lines and cables – data were obtained from the National Grid and a 10m buffer was applied around both features. This constraint was only applied when woodland opportunities were being mapped, as it would not be possible to plant trees in these areas, although grassland and wetland habitats would be feasible.
- For wet grassland and wetland habitats it was assumed that hydrology (wetness) would be a limiting factor. Therefore, habitat opportunity areas were restricted to areas within the indicative floodplain, as indicated by the Environment Agency's Flood Zone 2 map.

Box 3: High quality habitats

The following habitats were identified from the basemap and used as constraints:

- | | |
|---|----------------------------|
| • Broadleaved woodland | • Floodplain grazing marsh |
| • Mixed woodland | • Marshy grassland |
| • Woodland/scrub with semi-natural habitats | • Heathland |
| • Unimproved and semi-improved acid grassland | • Fen, marsh and swamp |
| • Unimproved and semi-improved neutral grassland | |
| • Unimproved and semi-improved calcareous grassland | |

Opportunity mapping constraints

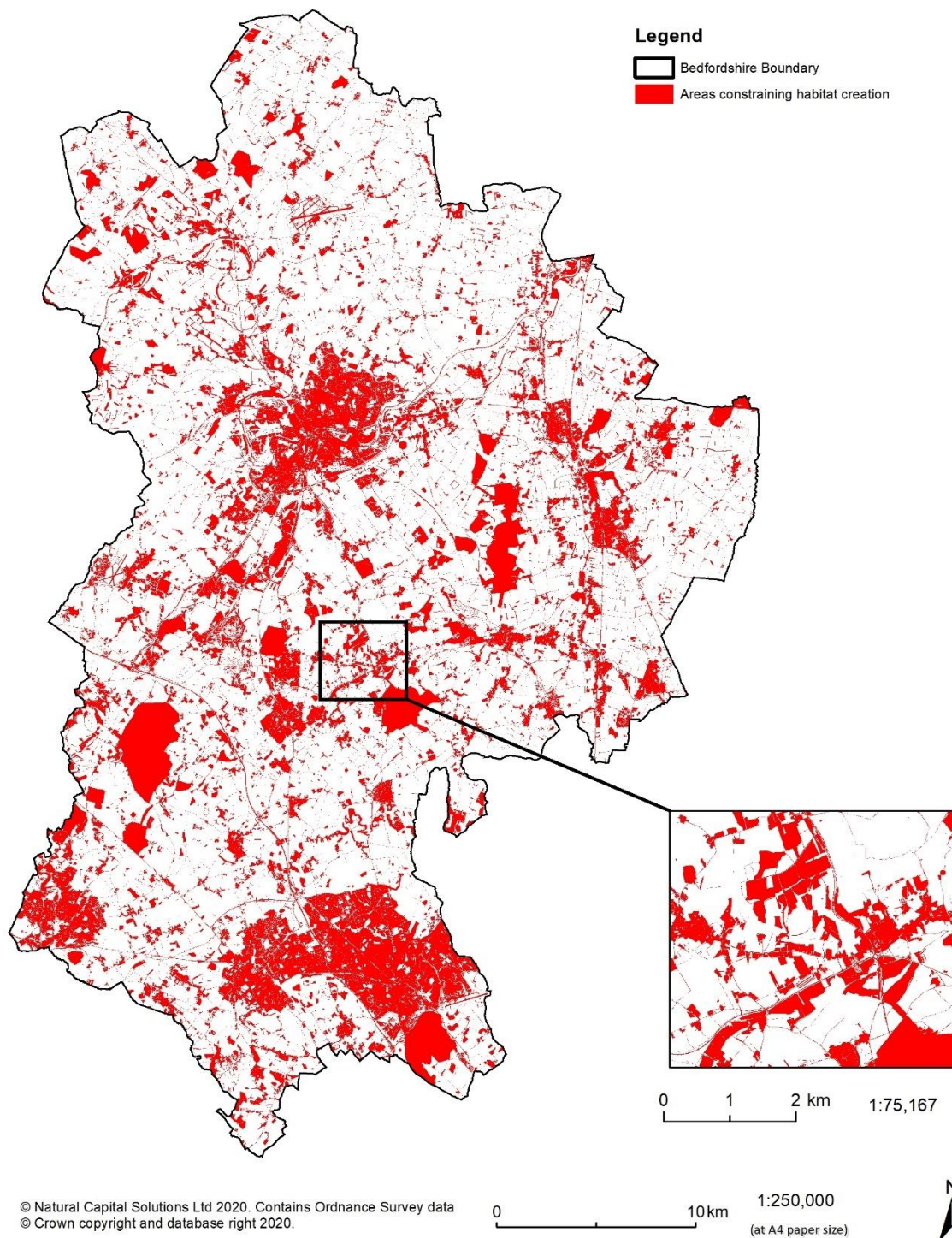


Figure 27 The areas of key constraints taken into account during habitat opportunity mapping across Bedfordshire.

Note that additional factors could be used as constraints, for example best and most versatile agricultural land (or the more stringent Grade 1 land). This was not applied as a constraint here as it would still be possible to create riparian buffer strips and similar small habitat enhancements in such areas, even if whole fields are not converted. Hence it was felt that agricultural land classification would work better as a factor to screen against when deciding on areas to take forward, rather than as a fixed constraint.

4. Habitat opportunity for biodiversity

In the next step, the constraints map was used to exclude areas that would be unsuitable or unavailable for new habitat. Two layers of habitat opportunity were then created:

- **Buffer opportunity** – this layer identified habitat opportunity areas that are immediately adjacent to existing habitat patches and fall within the previously identified ecological network.
- **Stepping-stone opportunity** – this layer identified potential sites that fall outside of the ecological network, but are immediately adjacent to it. These areas could potentially be used to create stepping-stone habitats that could link up more distant habitat patches.

For both opportunity layers, a minimum threshold size was set at 0.1 ha, to remove tiny fragments of land and to replicate the minimum sizes of habitat creation grant schemes.

As the above map identifies portions of land in relation to the ecological network for each habitat, it often results in thin slivers of land being identified adjacent to existing habitats, which bear no relationship to existing fields and boundaries. As habitat creation or restoration projects usually operate on whole fields, an additional step was taken to identify those fields that present buffer opportunities. To do this, the buffer layer was overlain over the basemap to identify whole fields that are immediately adjacent to existing habitat patches and are not constrained by the factors described in Step 3. Parts of these fields fall within the previously identified ecological network and creating new habitat will extend the network. To remove spurious results where only a tiny fraction of a field fell within a buffer zone, fields where less than 10% of the whole field overlapped with the buffer zone were removed. In the same way, the stepping stone layer was also overlain to identify whole fields that fall outside of the ecological network, but are immediately adjacent to it.

7.2.2 Results

The results are illustrated here for semi-natural grassland habitats, with the broadleaved and mixed woodland, and wet grassland and wetland maps following in Annex 1. The inset map shown on each map page is included to show more clearly the detail of each layer, although the location chosen is not significant.

The permeability of the landscape for typical semi-natural grassland species is shown on Figure 28. Darker areas are more permeable, meaning that typical species are expected to travel further across these habitats and hence will be less of a barrier to movement. For all three broad habitat types, arable fields are the most significant barrier to movement. Buildings and infrastructure are also significant barriers, but gardens and greenspaces help to make urban areas less impermeable.

The habitat network map for semi-natural grassland is shown on Figure 29. Habitats that are ecologically connected are linked within a network shown in grey. White space between habitat patches indicate that the patches are not ecologically connected and dispersal between the patches is less likely to occur.

Semi-natural grasslands are evenly dispersed across Bedfordshire (Figure 29). However, although a number of these patches are ecologically connected into a network, many patches remain disconnected, although there is good opportunity to enhance connectivity through habitat creation (see below). A few other moderately large patches exist in the south-west and east of the county, with other smaller patches spread across the area. Broadleaved and mixed woodland habitat networks (Figure A2) are concentrated in the north and across the centre of Bedfordshire, along the Yardley Whittlewood Ridge and the Greensand Ridge, where a number of patches are ecologically connected. Woodland in the rest of the county is much more ecologically isolated. Wet grassland and wetland habitat networks (Figure A6) are much less significant in Bedfordshire, with only a few small and ecologically isolated habitat patches.

Once constraints have been removed, the resulting maps show biodiversity opportunity areas. Figures 30 and 31 illustrates these for semi-natural grassland habitats, with the other habitats in Annex 1. Figure 30 shows the opportunity zones as buffers around existing sites, while Figure 31 highlights whole fields where habitats could be created, as these are a more meaningful management unit for conservation action. There are multiple areas in the south-west and east of Bedfordshire around the previously identified habitat network where semi-natural grassland could be created to considerably enlarge and connect existing networks, along with smaller opportunities scattered throughout the rest of Bedfordshire. Broadleaved and mixed woodland opportunities (Figure A4) exist throughout the study area, although with particular density in the north and centre, where field-scale habitat creation could increase the connections between woodland patches, or connect more isolated fragments to create a more resilient network. For wet grassland and wetlands (Figure A8), opportunities are much more limited and are mostly focussed on expanding existing habitat patches.

Please note that in many places the biodiversity opportunity maps overlap, hence a piece of land may have been identified as being potentially suitable for habitat creation for two, or even all three, different habitat types. This occurs where existing areas of the three habitat types are in close proximity to each other. This issue can be addressed by setting priorities for habitats to take forward in different locations (see Section 9.1).



Landscape permeability for typical semi-natural grassland species

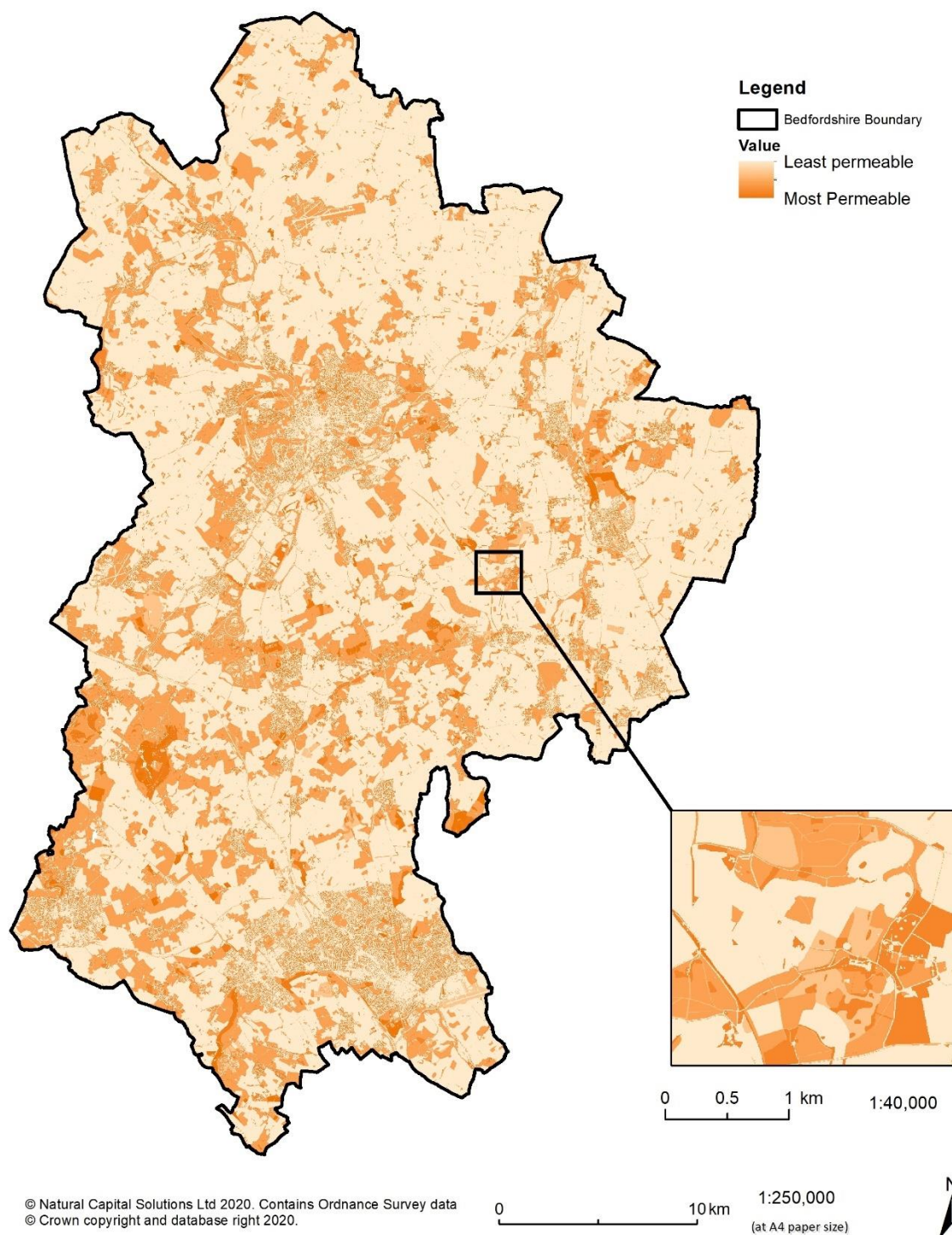
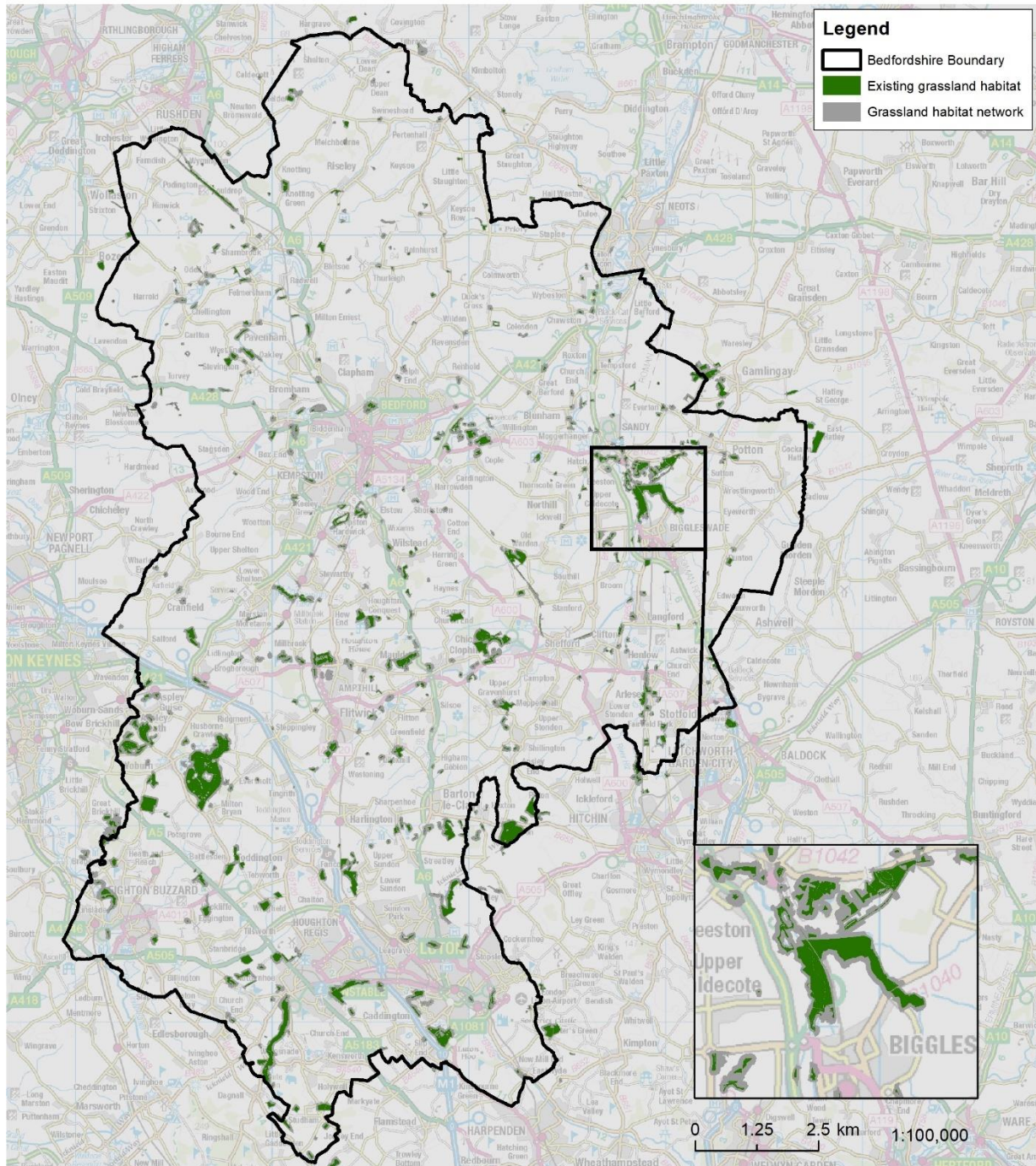


Figure 28 Landscape permeability for typical semi-natural grassland species across Bedfordshire.



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Semi-natural grassland habitat network



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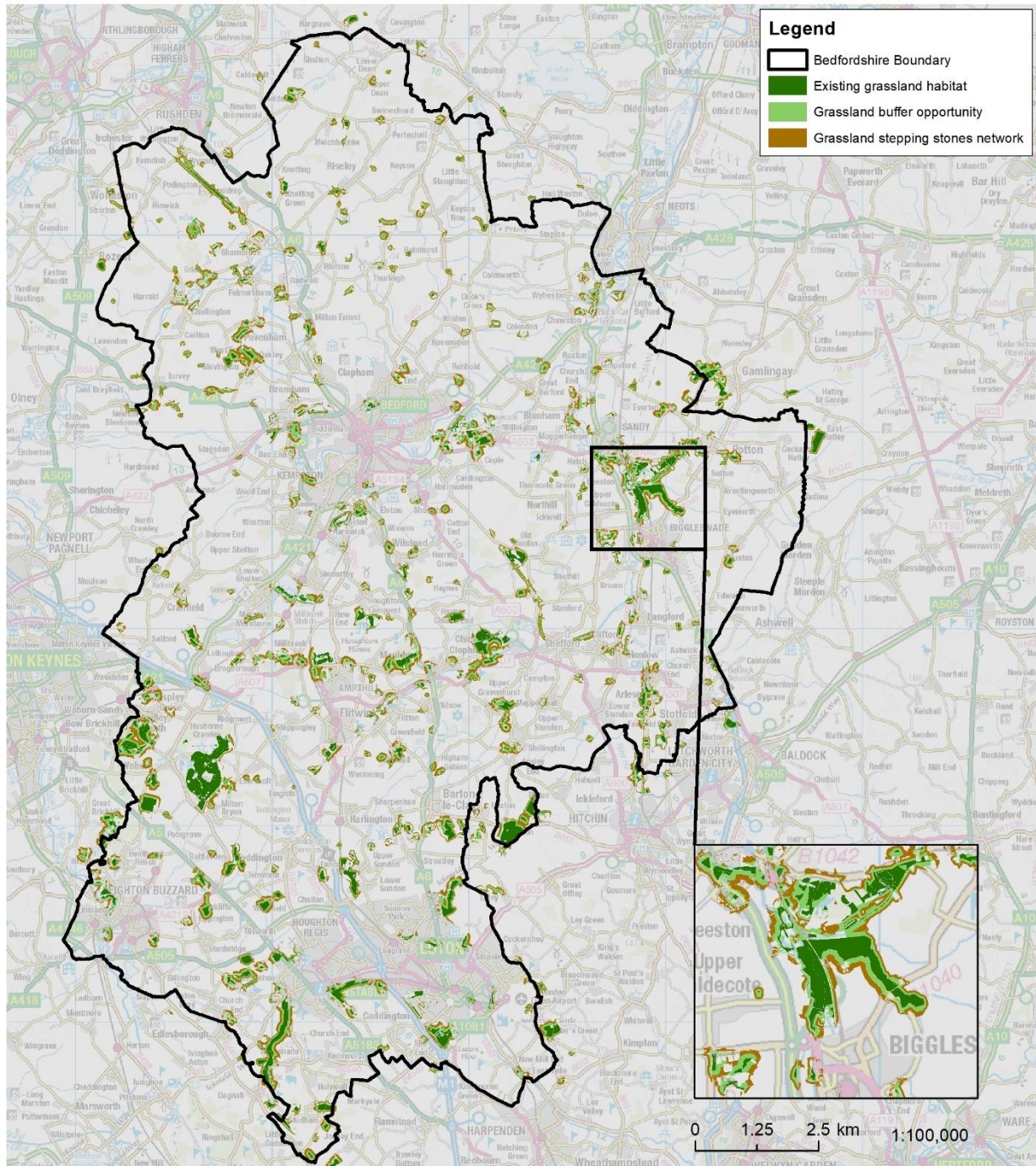
0 10 km

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Figure 29 Habitat network for semi-natural grasslands across Bedfordshire.

Semi-natural grassland habitat opportunity 1



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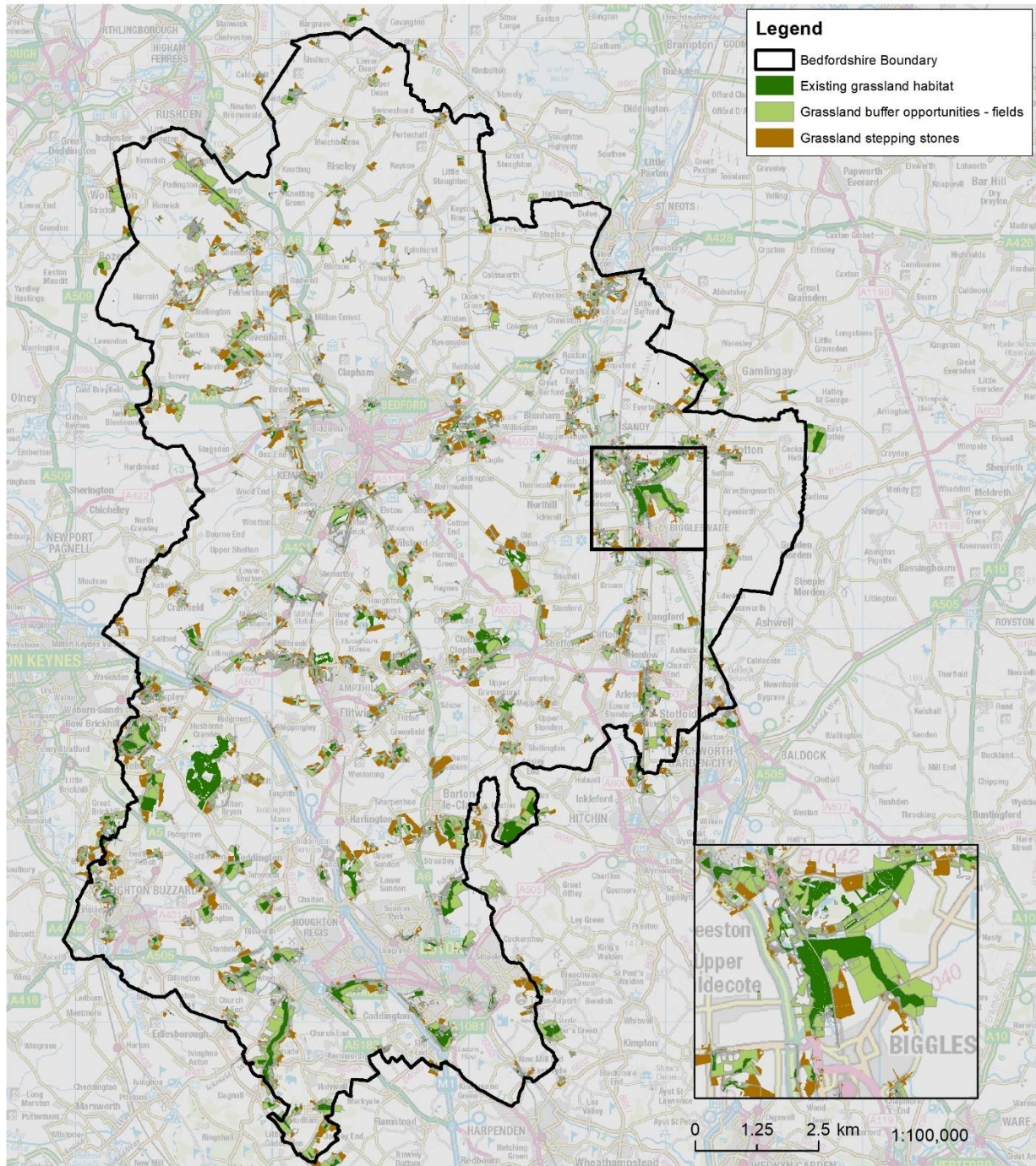
0 10 km

1:250,000
(at A4 paper size)



Figure 30 Buffer biodiversity opportunity areas for semi-natural grassland across Bedfordshire.

Semi-natural grassland habitat opportunity 2



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0 10 km

1:250,000
(at A4 paper size)



Figure 31 Field scale biodiversity opportunity areas for semi-natural grassland across Bedfordshire.

7.3 Opportunity mapping to reduce surface runoff

There is growing interest in working with natural process to reduce downstream flood risk. These projects aim to “slow the flow”, reduce surface water runoff and retain water away from the main river channels for as long as possible. The most likely approach to achieve this aim will involve planting woodland, although measures could also include woody debris dams and attenuation ponds in upstream areas. Opportunity mapping to reduce surface runoff was undertaken based on the water flow model described in Section 4.9 and highlights areas across the whole catchment where changing land-use would have the greatest impact on reducing runoff.

7.3.1 Method

Constraints were identified and mapped in the same way as described in Section 7.2.1 (Figure 27). These locations were then erased from the water flow regulation map developed in Section 4.9, to leave a map showing water flow regulation in all unconstrained locations. This was then classified into quartiles and the top quartile was extracted into a different map layer. Therefore, this shows the top 25% of areas of land across the study area where surface water runoff is currently highest and where there are no constraints on potentially altering land use. Note that it would also be possible to produce maps showing the top 10% of areas, or any other value, to show a narrower range of sites, if desired.

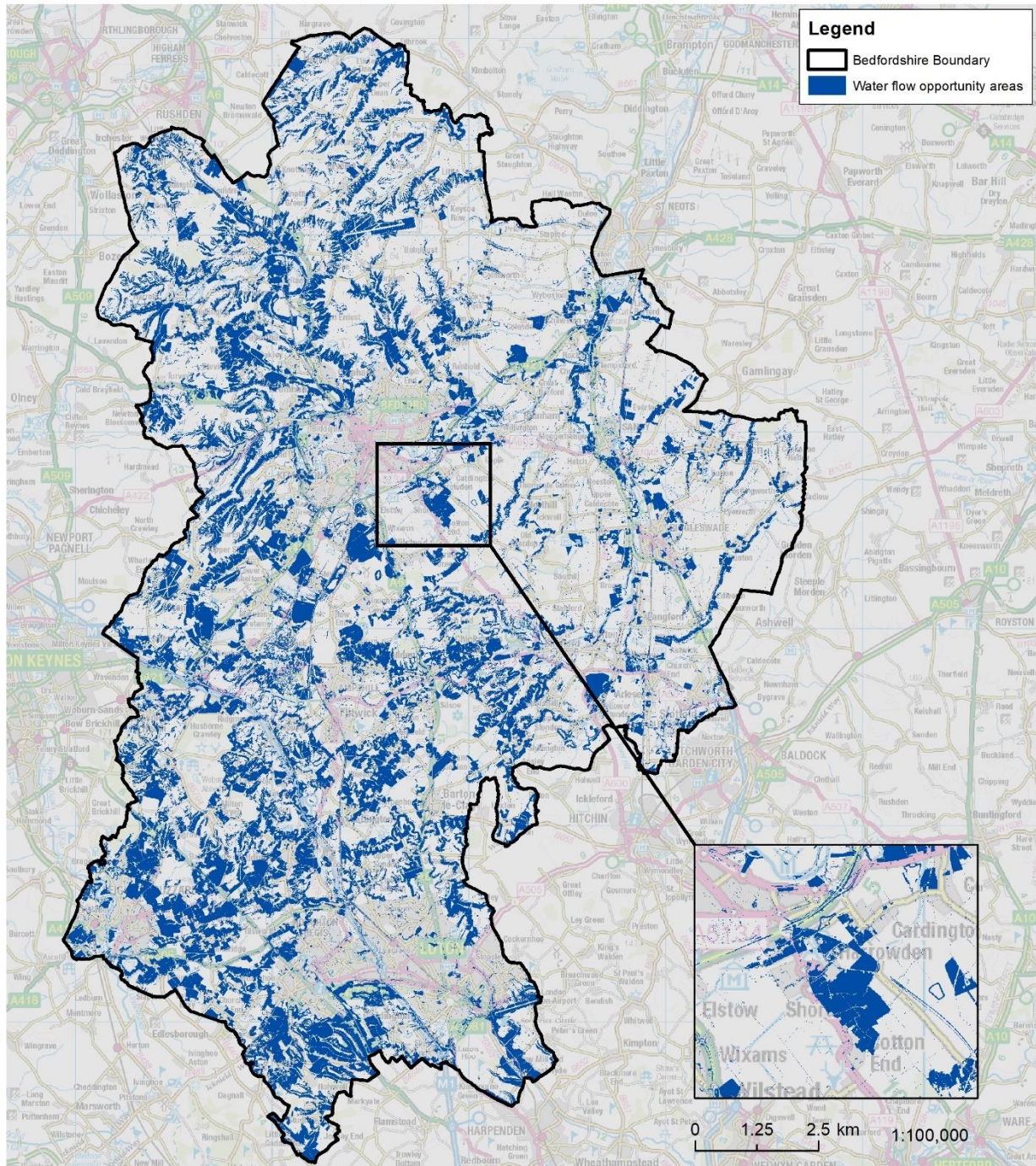
The final opportunity map identifies a large number of very small polygons and many polygons do not coincide with fields, the scale over which management and land use change is likely to take place. Therefore, as for biodiversity opportunity areas, it was considered beneficial to identify whole fields offering the greatest opportunity to reduce surface water runoff. To do this, all the previously identified constraints were removed or erased from the underlying habitat basemap. The degree of intersection between the opportunity map and the underlying fields (polygons) in the basemap was then calculated. Fields where at least 50% of the field overlapped with the opportunity map were selected and exported to a new layer. Finally, very small polygons were deleted, so that only fields and plots at least 0.1 ha in size were included in the final map.

7.3.2 Results

Once land use constraints were removed, many areas that are currently poor for surface water runoff remained and these were identified as opportunity areas on Figure 32. Opportunities are present over much of Bedfordshire, with the majority of opportunities relating to areas of arable fields on sloping land. The opportunity areas have been displayed in relation to fields and plots of land in Figure 33.

Note that some of the worst areas for water flow regulation highlighted in Figure 19 relate to buildings and infrastructure, which were not assessed as part of this project, although could be suitable for the installation of green roofs and other types of retrofitted Sustainable Drainage Systems (SuDS).

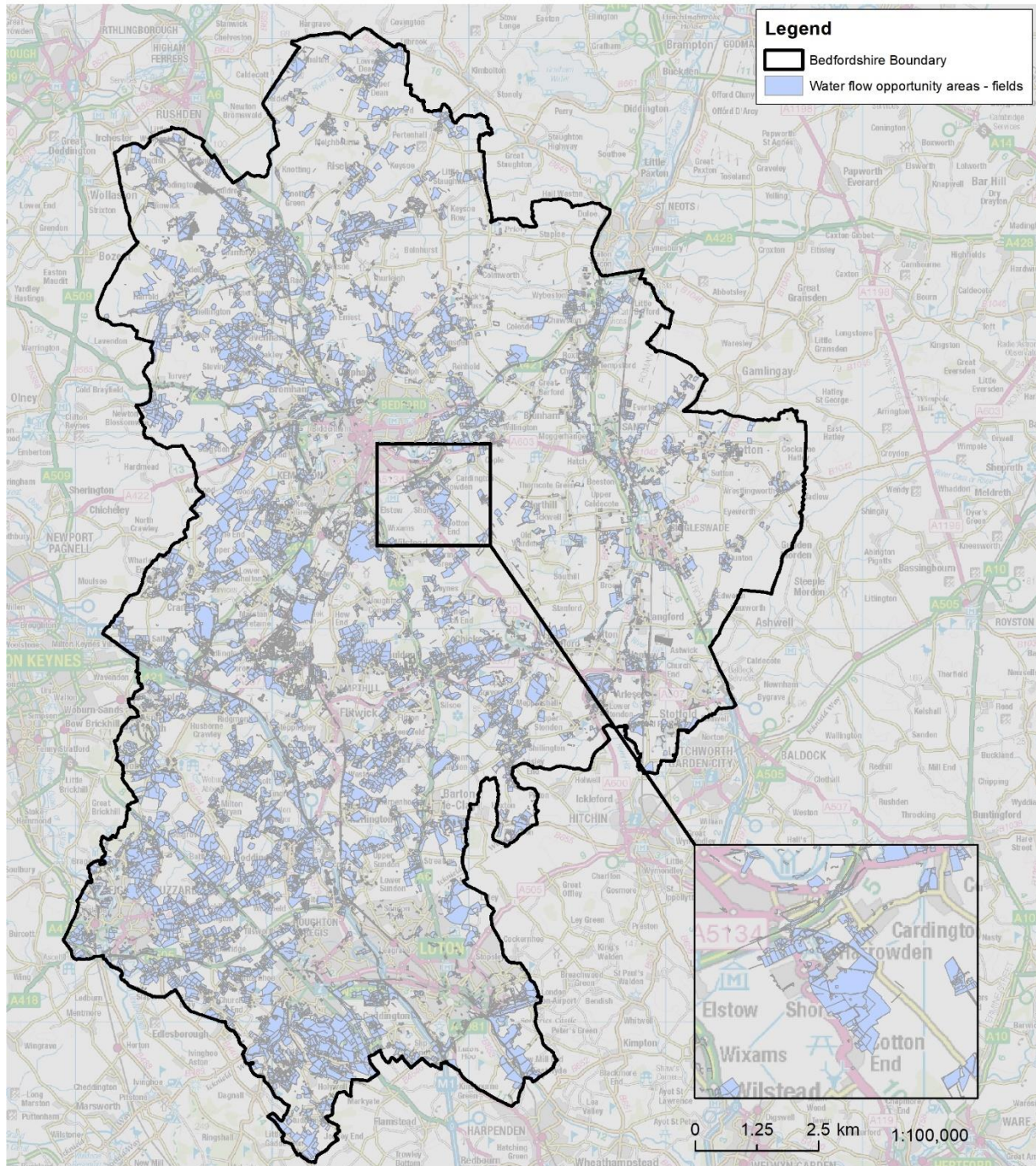
Water flow regulation opportunity areas



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Figure 32 Water flow regulation opportunity areas across Bedfordshire.

Water flow regulation opportunity areas 2



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0 10 km

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(at A4 paper size)



Figure 33 Field scale water flow regulation opportunity areas across Bedfordshire

7.4 Opportunity mapping to reduce soil erosion and improve water quality

Agricultural and urban diffuse pollution have a major impact on water quality in lowland areas in the UK. There is growing interest in catchment sensitive farming and working with natural processes to tackle this issue. These aim to reduce the amount of sediment and pollutants entering the watercourses in the first place by, for example, adjusting farming practices and planting riparian buffer strips. Opportunity mapping focussed on identifying areas at highest risk of sedimentation and soil erosion, based on catchment land use characteristics, distance to watercourse, slope length and land use erosion risk. It highlights areas across the whole catchment where changing land use would have the greatest impact on reducing soil erosion and hence improving water quality. Note that the focus is on sedimentation risk from agricultural diffuse pollution, and built-up areas (urban diffuse pollution) are not as well accounted for in the existing model.

7.4.1 Method

Constraints were identified and mapped in the same way as before. These areas were erased from the water quality regulation map, to leave a map showing water quality regulation in all unconstrained locations. This was then classified into quartiles and the top 25% were extracted into a different map. Therefore, this shows the top 25% of areas of land across the study area where sedimentation risk and soil erosion is currently highest and where there are no constraints on potentially altering land use.

As for water flow, the final opportunity map identifies a large number of very small polygons and long thin polygons that do not coincide with fields. The long thin polygons usually follow watercourses and are useful at identifying locations where riparian buffer strips would be appropriate. However, there may also be opportunities for whole fields to be converted to other habitats (especially woodland), therefore, whole fields offering the greatest opportunity to reduce soil erosion were identified. To do this, all the previously identified constraints were removed or erased from the underlying habitat basemap. The degree of intersection between the opportunity map and the underlying fields (polygons) in the basemap was then calculated. Fields where at least 50% of the field overlapped with the opportunity map were selected and exported to a new layer. Finally, very small polygons were deleted, so that only fields and plots at least 0.1 ha in size were included in the final map. Note that if the focus is on installing buffer strips, rather than altering whole fields, then the previous non-field based map (Figure 34) is likely to be more appropriate to identify sites, whereas the field based map (Figure 35) is more appropriate when identifying larger blocks.

7.4.2 Results

Arable farmland scores particularly badly when mapping water quality regulation (Section 4.10) at both a coarse and a fine scale of assessment and these areas are, therefore, highlighted as the areas with greatest opportunity to reduce sediment loads and enhance water quality on the opportunity map (Figure 34). In addition, distance to watercourses is another key factor. The greatest number of nature-based intervention opportunities to improve water quality are located in the north half of the county, but there are plenty of similar opportunities across the rest of Bedfordshire except in urban areas.

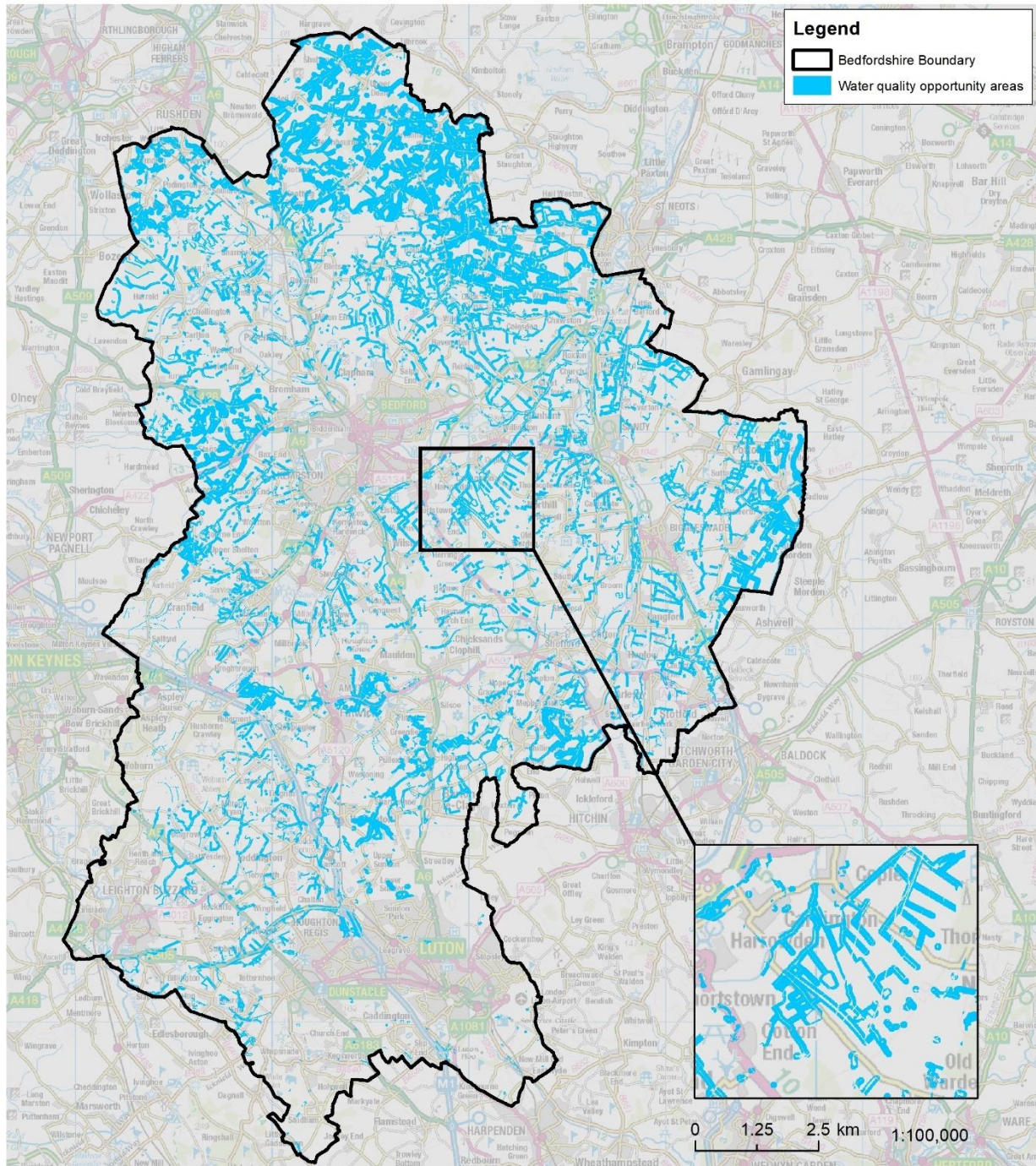
Sediment loads, and therefore opportunity areas, can be variable across short distances as it is partly dependent upon slope and distance to water course, which change rapidly over short spaces, and is why many of the identified areas are linear stretches adjacent to watercourses. These areas would be ideal places to install riparian buffer strips. Note that a significant number of watercourses in

Bedfordshire are managed by IDBs (Internal Drainage Boards), who may not allow woodland planting on banksides, hence any planned planting works would need to be conducted in consultation with the IDBs and non-woodland buffer habitats may be preferable in such locations.

A map of whole fields where opportunities for reducing soil erosion and enhancing water quality would be most effective has been created (Figure 35). As noted, however, the areas that would be most effective for tackling water quality are often zones adjacent to watercourses, and changing land use in riparian buffer strips may be the most effective solution, rather than converting whole fields.

Comparing the opportunity maps for water flow (Figure 32) with water quality (Figure 34), reveals that opportunities to improve these ecosystem services do not always overlap. This is because the most effective locations for reducing surface water runoff tend to occur on slopes, whereas the most effective areas to enhance water quality are immediately adjacent to water courses on arable fields. It is likely that habitat features created for one will still enhance the other, it is simply that the top 25% of target areas do not overlap in many locations.

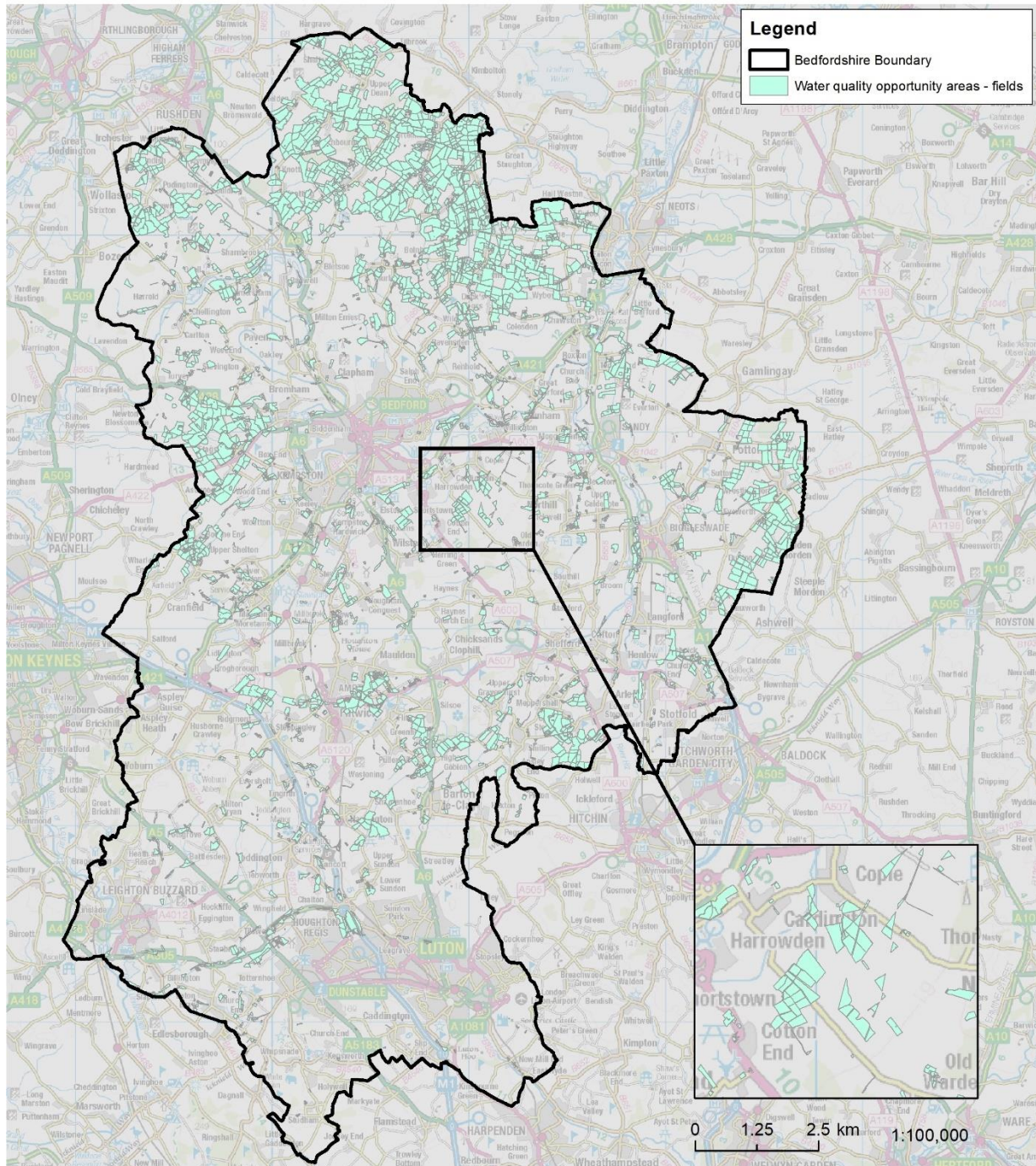
Water quality regulation opportunity areas



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Figure 34 Water quality regulation opportunity areas across Bedfordshire.

Water quality regulation opportunity areas 2



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Figure 35 Field scale water quality regulation opportunity areas across Bedfordshire.

7.5 Opportunity mapping to ameliorate air pollution

To map opportunities to use the natural environment to ameliorate air pollution, a slightly different approach was used compared to water flow and water quality. Air pollution is often highly localised. and vegetation is most effective at mitigating pollutants when planted close to pollution sources. Opportunities to ameliorate air pollution were therefore focussed around areas with greatest demand. As described in Section 4.4, demand is assumed to be highest in areas where there are likely to be high air pollution levels and where there are lots of people who could benefit from the air quality regulation service. The opportunity maps therefore highlight areas that currently have no trees, but where it would be most beneficial to plant them.

7.5.1 Method

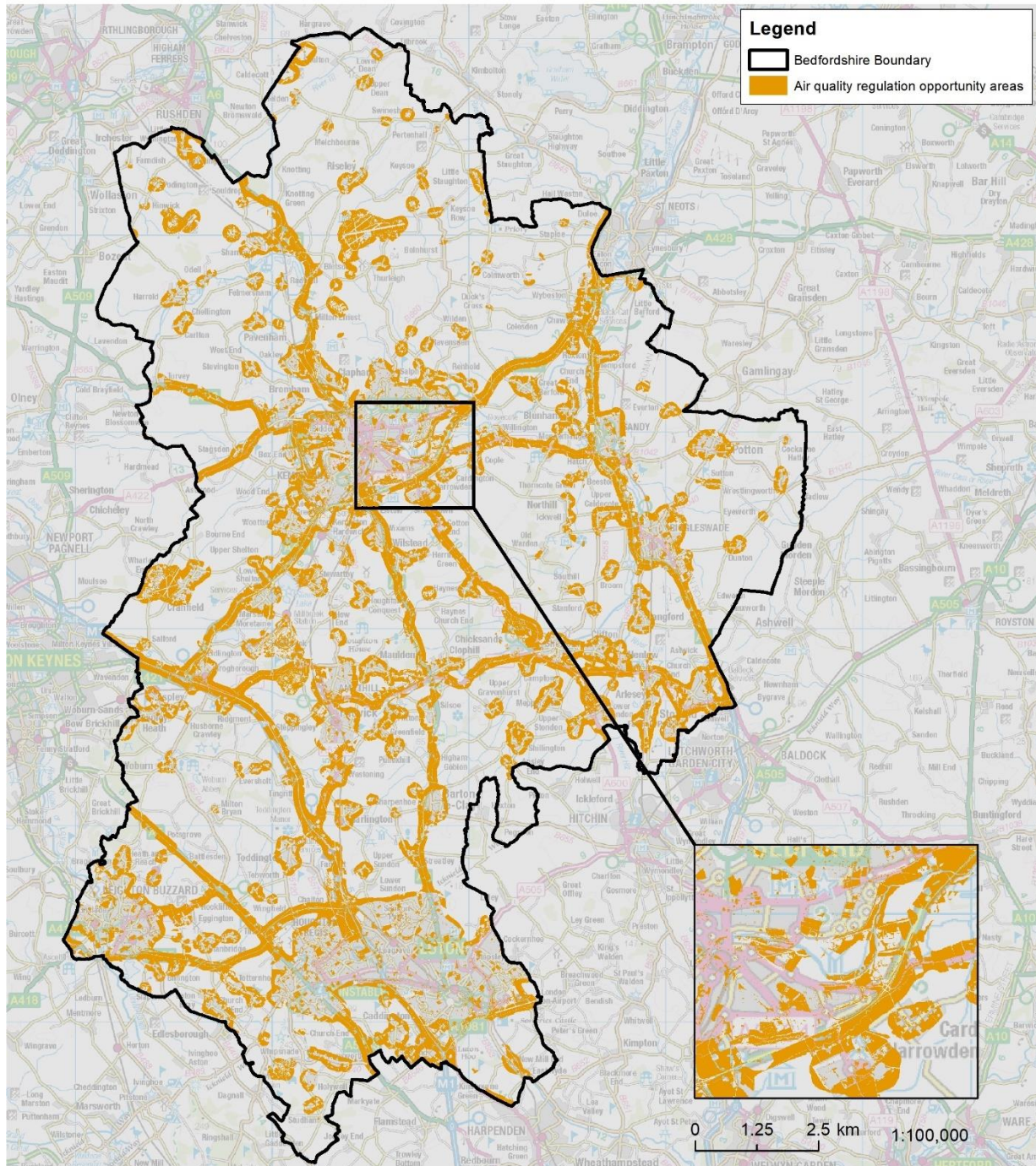
The constraints identified previously were erased from the air quality regulation demand map, to leave a map showing demand in all unconstrained locations. As before, this was then classified into quartiles and the top quartile was extracted into a different map. This map therefore highlights the top 25% of areas of land across the study area where demand for air quality amelioration is greatest and where there are no constraints on potentially altering land use. As previously, it would also be possible to produce maps showing the top 10% or 5% (or any other value), to focus on the worst pollution hotspots with the greatest demand.

To match the other ecosystem services, the opportunity map was used to identify whole plots and fields in the basemap where the degree of intersection was at least 50% and a new layer was created. On this occasion very small polygons were not deleted, as it may be possible to plant an individual tree in very small plots of land.

7.5.2 Results

As described previously, demand for air quality regulation (Figure 14) is highest in the main urban centres as these have both higher air pollution levels and higher populations that would benefit from better air quality, and also along the main road networks. Inevitably, when the focus on air quality regulation is in the major towns, large areas are constrained, where it would not be possible to plant trees or other green infrastructure. However, unconstrained areas do remain, and these were highlighted on the opportunity map (Figure 36). Opportunity areas along the main roads were also highlighted. Whole plots were also identified (Figure 37), although on this occasion this was similar to the previous map. These locations potentially provide the opportunity to plant trees that could trap air pollution in areas where there is the greatest need for this service. Note that this does not include pavements, where further opportunities may be present, if pavements are sufficiently wide.

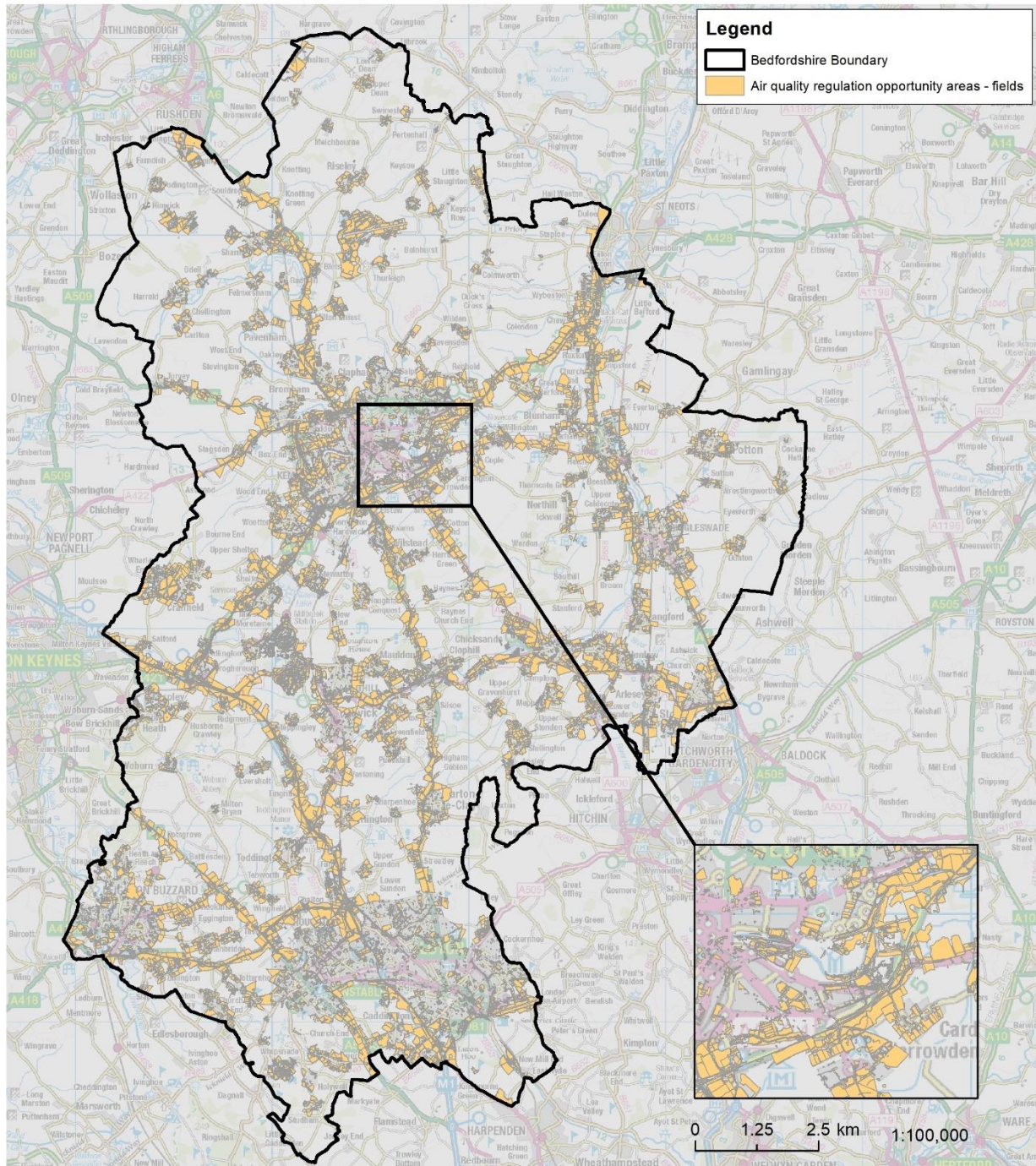
Air quality regulation opportunity areas



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Figure 36 Air quality regulation opportunity areas across Bedfordshire.

Air quality regulation opportunity areas 2



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Figure 37 Field (plot) scale air quality regulation opportunity areas across Bedfordshire.

7.6 Opportunity mapping to reduce noise pollution

Opportunities to reduce noise pollution were mapped in a very similar way to the air quality regulation opportunity mapping just described. This was focussed around areas with greatest demand for noise regulation, as described in Section 4.6. Dense plantings of trees and scrub are the habitat type that could potentially reduce noise pollution; the opportunity maps therefore highlight areas that currently have no trees, but where it would be most beneficial to plant them.

7.6.1 Method

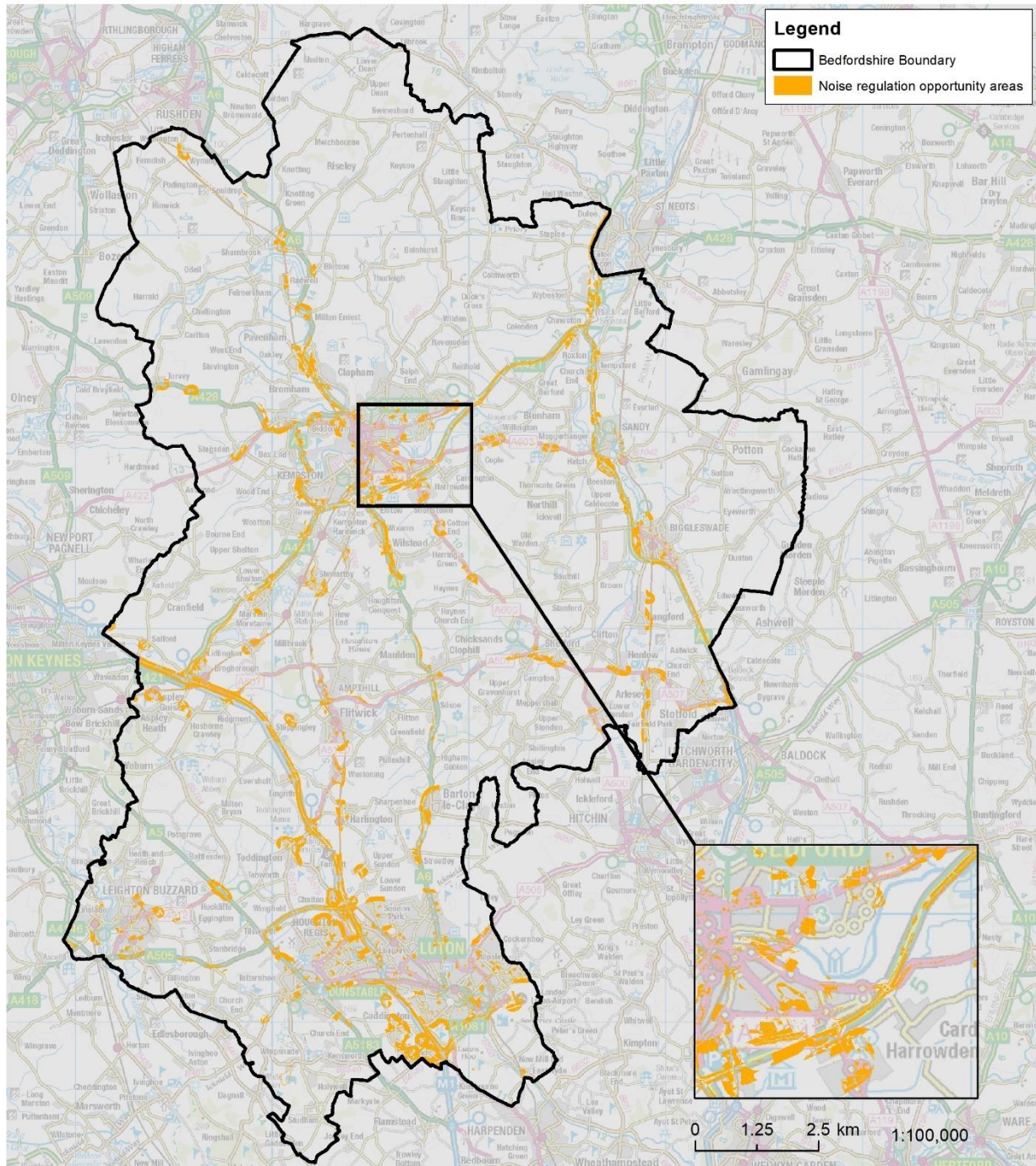
The constraints identified previously were erased from the noise regulation demand map, to leave a map showing demand in all unconstrained locations. As before, this was then classified into quartiles and the top quartile was extracted into a different map. This map therefore highlights the top 25% of areas of land across the study area where demand for noise regulation is greatest and where there are no constraints on potentially altering land use.

As before, the opportunity map was used to identify whole plots and fields in the basemap where the degree of intersection was at least 50% and a new layer was created. As individual trees or very small groups of trees are largely ineffective at blocking noise, polygons less than 200m² were deleted.

7.6.2 Results

Similarly to air quality regulation, demand for noise regulation (Figure 16) is highest in the main urban centres and adjacent to the road and rail network, as these have both higher noise pollution levels and higher populations that would benefit from noise screening. Given the large number of constraints in urban centres, the majority of the opportunity areas identified fall on the outer fringes of urban areas and adjacent to the road network, although a number of urban centre locations have also been identified (Figure 38). Whole plots were also identified and shown in Figure 39. These locations potentially provide the opportunity to plant trees and scrub belts that could help to block and screen noise pollution.

Reducing noise pollution opportunity areas



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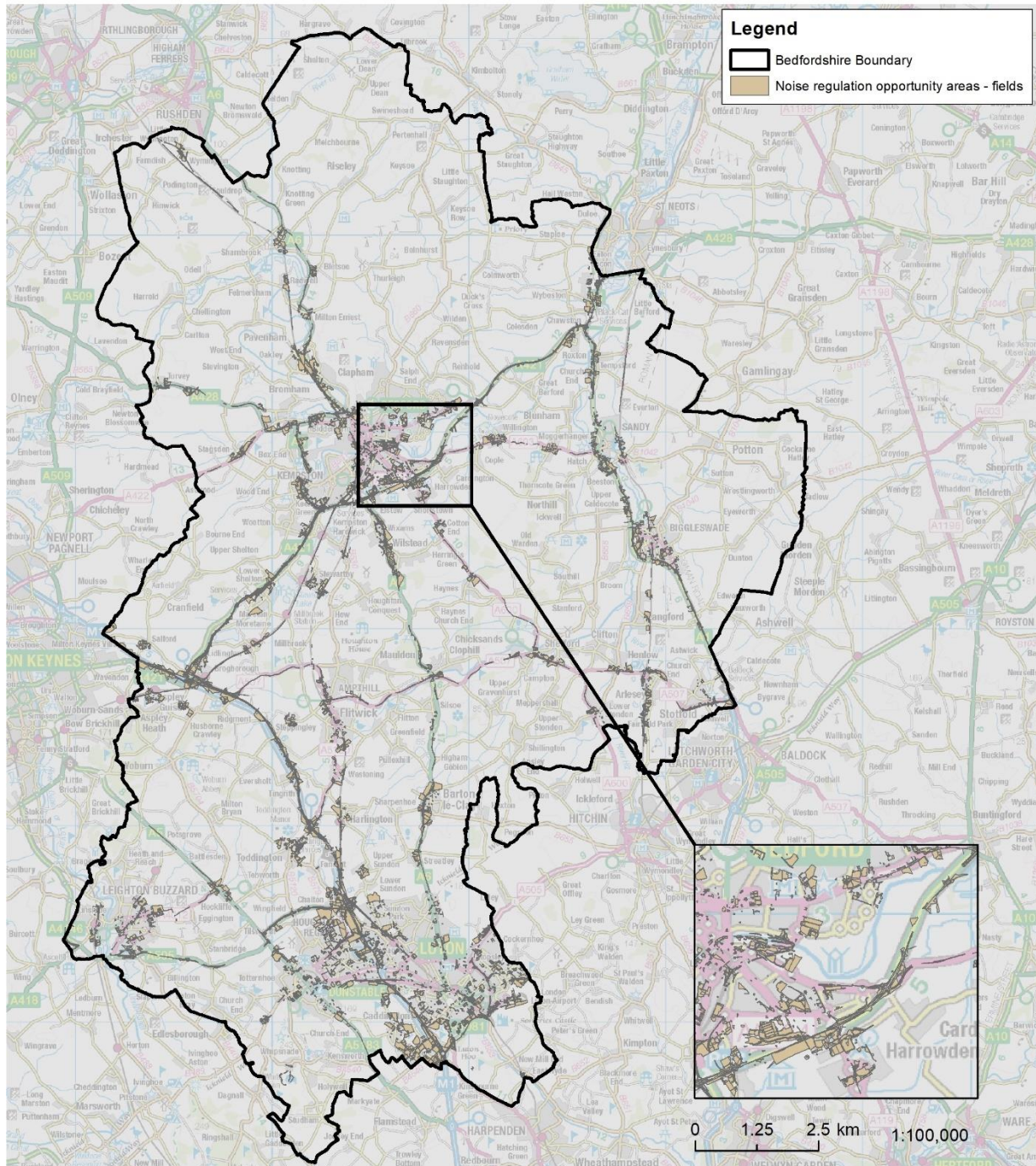
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Figure 38 Noise regulation opportunity areas across Bedfordshire.

Reducing noise pollution opportunity areas 2



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(at A4 paper size)



Figure 39 Field (plot) scale noise regulation opportunity areas across Bedfordshire.

7.7 Opportunity mapping to regulate local climate (reduce urban heat)

Opportunities to regulate local climate were mapped using the same approach as for air quality regulation and noise regulation. This, therefore, focuses on areas of highest demand, where there is currently low capacity. Using the natural environment to regulate local climate can best be achieved by either planting trees / woodland, or creating waterbodies such as ponds and lakes. The larger the area of habitat created, the greater the effect that it will have on urban temperatures, although even individual trees will have a small positive impact.

7.7.1 Method

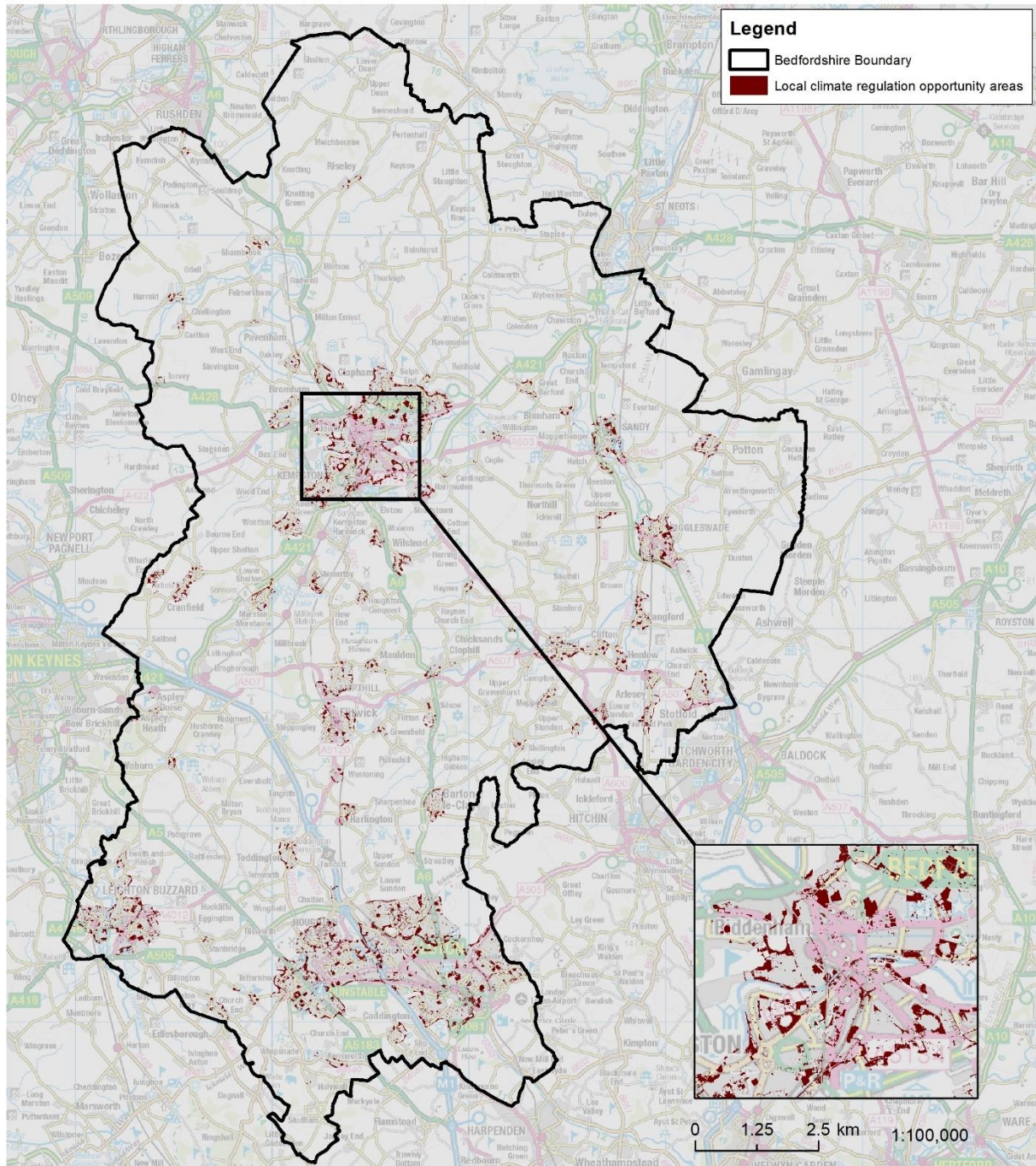
The constraints identified previously were erased from the local climate regulation demand map (Section 4.8), to leave a map showing demand in all unconstrained locations. As before, this was then classified into quartiles and the top quartile was extracted into a different map. This map therefore highlights the top 25% of areas of land across the study area where demand for local climate regulation is greatest and where there are no constraints on potentially altering land use.

As before, the opportunity map was used to identify whole plots and fields in the basemap where the degree of intersection was at least 50% and a new layer was created. All polygons were retained, as even planting individual trees could be beneficial, although will have a smaller effect.

7.7.2 Results

Demand for local climate regulation (Figure 18) is highest in the main urban centres and the size of the urban heat island effect increase with size of urban area and amount of sealed surface. As with air pollution regulation and noise regulation, the majority of the opportunity areas identified fall on the outer fringes of urban areas, due to the large number of constraints in urban centres, although some of the urban centre locations have also been identified (Figure 40). As for the other services, whole plots were also identified and shown in Figure 41. These locations potentially provide the opportunity to plant trees and woodland or to create water features that could help to reduce the urban heat island effect.

Local climate regulation opportunity areas



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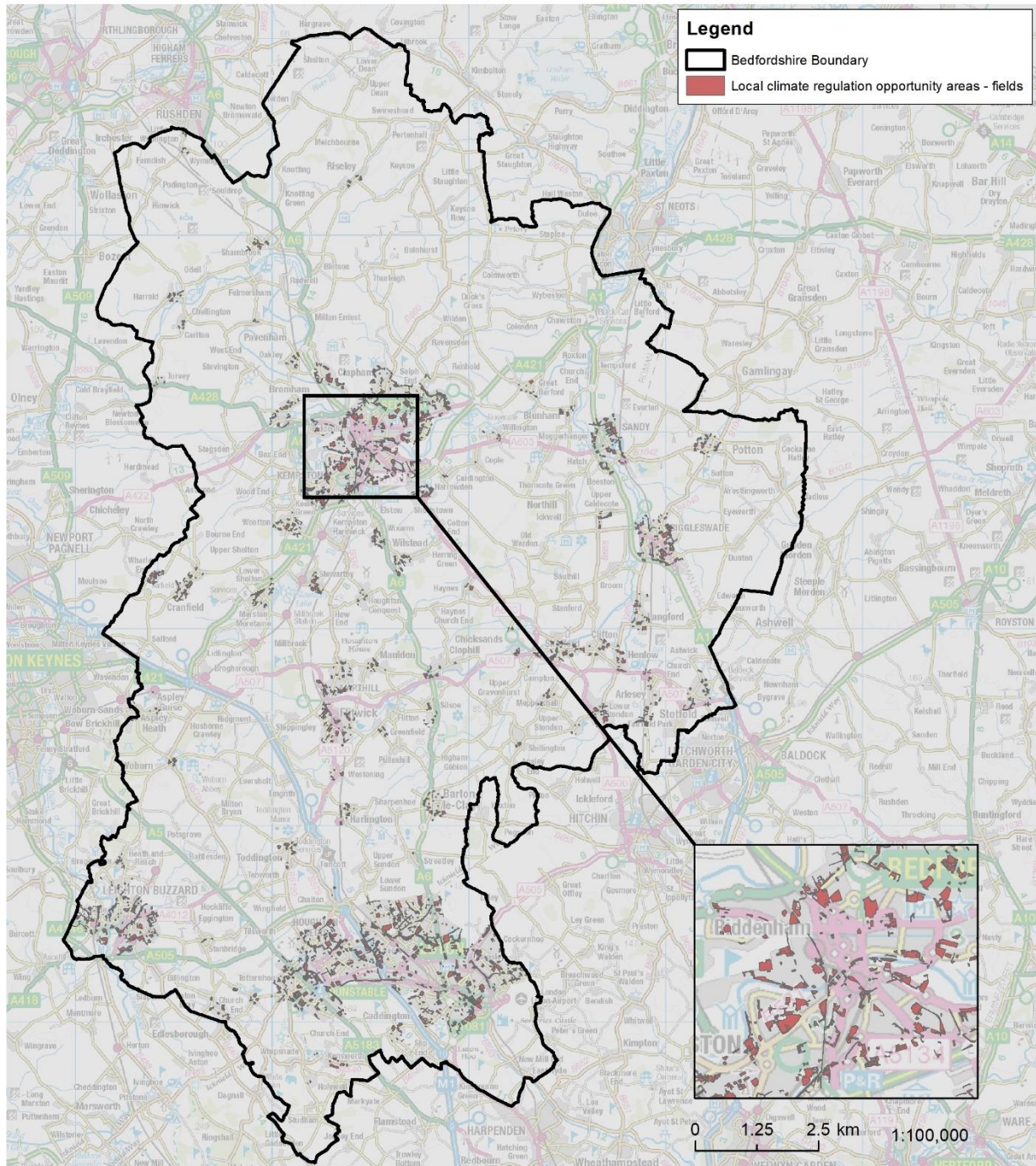
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Figure 40 Local climate regulation opportunity areas across Bedfordshire.

Local climate regulation opportunity areas 2



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(at A4 paper size)



Figure 41 Field (plot) scale local climate regulation opportunity areas across Bedfordshire.

7.8 Opportunity mapping to enhance recreation in the natural environment

There are many benefits of enhancing public access to natural greenspaces and the key features that maximise benefits are proximity to where people live and the naturalness of the habitats. Here, opportunities to provide accessible natural greenspace were mapped, first based on creating new habitats at new sites, based purely on demand, and then by also considering opening up access to existing sites, by taking into account the naturalness of existing habitats.

7.8.1 Method

1. Identifying constraints

It may be possible to create accessible natural greenspace simply by opening up public access to existing areas, rather than changing habitats. Therefore, many of the constraints that would need to be taken into account when planting new habitats for water flow, water quality or air quality regulation, do not need to be taken into account. For example, opportunities do not need to be constrained by existing high quality habitats and historic sites, although these areas would need to be carefully considered on a case-by-case basis to avoid any damage to existing features. The only constraints taken into account were, therefore, the land use constraints identified previously – buildings, infrastructure, gardens and water. It would be possible to include water features as part of larger sites, but that was not investigated here. A map was created showing all the land use constraints on one map.

In addition to these constraints, a map was created from the basemap showing all areas of green infrastructure currently existing across Bedfordshire. This was based on the accessible greenspace map previously described in Section 6, but was merged with a layer showing green infrastructure that is not fully publicly accessible (includes golf courses, allotments, and institutional (e.g. school) grounds).

2. Identifying opportunity areas

The land use constraints identified above were erased from the accessible natural greenspace demand map, along with the existing areas of green infrastructure, to leave a map showing demand in all unconstrained locations where there is currently no green infrastructure. As before, this was then classified into quartiles and the top quartile were extracted into a different map. This map highlights the top 25% of areas of land across the study area where demand for accessible natural greenspace is greatest and where there are no constraints on potentially creating this. As before, the opportunity map was used to identify whole plots and fields in the basemap where the degree of intersection was at least 50%.

3. Mapping the perceived naturalness of existing habitats

As well as mapping opportunities based purely on demand, it's also possible to look at the link between demand and the current capacity of the landscape to supply that demand if access were improved. In other words, determining which existing areas would be best to open up to public access with no change of habitats. As stated previously, there is a link between perceptions of naturalness and wellbeing, hence more natural areas are able to deliver accessible natural greenspace of greater value.

Perceived naturalness was therefore mapped based on an EcoServ GIS model. All habitats were scored for their perceived level of naturalness, with scores taken as a mean from the scientific literature. Naturalness was scored in a 300m radius around each point, representing the visitors experience within a short walk of each point. This means that larger continuous blocks of more natural habitat types will

have higher scores than smaller isolated sites of the same habitat type. Scores are on a 1 to 100 scale, relative to values present within the study area.

4. Identifying opportunity areas to enhance access to existing sites

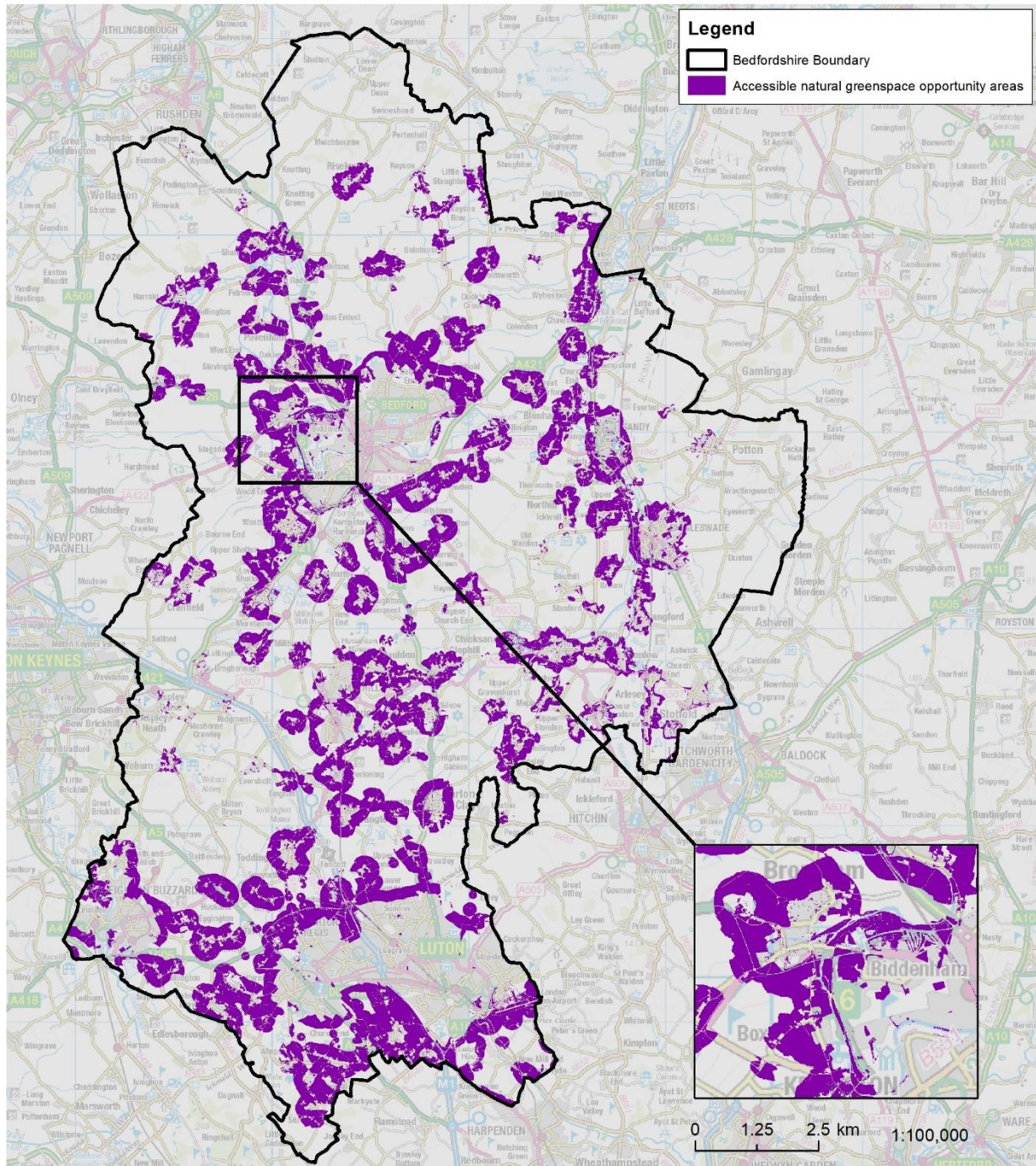
The land use constraints identified in Step 1 were erased from the perceived naturalness map, along with the existing areas of green infrastructure, to leave a map showing the perceived naturalness of all unconstrained locations where there is currently no green infrastructure. This was then classified into 10 percentiles (i.e. the top 10% were identified. 10-20%. 20-30% and so on) and each pixel reclassified from 1-10. The demand map (from step 2) was also re-classified in exactly the same way into 10 percentiles. The two maps were then joined together so that each pixel was given a score based on the naturalness score (out of 10) plus the demand score (out of 10). Finally, the top 25% of combined scores were identified and extracted into a different layer. This map therefore highlights the top 25% of areas of land across the study area where there is both high demand for accessible natural greenspace and the perceived naturalness of the current habitats are greatest (plus there are no constraints). As before, the opportunity map was used to identify whole plots and fields in the basemap where the degree of intersection was at least 50%.

7.8.2 Results

Demand for accessible natural greenspace was described in Section 4.14 and is strongly focussed around the urban areas in the study area. Therefore, it is perhaps unsurprising that the majority of the opportunity areas identified (Figures 42 & 43) are centred around the major and minor towns across the study area. As opportunities for new greenspaces are usually highly constrained within towns, opportunity areas tend to form a ring around the edges of these towns. These are also often locations that have been targeted for sustainable urban extensions and other development, so it is important that planners and developers take into account the strong demand for greenspace at these sites from both the new developments and from the existing population.

Although demand is greatest around the larger towns, these locations often do not contain the most natural habitats, and the perceived naturalness of habitats throughout the study area is shown on Figure 44. Woodland, semi-natural grassland, and water features are considered to be the most natural habitats in the area and can be clearly identified in red on the map, especially the larger blocks of these habitats. When demand is balanced against the naturalness of the existing habitats, a different pattern of opportunity areas emerges (Figures 45 & 46). The association with the larger towns is now much weaker, although still present, as areas of poor habitat adjacent to towns are not selected. Areas of higher quality habitat are now more likely to be selected, especially when those are relatively close to towns. In general, when considering only demand for access to greenspace, opportunities are selected that are immediately adjacent to urban areas, but these are often on arable fields and improved grassland. Hence new habitats would need to be created to enhance the quality of the greenspace offering. When the perceived naturalness of existing habitats is also considered, areas are often slightly further from towns so with slightly poorer access, but more natural habitats, such as woodland are often selected.

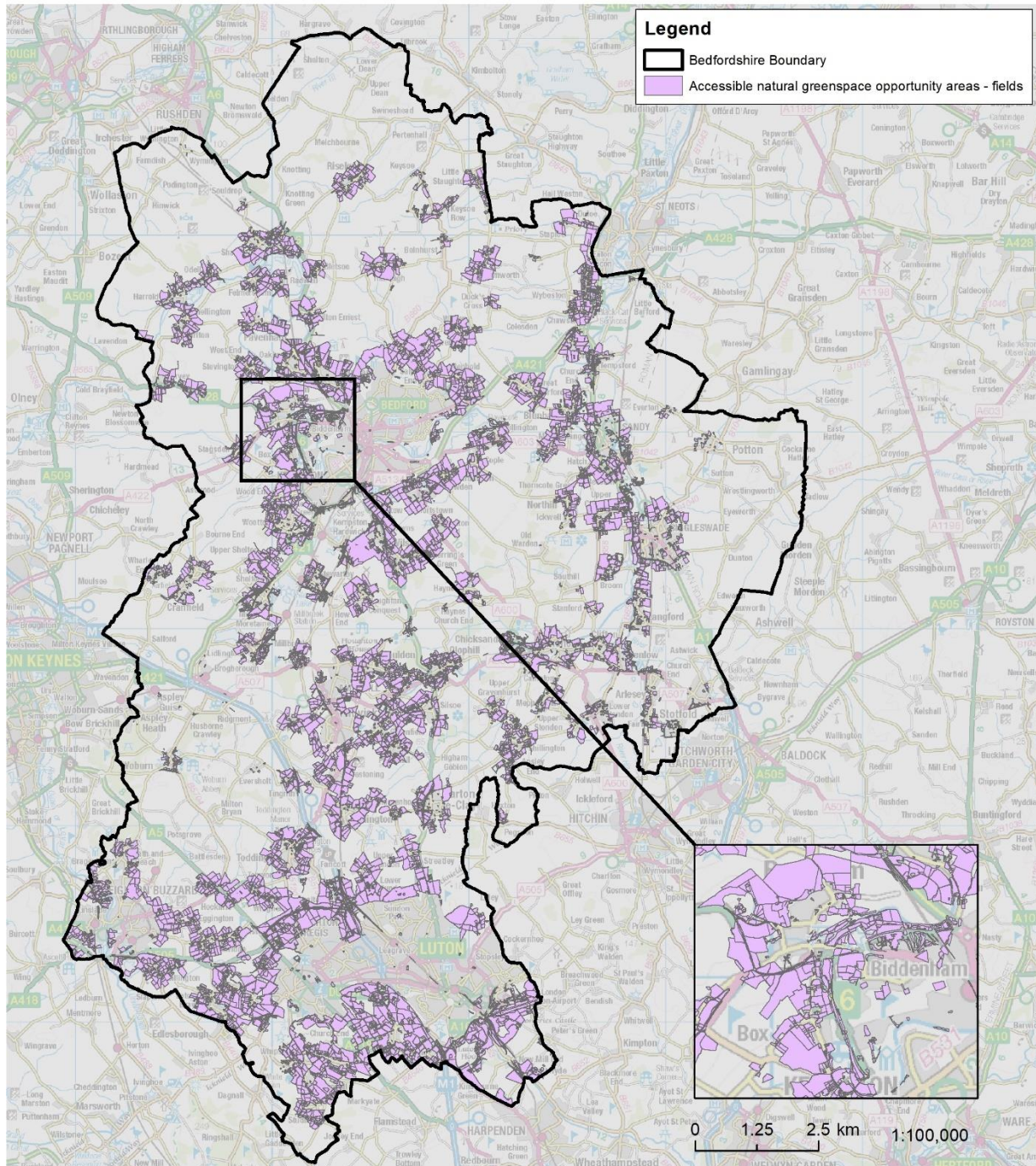
Accessible natural greenspace opportunity areas



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Figure 42 Accessible natural greenspace opportunity areas across Bedfordshire.

Accessible natural greenspace opportunity areas 2



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(at A4 paper size)



Figure 43 Field (plot) scale accessible natural greenspace opportunity areas across Bedfordshire.

Perceived naturalness

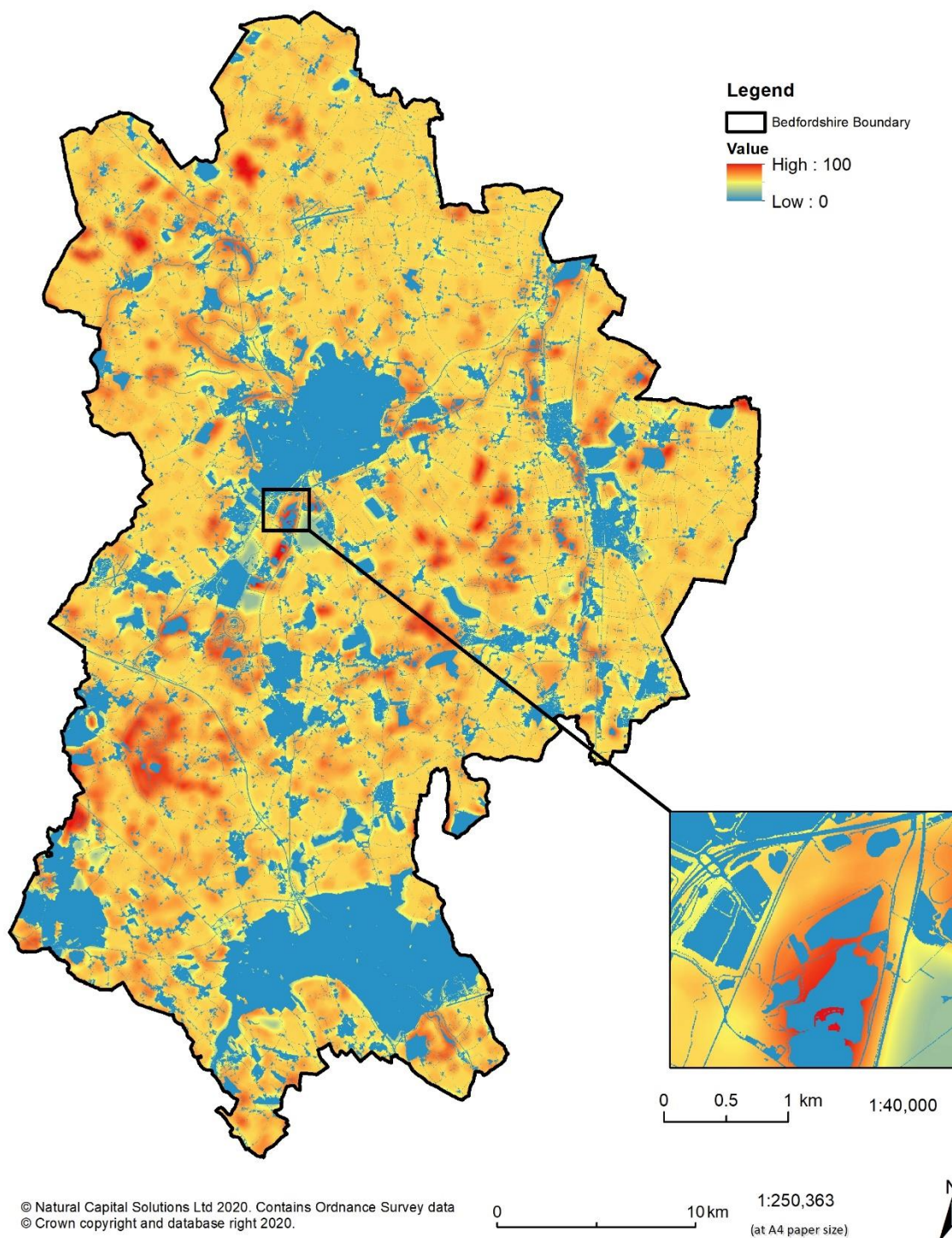
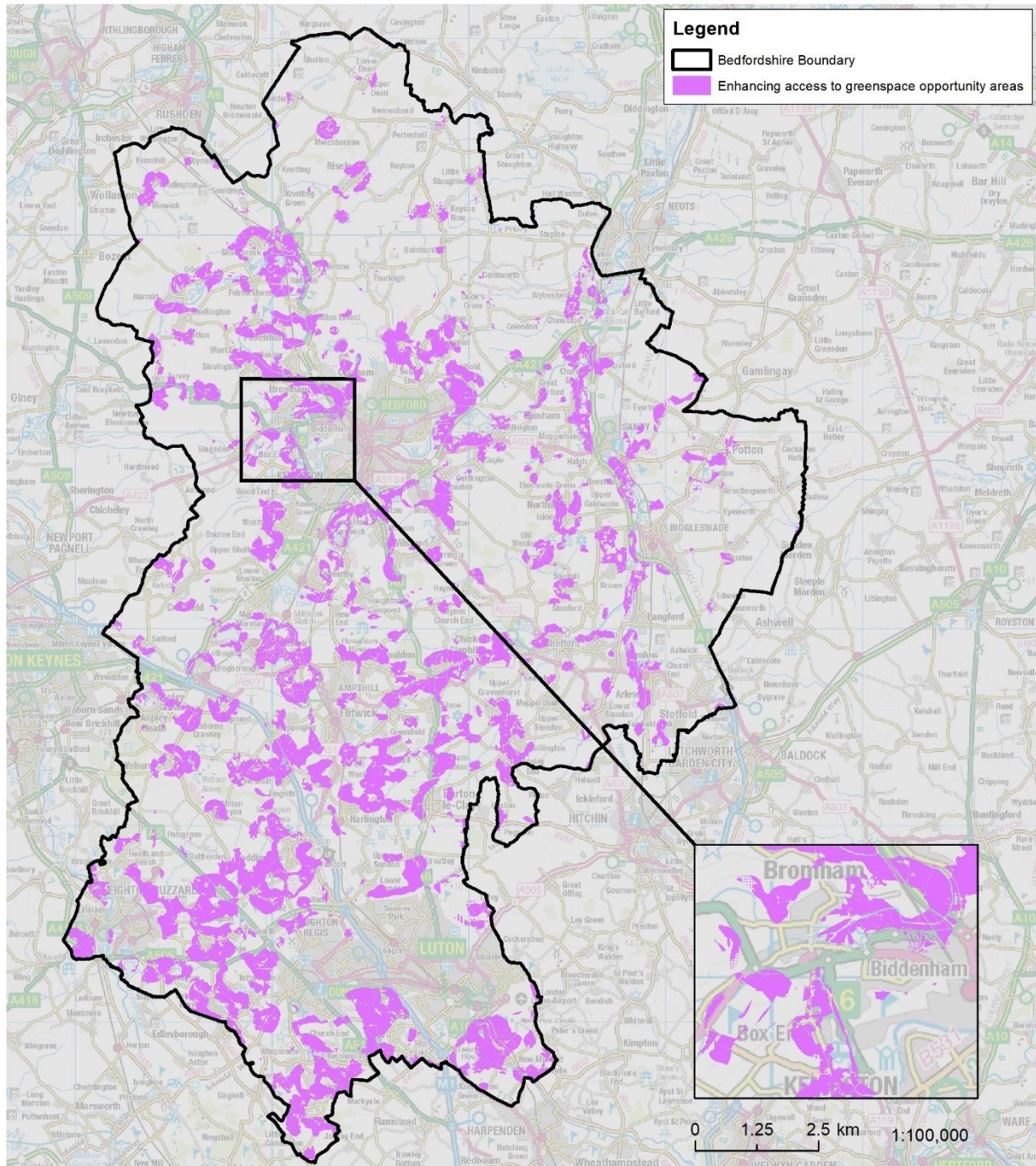


Figure 44 Perceived naturalness of habitats across Bedfordshire.

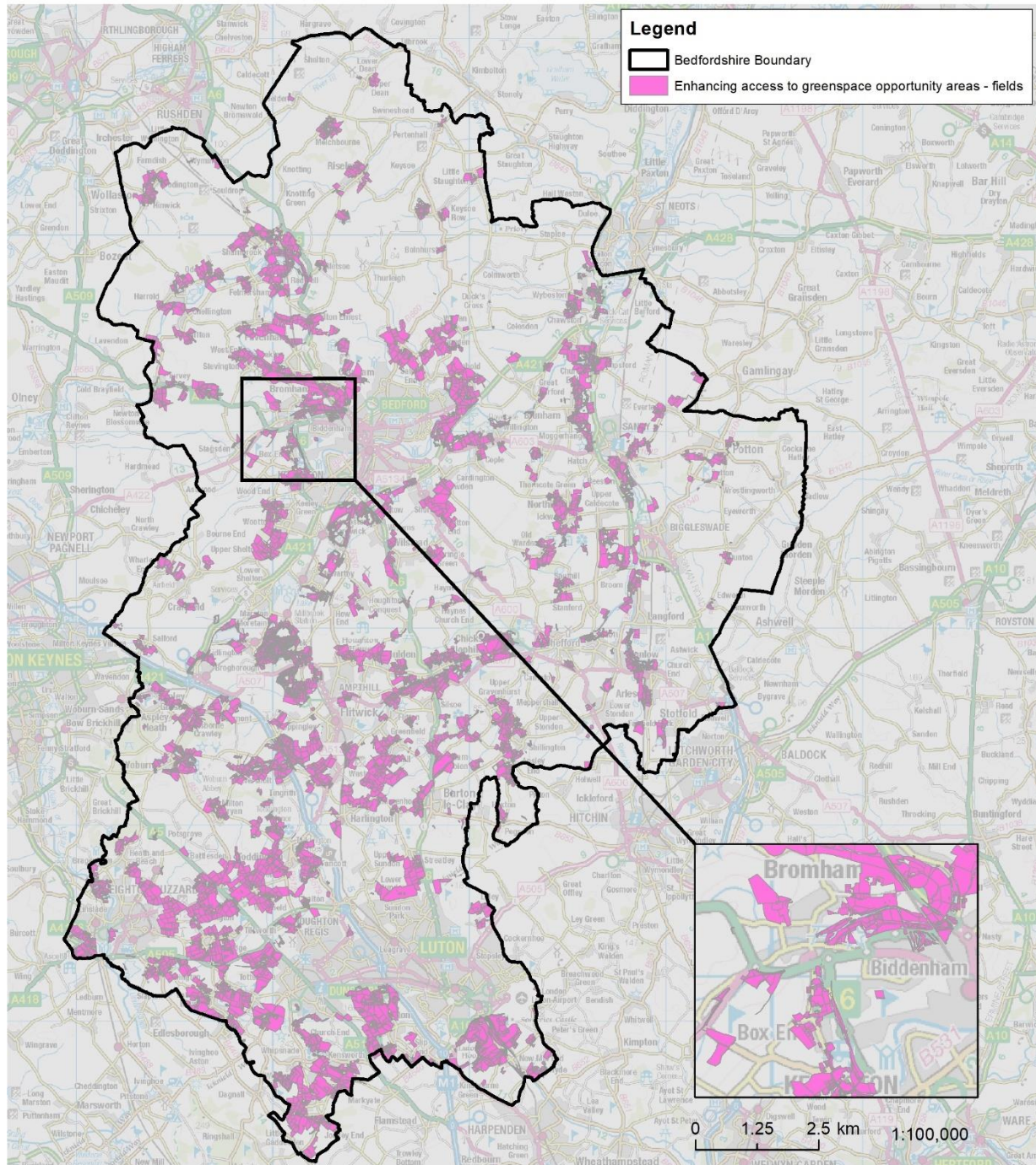
Enhancing access to greenspace opportunity areas



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Figure 45 Opportunities for enhancing access to existing natural greenspaces across Bedfordshire.

Enhancing access to greenspace opportunity areas 2



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(at A4 paper size)



Figure 46 Field (plot) scale Opportunities for enhancing access to existing natural greenspaces across Bedfordshire.

8. Combined opportunities for new habitats

In addition to mapping the individual opportunities presented in Sections 7, it is also possible to examine multiple opportunities, which are areas where new habitat can be created that provides opportunities to enhance more than one of the services mapped previously. This is assessed by overlaying each individual opportunity map already created to determine the degree of overlap, examining each of the main habitat types in turn. This is focussing on the top 25% of opportunity areas for each ecosystem service, so is only considering the higher levels of service provision. In reality, creating any new habitat for one ecosystem service is likely to provide benefits for other services, even if this does not fall within the top 25%. We have combined maps in two ways for each habitat:

1. Treating biodiversity opportunities and all ecosystem service opportunities equally, hence all opportunities are included in the final maps.
2. Restricting combined opportunities to areas that present a biodiversity opportunity. Hence opportunities are only included for areas that are ecologically connected to existing habitats. This follows the ethos of environmental net gain being focused on biodiversity net gain first, and then natural capital net gain as an additional feature.

It would also be possible to create maps with different weightings for different services. For example, if stakeholders considered water flow and access to nature as being the most important local priorities, then these opportunities could be given greater weighting. This has not been attempted here, but it would be possible to combine the maps in any way wanted. Note that as the assessment below is concerned with creating new habitats, the opportunity map for accessible natural greenspace based solely on demand (Figure 42), was used rather than the one that examined existing habitats alongside demand (Figure 45).

8.1 Combined opportunities for new broadleaved and mixed woodland

Opportunities to deliver enhancement to water flow, water quality, air quality, noise, and local climate regulation (Sections 7.3-7.7), can all be best achieved through planting trees and woodland. Woodland is also one of the best habitats for creating high quality accessible natural greenspace (Section 7.8). Therefore, the opportunity maps for all of these services were overlain with the opportunity map for biodiversity enhancement through the creation of broadleaved and mixed woodland. Note that creating woodland habitats will also deliver benefits in the form of **carbon sequestration**. These have not been mapped separately as location is not especially important for carbon sequestration (although there will be some difference in the growth rate of trees in different places). Hence all of the locations identified in the maps below would also deliver this service.

The results are shown on Figure 47, which maps the existing areas of broadleaved and mixed woodland and an overlay of all the seven different opportunity areas, and on Figure 48 when constrained to areas that present biodiversity opportunities. The maps highlight the number of different opportunity areas that overlap (out of a maximum of seven) for each 10m by 10m pixel across the study area. The results show that while there are large areas that only offer one opportunity, there are many areas that offer multiple opportunities. Locations at the edges of the main towns are most often highlighted as being able to deliver multiple services on Figure 48. If the aim of woodland creation was to maximise the delivery of as many ecosystem services as possible, then it is these locations that would deliver the greatest benefits to society.

When considering habitat creation for biodiversity as the primary driver (Figure 48), the number of locations is reduced, but there remain many. Areas close to towns and the road network remain the best locations for delivering multiple benefits.

8.2 Combined opportunities for new semi-natural grassland

Creating semi-natural grassland will not be as effective at reducing water flow or enhancing water quality as planting woodland, but it is likely to be significantly better than arable and is likely to enhance the provision of these services. It will not, however, be very effective at ameliorating air pollution, reducing noise pollution, or regulating local climate (although better than sealed surfaces for each of these services). Hence combined opportunities were examined for four out of the seven services: water flow, water quality, accessible natural greenspace, and biodiversity enhancement, while air quality, noise, and local climate regulation were not included.

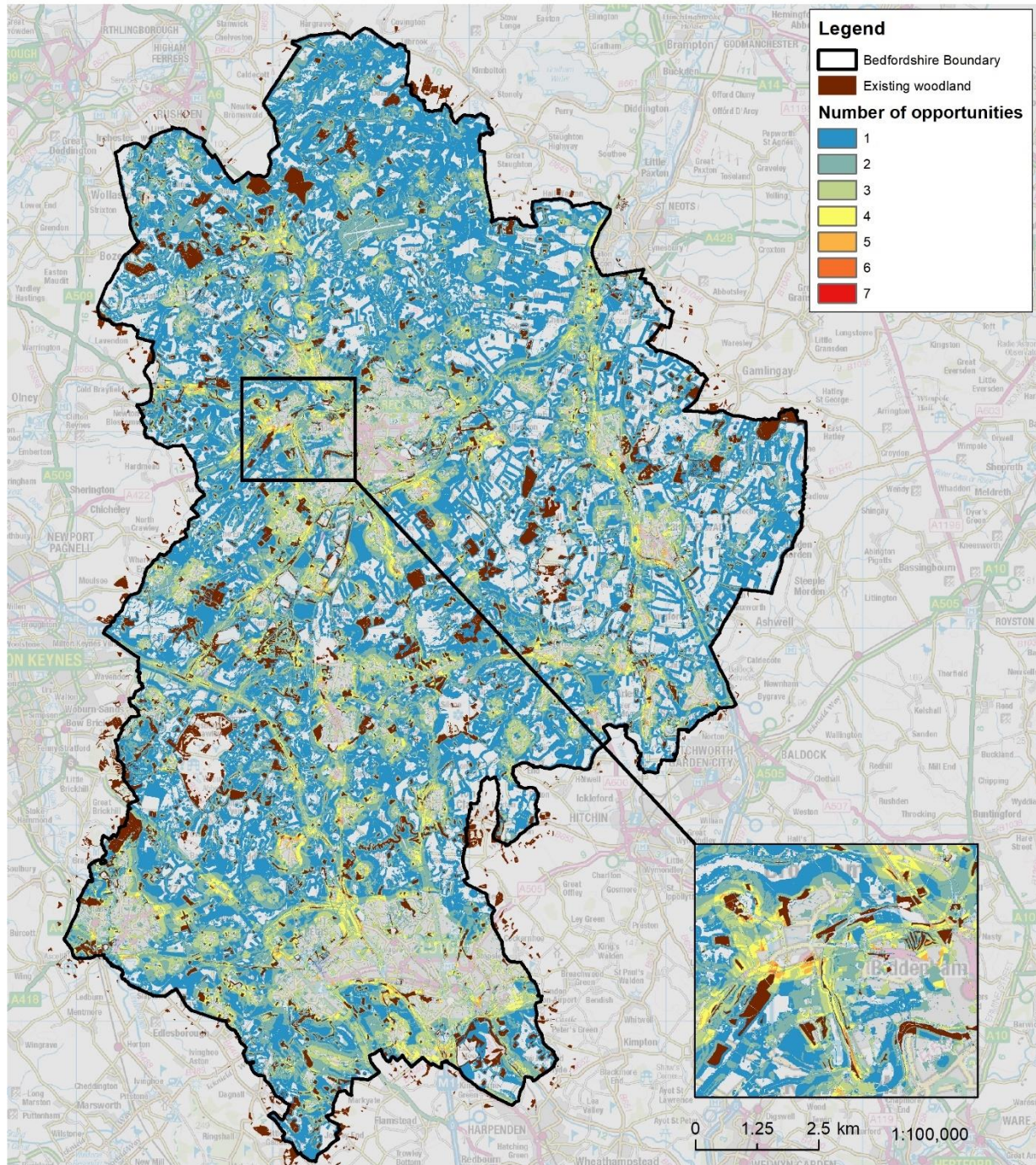
Combined opportunities for new semi-natural grasslands are not quite as extensive as for woodland, but are still spread across the whole county (Figure 49). Similarly to woodland, there are many areas that support multiple opportunities, with the majority of these being close to the towns. When opportunity areas are restricted to areas that deliver biodiversity benefits for this habitat (Figure 50), opportunity areas are reduced, although still extensive, and are particularly focussed in areas to the east and south-west of Bedfordshire that contains a reasonable amount of existing semi-natural grasslands.

8.3 Combined opportunities for new wet grassland and wetlands

Opportunities for new wet grassland and wetlands were mapped in the same way as for semi-natural grassland, except that all opportunities were restricted to areas within the indicative floodplain. Thus four out of the seven services were included, with air quality, noise, and local climate excluded. Wetland habitats can be effective at reducing water flow and enhancing water quality.

The location of opportunities for this habitat type is far more restricted than for the previous two (Figure 51), due to the requirement for being located on floodplains. The river networks in the north and centre of the county offer some opportunities, predominantly the River Great Ouse, the River Ivel and their tributaries, but there are very few opportunities in the far south of Bedfordshire and Luton. A few of these locations are opportunity areas for two or more services. There are very few opportunities close to existing habitats (Figure 52).

Combined opportunities for new woodland



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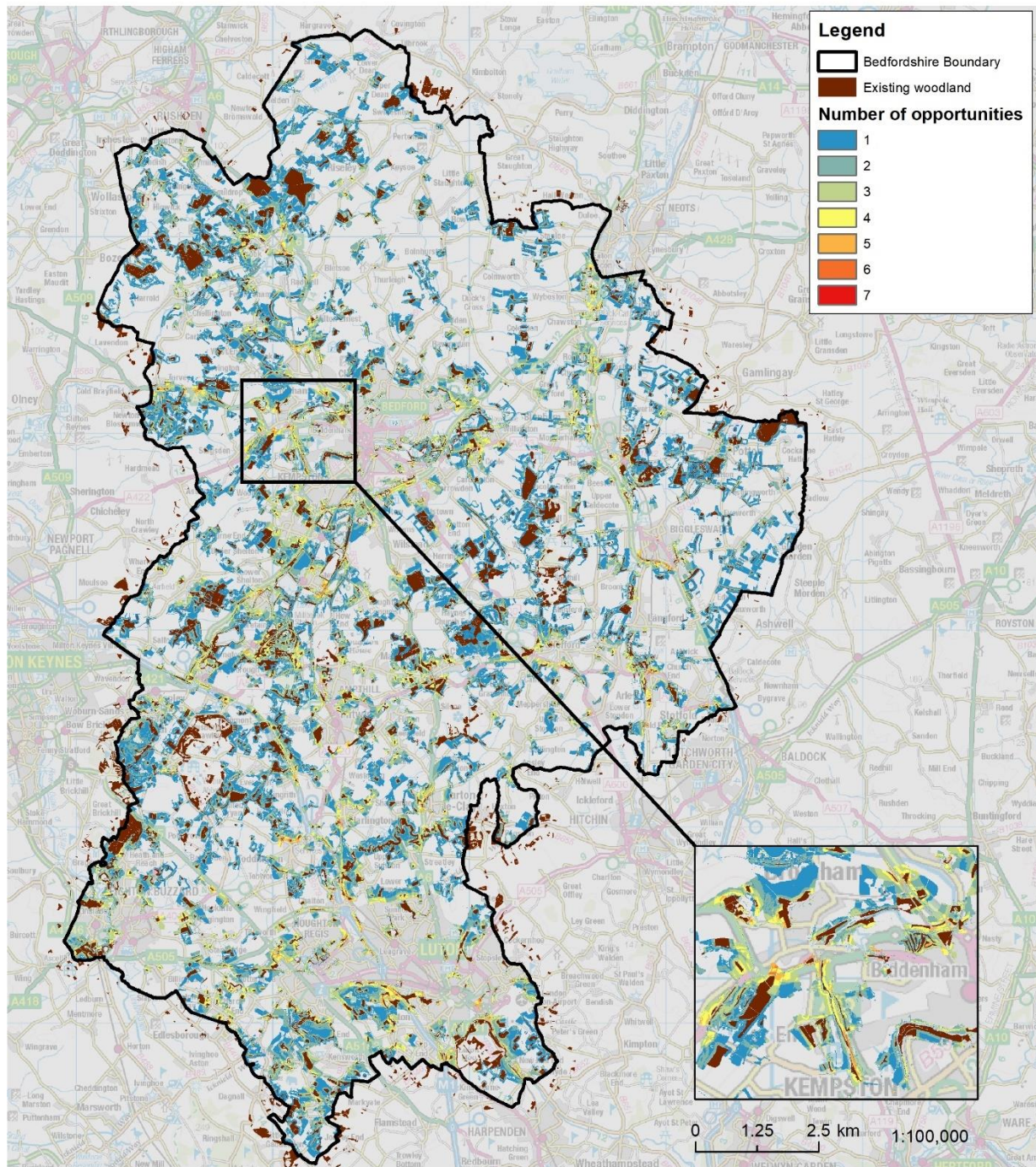
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Figure 47 Existing broadleaved and mixed woodland. and combined opportunities for new woodland across Bedfordshire.

Combined opportunities for new woodland - Biodiversity focus



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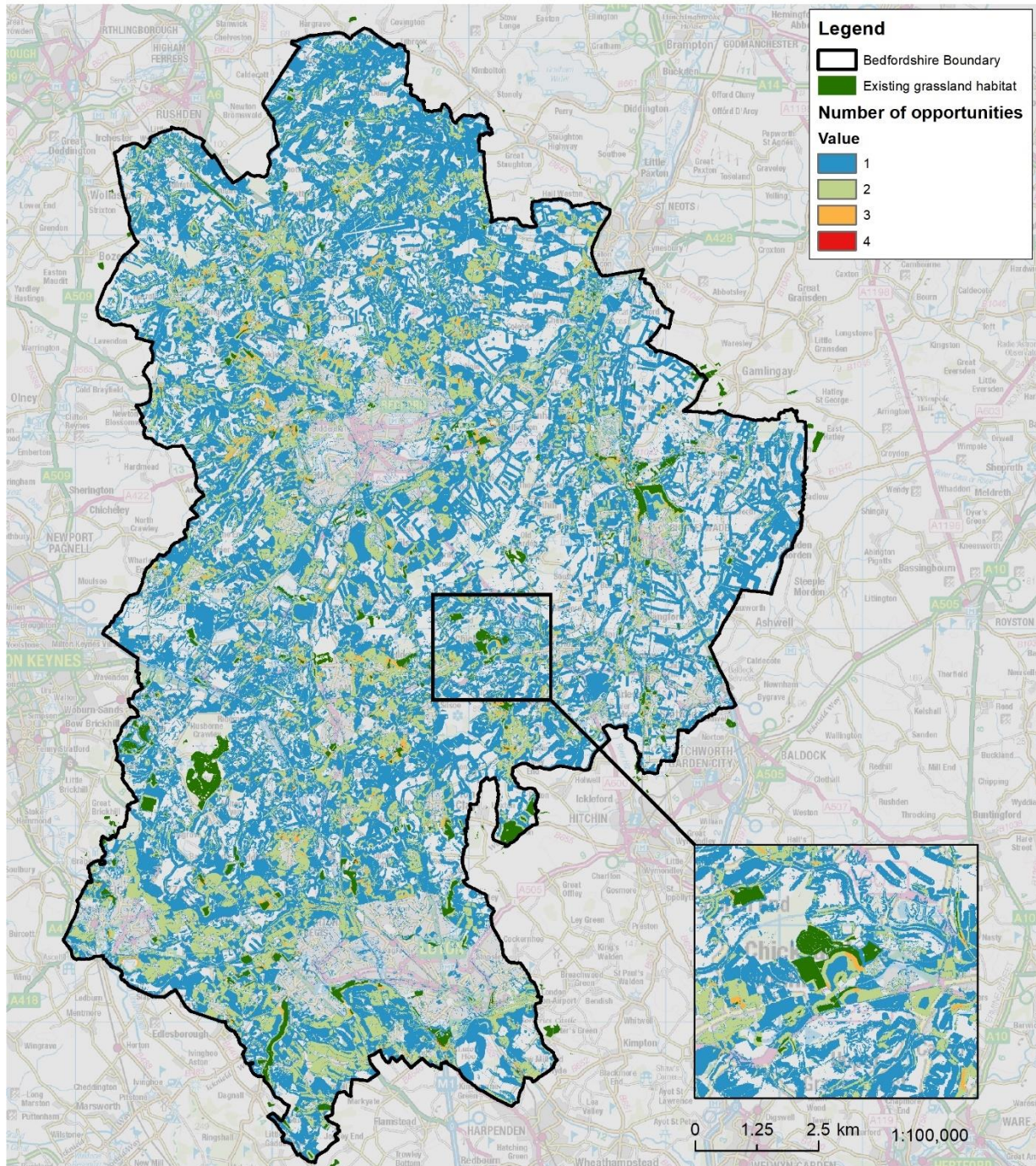
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Figure 48 Combined opportunities for new woodland across Bedfordshire, restricted to areas that are ecologically connected to existing woodlands.

Combined opportunities for new semi-natural grassland



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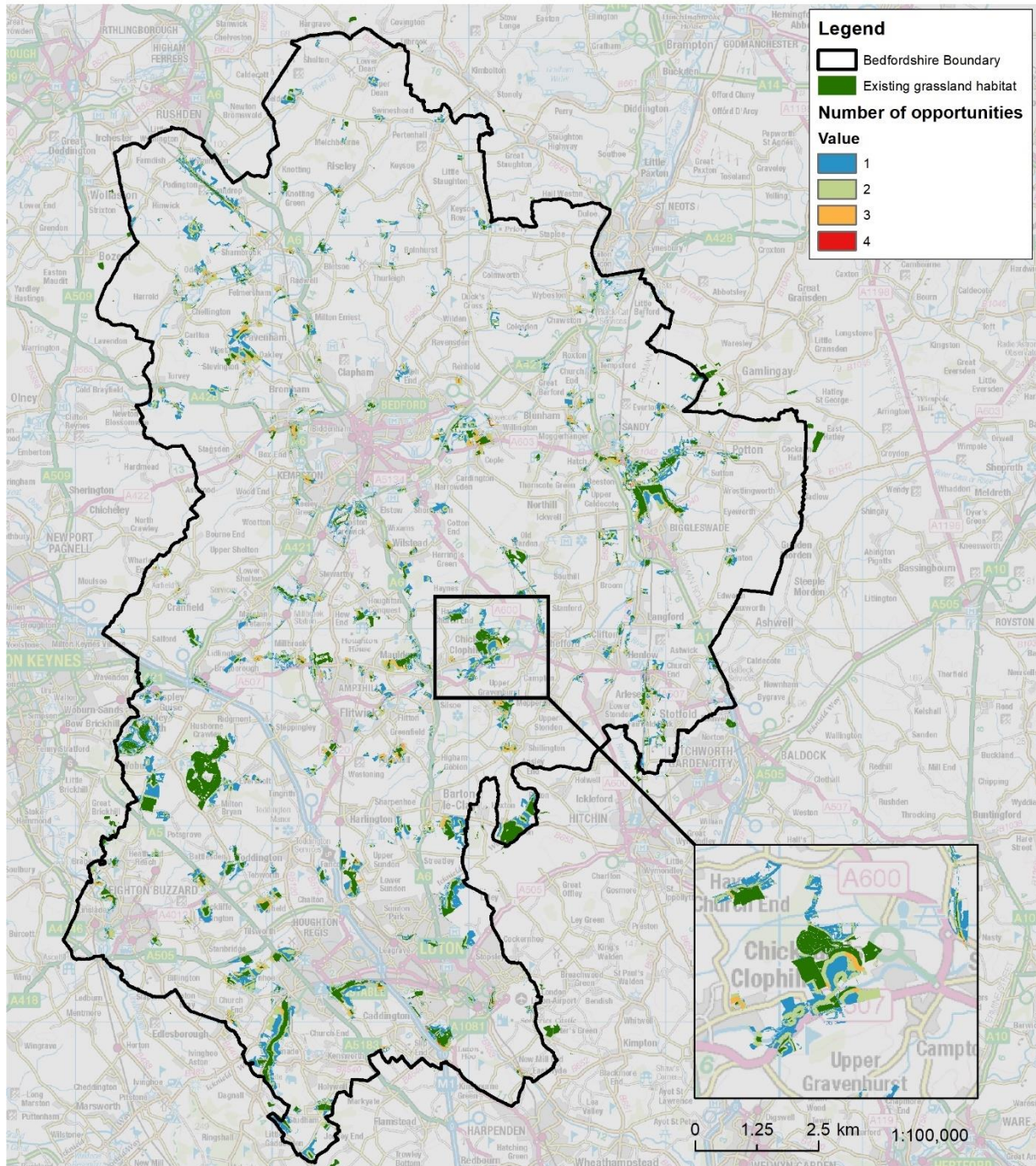
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Figure 49 Existing semi-natural grasslands. and combined opportunities for new grasslands across Bedfordshire.

Combined opportunities for new semi-natural grassland - Biodiversity focus



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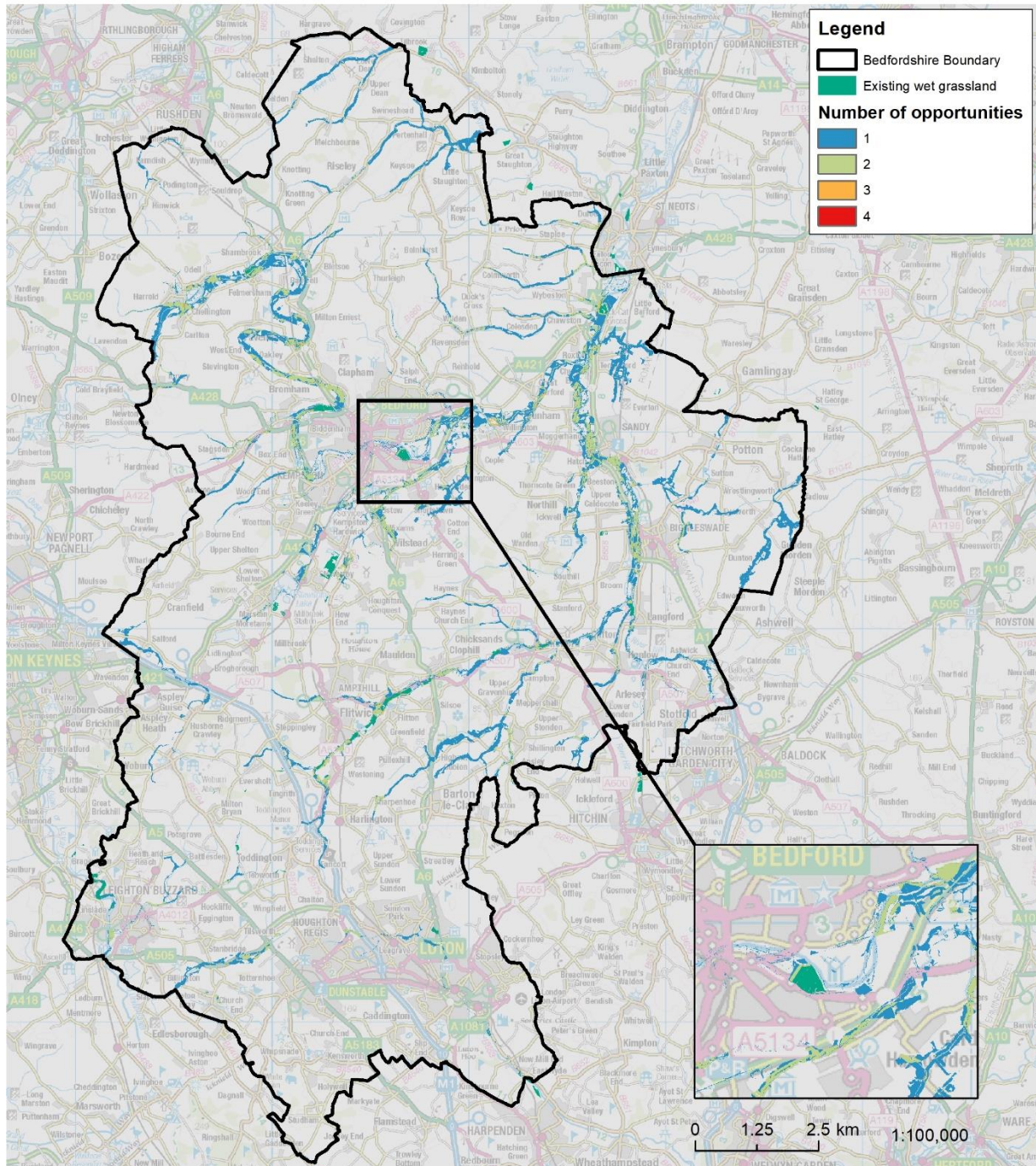
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Figure 50 Combined opportunities for new semi-natural grasslands across Bedfordshire, restricted to areas that are ecologically connected to existing grasslands.

Combined opportunities for new wet grasslands and wetlands



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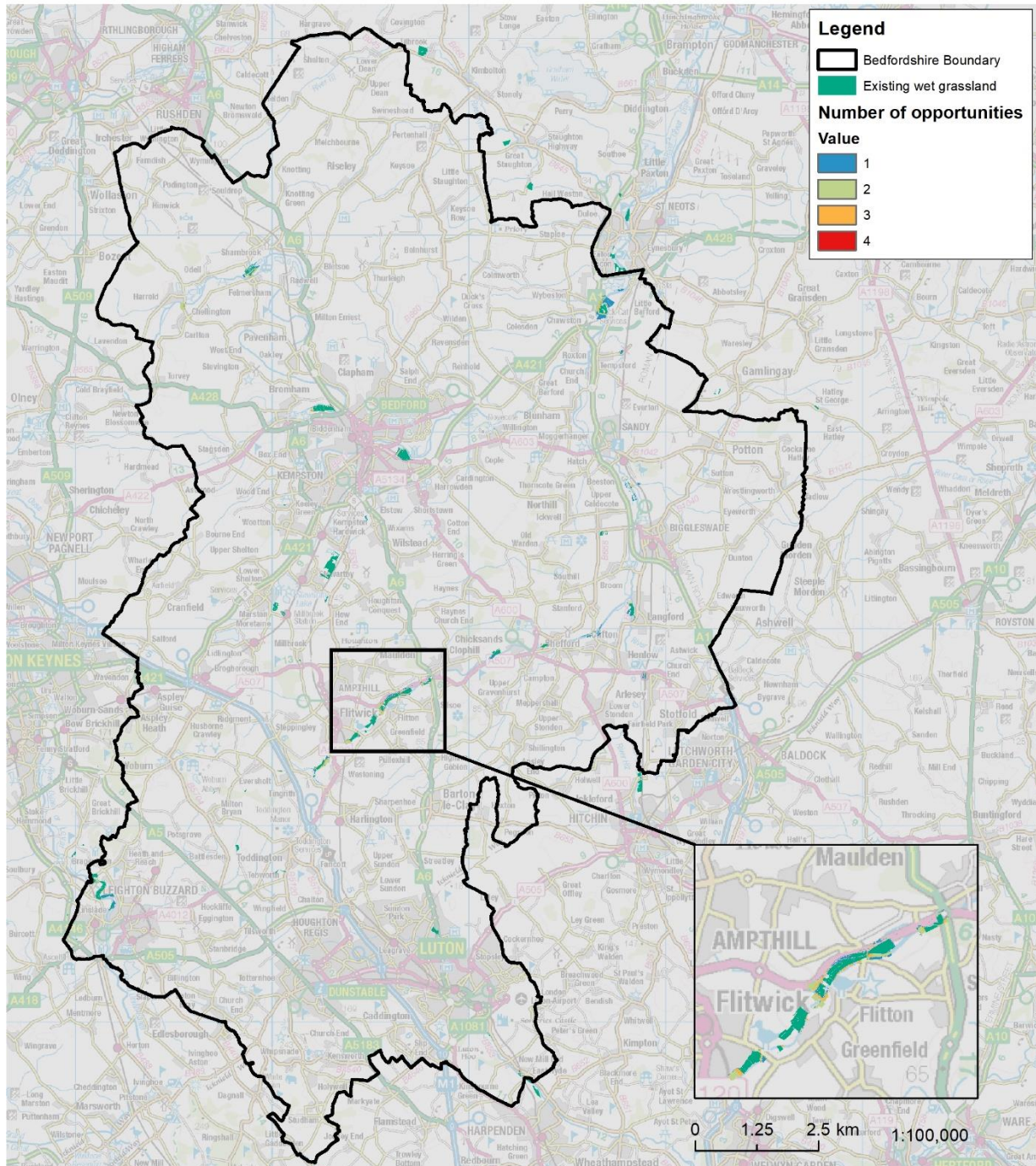


Figure 51 Existing wet grasslands and wetlands. and combined opportunities for new wetlands across Bedfordshire.



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Combined opportunities for new wet grasslands and wetlands - Biodiversity focus



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Figure 52 Combined opportunities for new wet grasslands and wetlands across Bedfordshire, restricted to areas that are ecologically connected to existing wetlands.

9. Conclusions

This project has produced a detailed habitat basemap using the best available data to assign Phase 1 habitat types to each plot of land and building across the whole of Bedfordshire. It provides the most comprehensive and detailed coverage that is possible at this time and should have a wide range of applications. Bedfordshire is dominated by arable land and improved grassland, but there are also extensive areas of woodland in the north and centre of the county associated with the Yardley Whittlewood Ridge and the Greensand Ridge respectively. Tree and woodland categories take up 9% of the county, which is below the national average. Built up areas, infrastructure and gardens make up a combined 8% of the area.

The ecosystem service maps demonstrate the spatial pattern of provision of ten different ecosystem services, and the demand for four. The maps demonstrate that the woodland asset is important for high levels of provision of carbon storage, carbon sequestration, air quality, noise, local climate and water flow regulation, and timber/woodfuel production benefits. The mapping also shows that many of these woodlands provide hotspots of access to nature. Ecosystem delivery is greatest in the central and northern part of the county, where the majority of woodland is located. Food production is also greater in the north and east.

The demand maps of air quality, noise, local climate regulation, and accessible nature show clearly the importance of ecosystem service delivery to the urban centres in Bedfordshire, with the highest demand in Bedford and Luton. Urban areas adjacent to the road network are also hotspots for demand. The capacity to provide these services can be quite high in northern and central Bedfordshire, where woodland and other semi-natural habitats occur, and these areas should be protected and expanded, even if not important for biodiversity. In the southern end of the county there is much more of a mismatch between demand and supply.

The monetary value of the benefits provided by natural capital are large: £208 million per annum across the whole of Bedfordshire, representing an asset value (present value) of £6.64 billion over 50 years. Benefits in terms of air quality regulation, recreation and physical health are particularly large. Overall values are larger for Beds Borough and Central Bedfordshire, but when calculated on a per hectare basis are highest for Luton, where publicly accessible greenspace will be providing benefits of high value, particularly for recreation and physical health. When carbon sequestration is balanced against agricultural emissions, Bedfordshire as a whole is a net emitter of carbon dioxide of 33,000 tonnes per year, at a cost of £2.3 million annually. This greenhouse gas balance is an important figure as it represents the agriculture and land use, land use change and forestry (LULUCF) sector for which national emissions information is collected. To move towards net zero in this sector (assuming no changes in agriculture) would require the planting of approximately 3,750 ha of broadleaved woodland, occupying about 3.0% of the land area of Bedfordshire. Note that this does not include greenhouse gas emissions from other sectors, such as transport, and manufacturing and construction.

An assessment of Accessible Natural Greenspace Standards (ANGSt) has shown that Bedfordshire has a good provision of medium sized greenspaces, with the vast majority of residents living within 2km of a 20 ha site and within 5km of a 100 ha site. However, only 42% of people live within 300m of a small greenspace (at least 2ha in size) and there are no large greenspaces in the county over 500 ha in size. Creating new accessible greenspaces should therefore focus on creating small neighbourhood greenspaces and on expanding existing sites to create large flagship site(s).

Habitat opportunity maps have been created showing where new habitats could be created for biodiversity enhancement for three broad habitat types, as well as for six different ecosystem services. Note, however, that the maps have not been ground-truthed or checked against other data, and so individual locations will need to be assessed further before being taken forward. The maps should be considered as a resource to highlight potential locations for habitat creation or restoration projects, rather than as an end in themselves. The maps are best examined on a Geographic Information System, and GIS layers have been provided to project partners.

The opportunity maps for biodiversity highlight areas that are best located in terms of their connectivity with existing habitat patches and are, therefore, most appropriate from an ecological point of view. Enhancing connectivity and expanding habitat networks is a key priority for biodiversity conservation and climate change adaptation at present, and these maps can be used as the basis for creating a Nature Recovery Strategy across the county. They also highlight areas where biodiversity offsetting should be focussed, under the new requirement to achieve biodiversity net gain for all new developments. Furthermore, the opportunity maps for ecosystem services highlight the best areas to create habitats to enhance the delivery of each ecosystem service in turn, based on where demand is high and capacity is currently low. These can be used to identify project locations to meet each particular need or can be combined to show areas where new habitat can deliver multiple objectives. If combined with the biodiversity opportunity maps, they can be used in offsetting projects to deliver additional benefits. Access to greenspace for people can be highly beneficial for physical and mental health and well-being and the monetary value of these benefits can be extremely high. Habitats for biodiversity and green infrastructure (GI) in general can also make important contributions to all the other ecosystem services mapped in this report. Semi-natural habitats are multi-functional, meaning that an investment focussing on one benefit (e.g. natural flood risk management), can deliver multiple additional benefits, hence offering excellent value for money.

9.1 Next steps

The maps and GIS layers produced for this project provide an extensive evidence base with a wide range of potential applications. The layers can also be combined in a wide variety of different ways, depending on the issue being addressed, the key priorities, and the location. Hence it would be possible to present the results in a number of different ways and there would be merit in producing different outputs for different audiences. It is also important to consider the further dissemination of results through, for example, a mapping portal, online storymap, or interactive pdf.

As well as dissemination of results, there are a number of possible projects that could be developed to take this work forward. Here we outline two possible projects:

1. Map habitat quality and ground-truth basemap

The basemap presented in Section 2 provides a detailed map of habitats across Bedfordshire, enabling an assessment of the type, extent and spatial attributes of habitats. However, it is based on the data available to us at the time, which did not include all habitat information that has been collected across the county. This means that the basemap is as good as it can be given the data, but will contain some errors. In particular it is known that it does not contain all areas of heathland, as these are often small patches of land, not captured well by coarse national scale datasets. In addition, it does not include an assessment of habitat quality (condition).

Both of these issues could be addressed by bringing in additional data sets and by engaging local volunteers in fieldwork to visit and assess sites. The **basemap could then be updated** and **opportunity mapping for heathland** then added to the outputs. A **habitat condition map** could also be created based on the data collected, supplemented by existing data on condition of SSSIs, and supported by a number of careful assumptions developed recently for a project for the OxCam Arc Local Natural Capital Plan Project. The opportunity maps presented in Sections 7 and 8 are focussed on creating new habitats, rather than enhancing existing ones, hence mapping habitat quality would provide a more complete understanding of Bedfordshire's natural capital assets by highlighting requirements for habitat restoration. The data could also be used to create a baseline biodiversity assessment using the Biodiversity Metric tool (that assigns the number of biodiversity units to each habitat parcel based on the condition and distinctiveness of the habitat). This would provide a baseline to enable the local authorities to monitor whether they are achieving net gain in biodiversity.

2. Refine most promising sites to take forward and other additional work

As stated above, the opportunity maps should be considered as a tool to guide decision making regarding the best locations to target for habitat creation projects. A number of steps are recommended in terms of taking this process forward:

- The maps should be compared to other studies such as green infrastructure plans, national maps created by Natural England, as well as Local Plan policies and strategies, to target particular areas to take forward.
- It is recommended that a workshop is held with local stakeholders in each area, to consider priorities for different zones within the study area. For example, the current biodiversity opportunity maps overlap, which means that in some areas two or three of the different habitats appear in the opportunity maps for the same location. In addition, different ecosystem services may be considered more important in particular areas. Simple rules could be created to target certain habitats or certain ecosystem services in different locations. The workshop could also be used to consider prioritising particular areas (projects) to take forward or to weight criteria to assess projects.
- A previous report mapped biodiversity opportunities across the area¹⁹ based predominantly on mapping 300m buffers around existing sites. There would be merit in additional work to bring some extra information on habitats contained in that report into the connectivity based opportunity mapping presented here.
- The historic analysis presented in Section 3 could also be integrated more fully, by using past land use patterns to help guide the most appropriate habitats to create in certain locations.
- Some sites of importance to biodiversity can be sensitive to disturbance. The current work does not consider disturbance or carrying capacity at existing sites, so there would be merit in a small piece of further work to consider these aspects when deciding on areas for investment. This could highlight where enhancing access was and was not appropriate and in some locations, alternative nearby sites could be created to relieve pressure at sensitive sites.

¹⁹ Rebuilding Biodiversity in Bedfordshire & Luton (2006). Bedfordshire and Luton Biodiversity Forum.

9.2 Delivering natural capital projects

Priority locations can be taken forward in a number of different ways. This includes:

- A number of specific habitat creation projects could be worked up into costed proposals. These could be offered as biodiversity offsetting and biodiversity net gain projects funded through the development process. Large and ambitious projects could potentially be put forward as part of the OxCam Arc proposals.
- **A Local Nature Recovery Strategy.** These will become mandatory under the forthcoming Environment Act and overlap heavily with the work presented here. The emphasis of these is on biodiversity opportunities, but with consideration of wider natural capital benefits. Hence, the combined opportunity maps that focus on biodiversity opportunities (Figures 48, 50 and 52) could form the basis of a LNRS, with the prioritisation work described above used to determine the best areas to take forward in the Strategy.
- Opportunity areas could be targeted through agri-environment schemes, particularly the new Environmental Land Management Scheme (ELMs) which will be paying farmers for environmental enhancements that deliver a range of public goods.
- Woodland areas could be taken forward through the Carbon Guarantee Scheme or other carbon offsetting initiatives, as well as more traditional woodland grant schemes. Location has little impact on the amount of carbon sequestered by such schemes, so additional benefits (as described in this report) could be used to help determine the best locations for such projects.
- A range of additional mechanisms exist for taking forward projects that deliver ecosystem services benefits. This includes projects that focus on working with natural processes for slowing the flow (natural flood risk management) and water quality, such as catchment sensitive farming. Opportunities for planting trees to enhance air quality could be part of air pollution reduction strategies, and increasing public access to natural greenspace could be incorporated into wellbeing initiatives and ideas around green prescribing.

It would be possible to take forward this work through a **Natural Capital Investment Plan**. This would involve identifying key projects / locations to take forward, determining the costs and monetary benefits of habitat creation at these sites and hence the return on investment, considering appropriate financial mechanisms and funding sources, and then presenting the plans in the form of a prospectus.

Annex 1: Additional biodiversity opportunity maps



Landscape permeability: Broadleaved and mixed woodland species

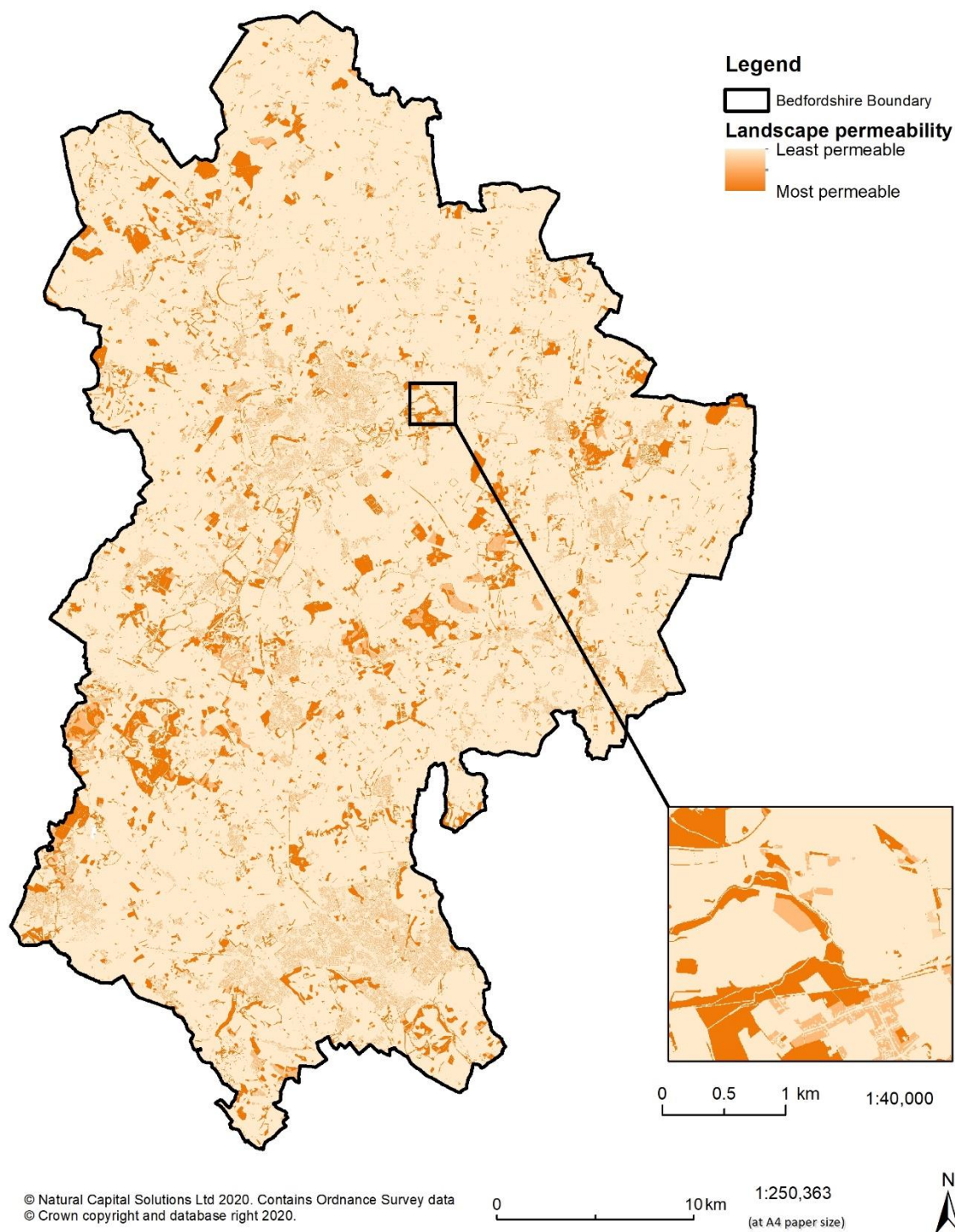
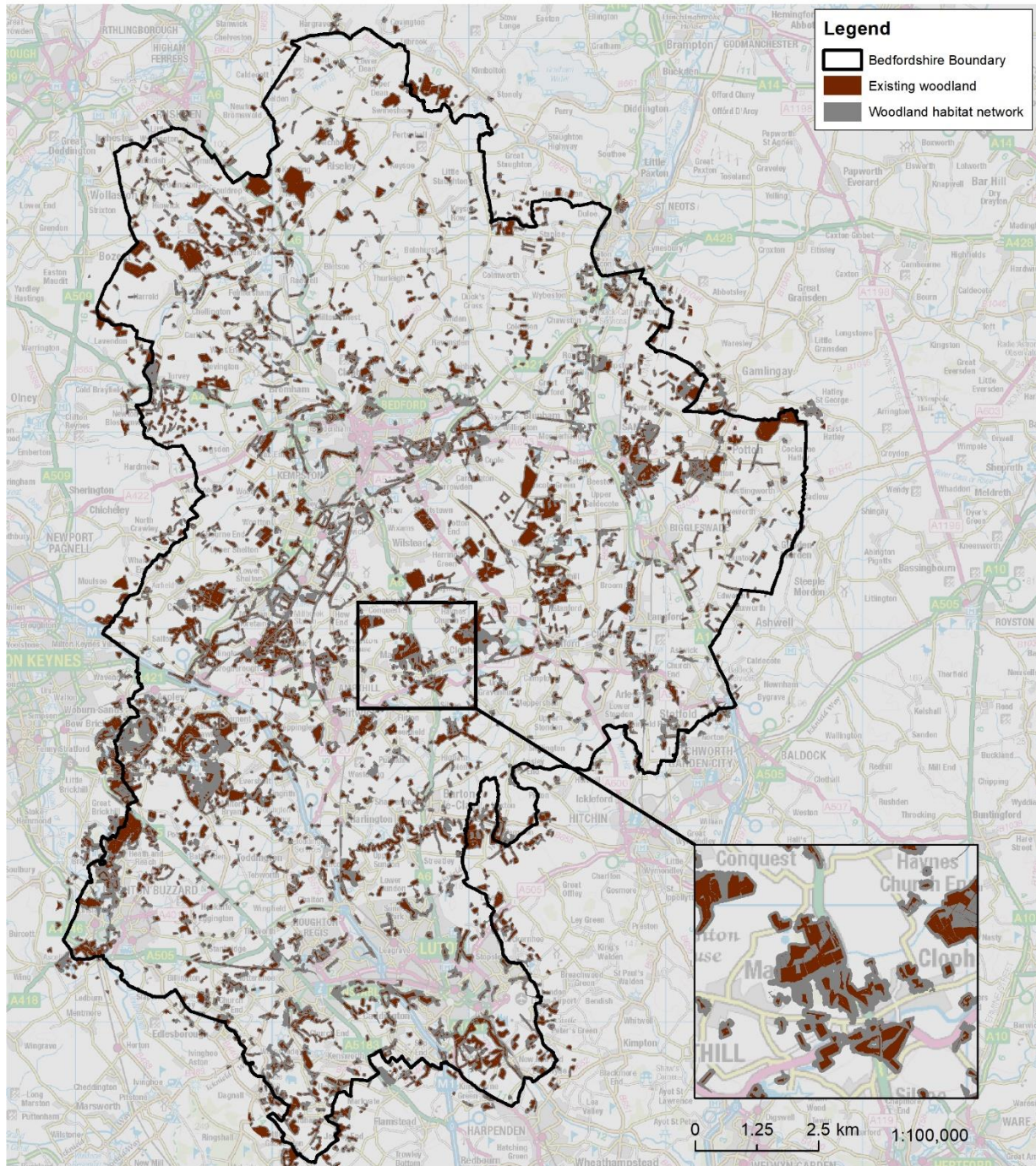


Figure A1 Landscape permeability for typical broadleaved and mixed woodland species across Bedfordshire.

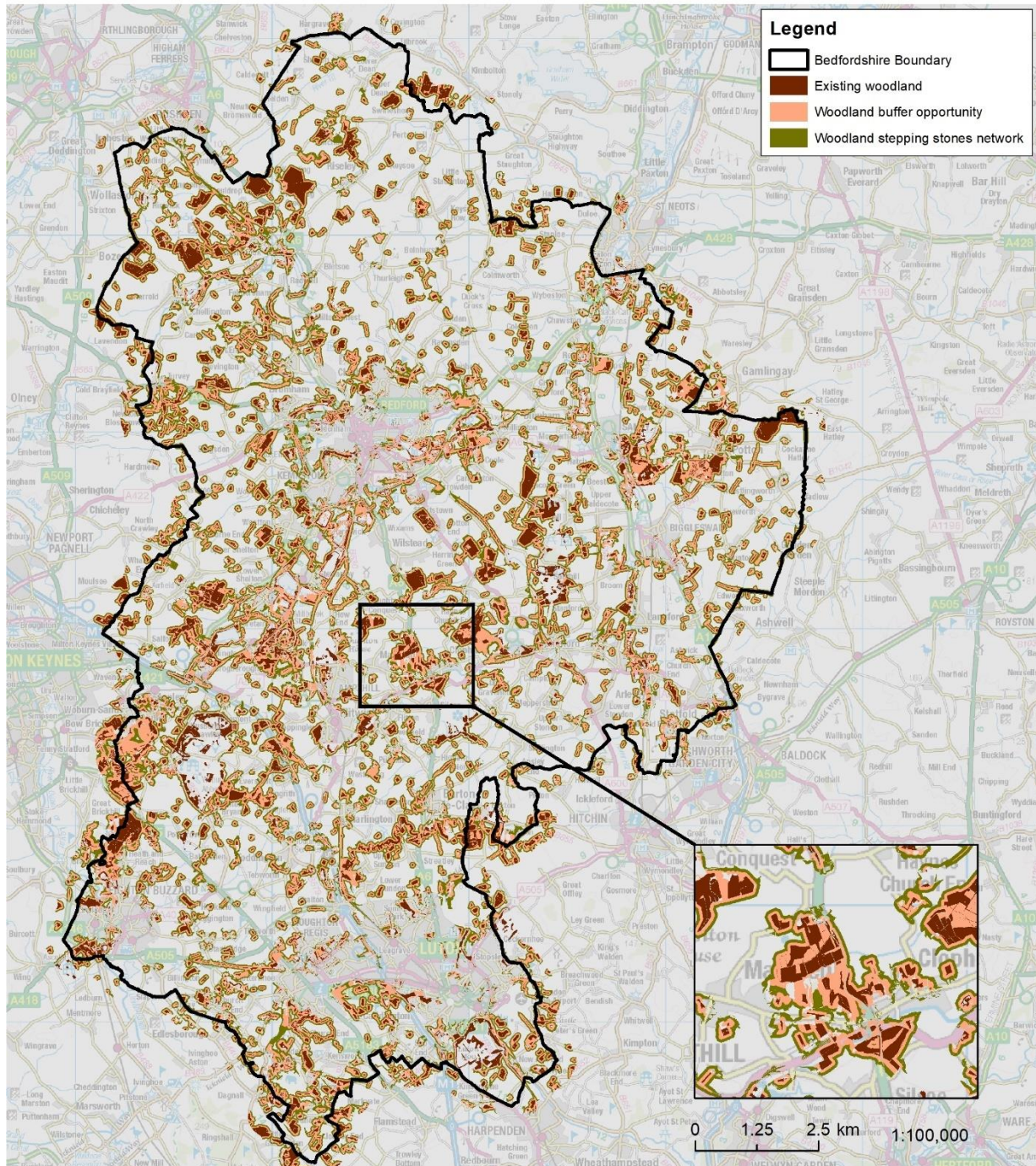
Broadleaved and mixed woodland habitat network



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Figure A2 Habitat network for broadleaved and mixed woodlands across Bedfordshire.

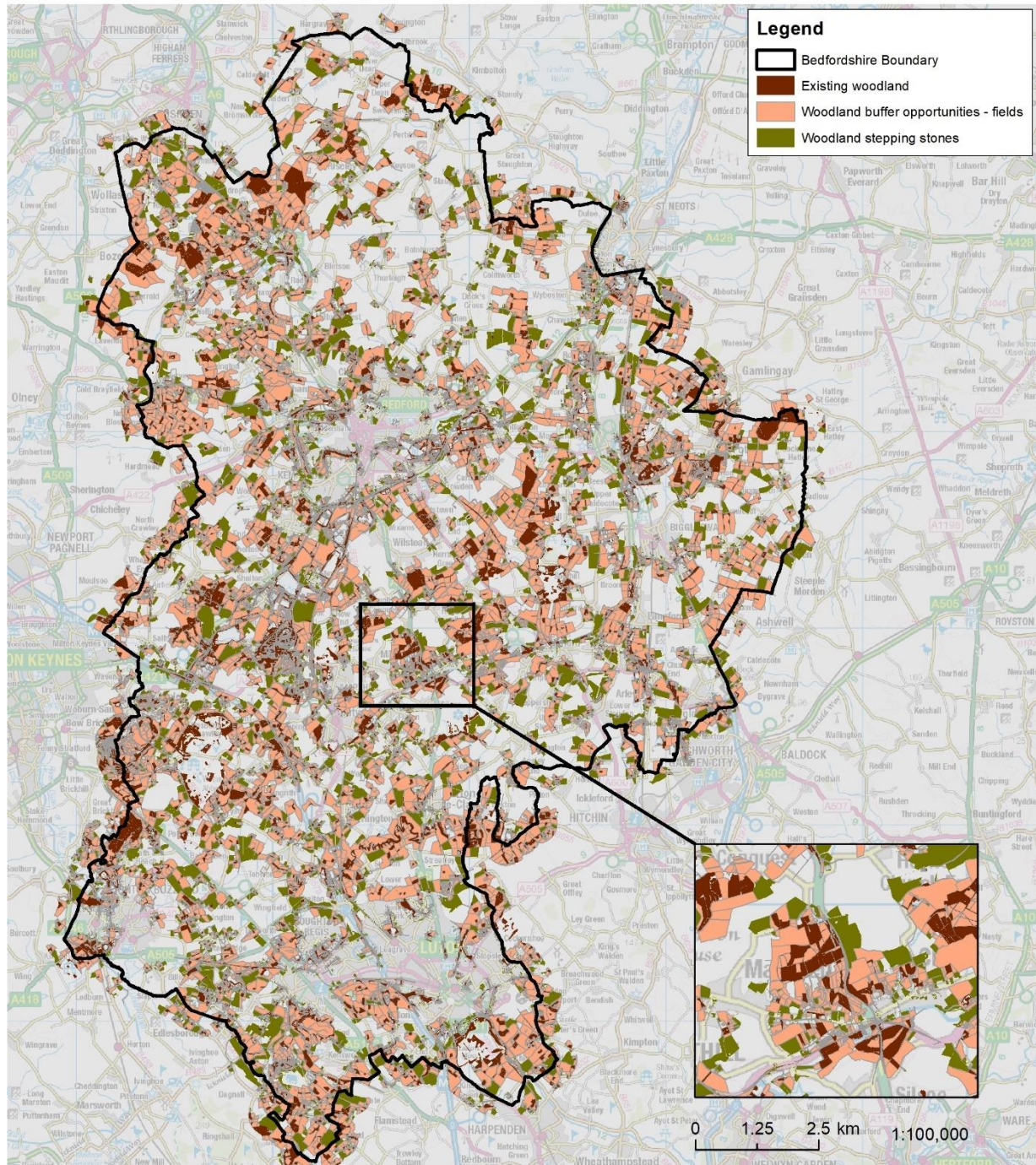
Broadleaved and mixed woodland habitat opportunity 1



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Figure A3 Buffer biodiversity opportunity areas for broadleaved and mixed woodlands across Bedfordshire.

Broadleaved and mixed woodland habitat opportunity 2



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0 10 km

1:250,000
(at A4 paper size)



Figure A4 Field scale biodiversity opportunity areas for broadleaved and mixed woodlands across Bedfordshire.



Landscape permeability: Wet grassland and wetland species

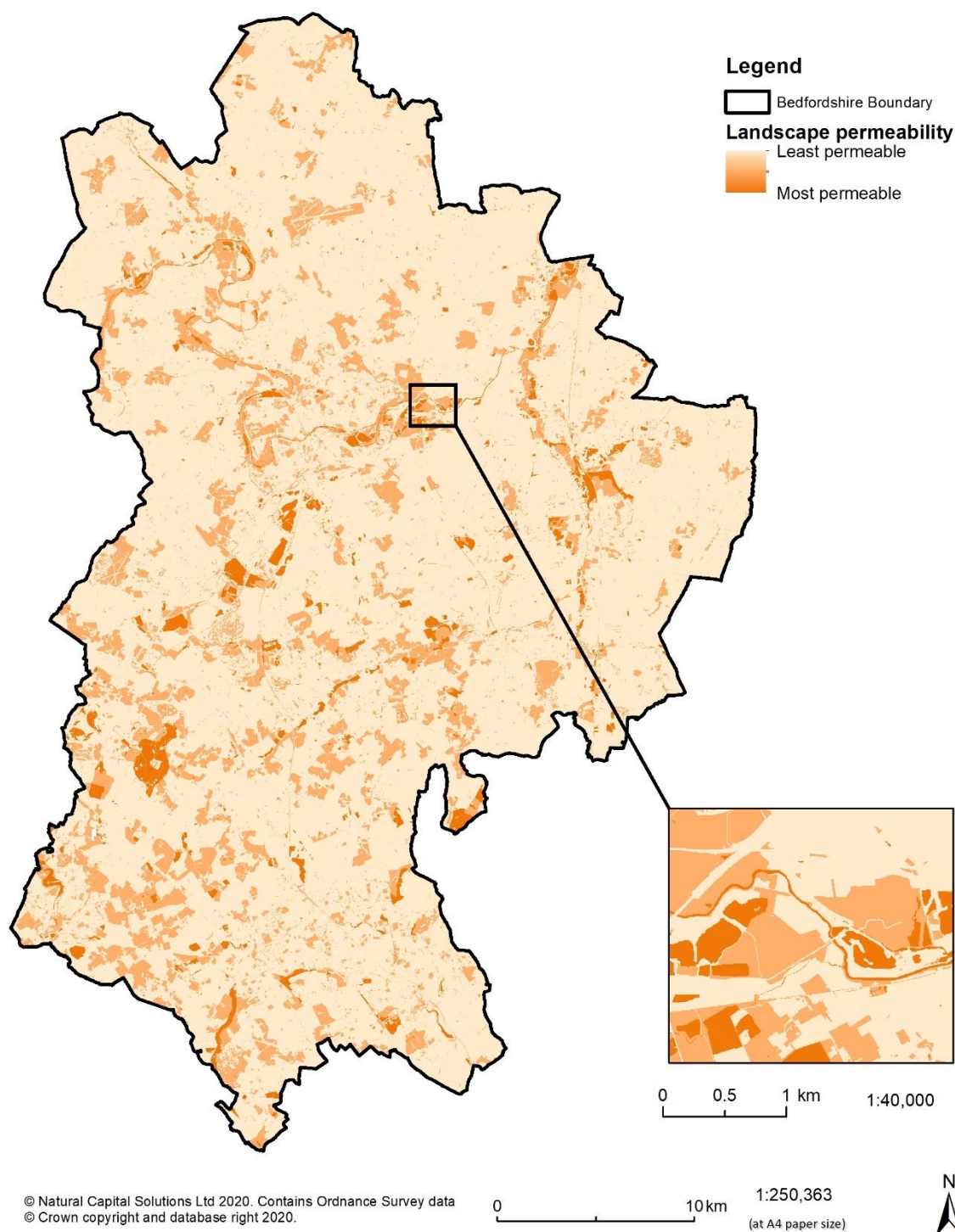
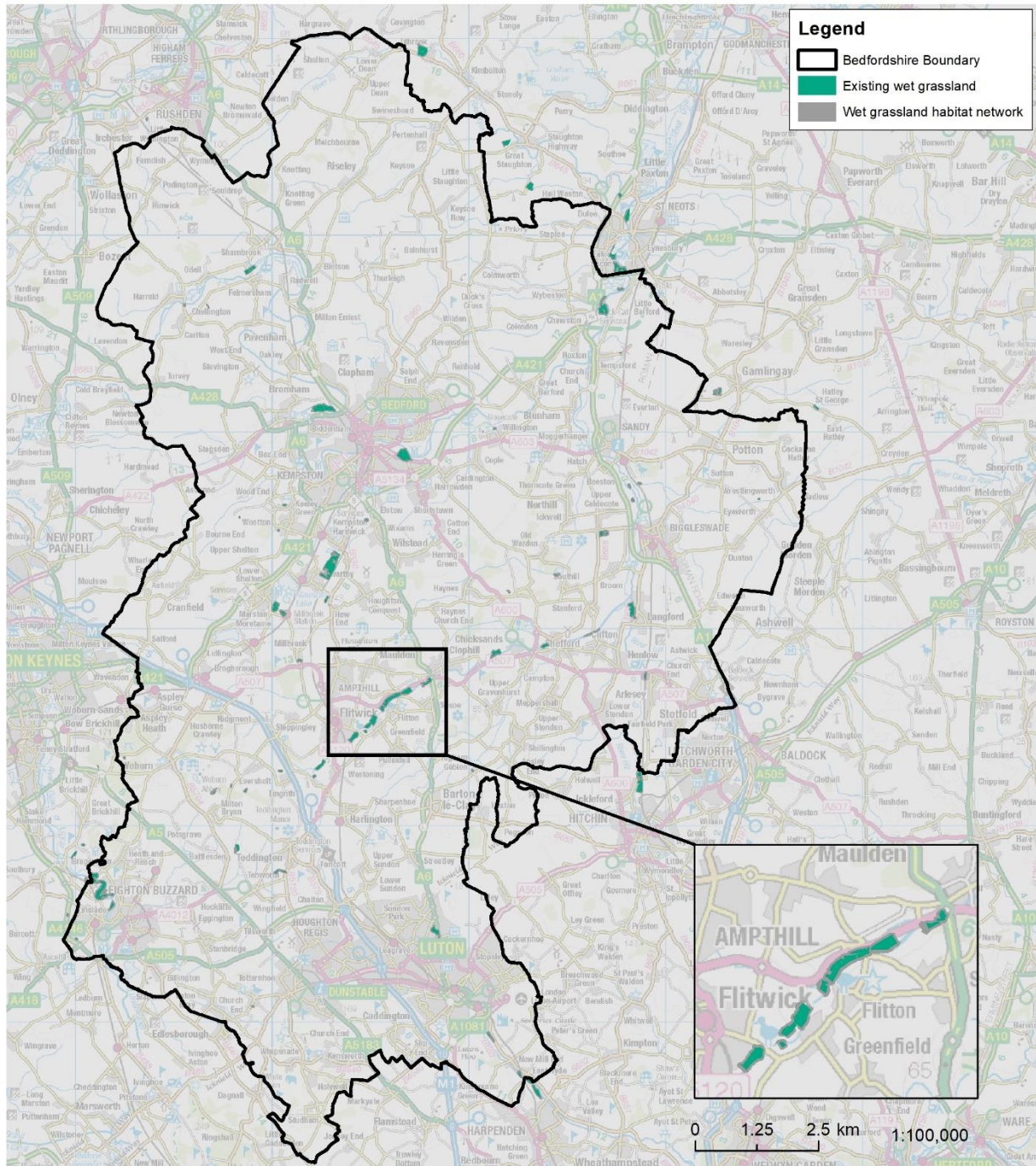


Figure A5 Landscape permeability for typical wet grassland and wetland species across Bedfordshire.

Wet grasslands and wetlands habitat network

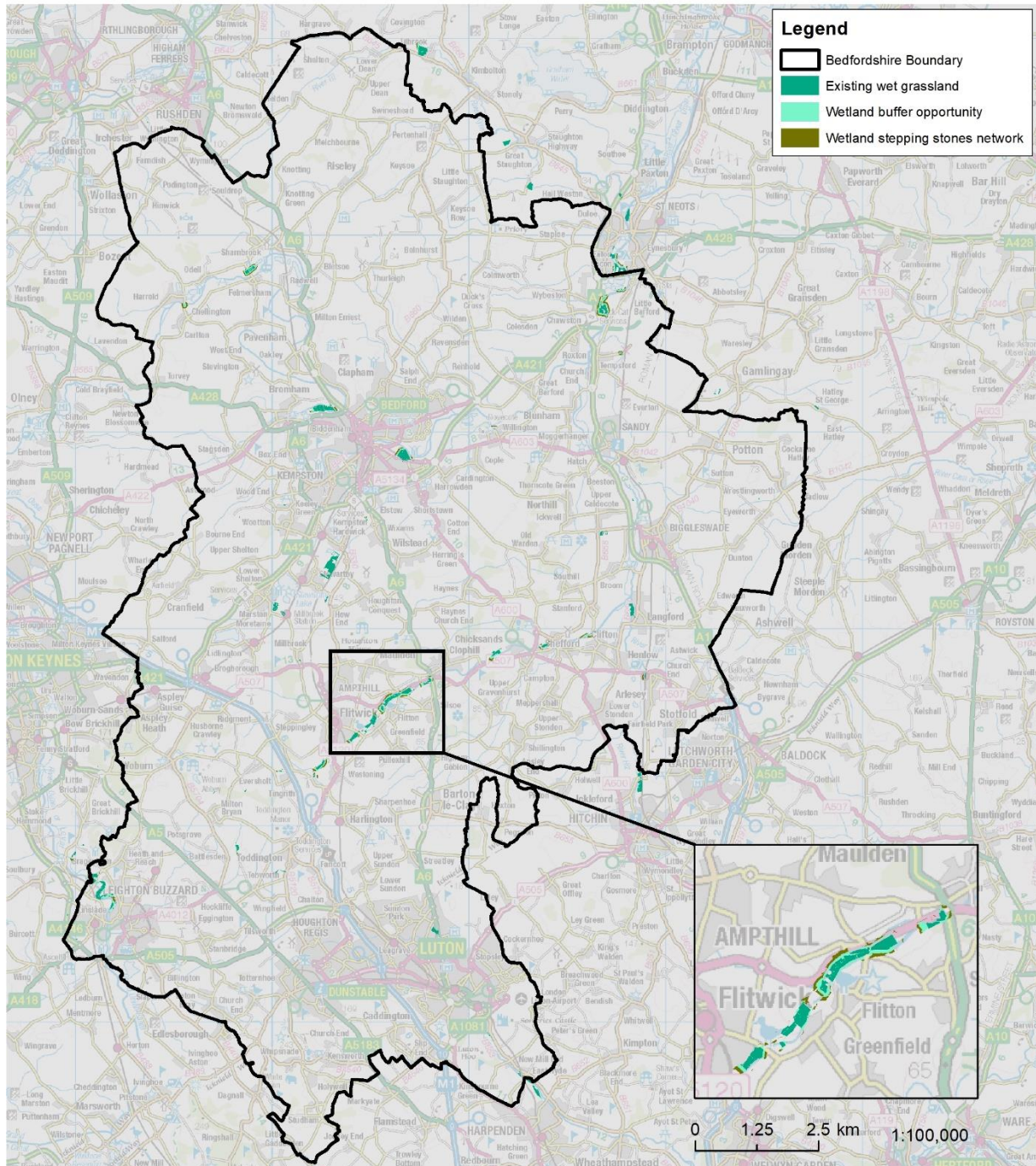


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0 10 km 1:250,000
(at A4 paper size)

Figure A6 Habitat network for wet grassland and wetlands across Bedfordshire.

Wet grasslands and wetlands habitat opportunity 1



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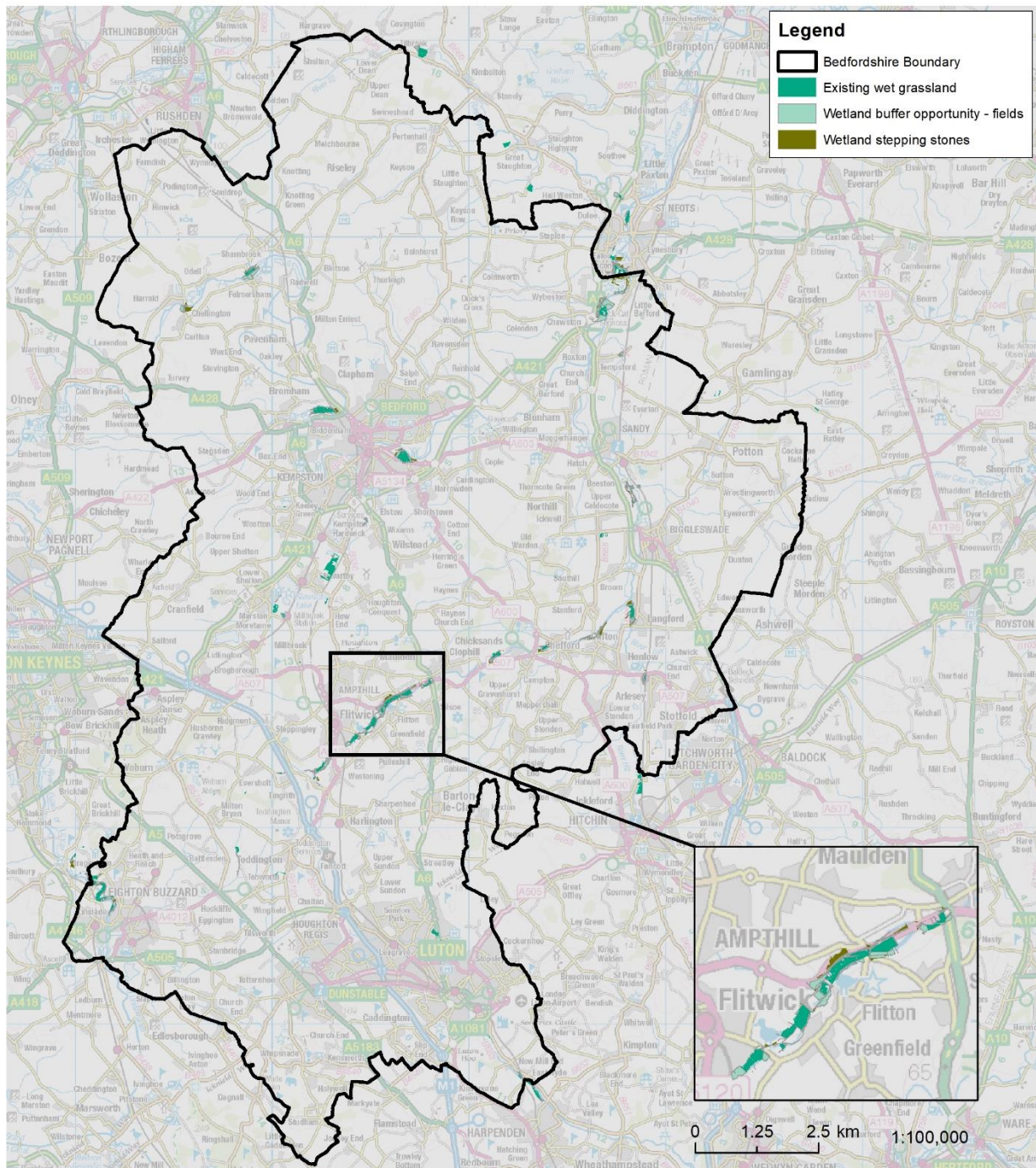
0 10 km

1:250,000
(at A4 paper size)



Figure A7 Buffer and stepping-stone biodiversity opportunity areas for wet grassland and wetlands across Bedfordshire.

Wet grasslands and wetlands habitat opportunity 2



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0 10 km

1:250,000
(at A4 paper size)



Figure A8 Field scale biodiversity opportunity areas for wet grassland and wetlands across Bedfordshire.

Annex 2: Technical Appendix for Baseline ecosystem service valuation

A2.1 Air quality regulation

The ability of the woodland and grassland vegetation in Bedfordshire to absorb particulate matter $\leq 2.5\mu\text{m}$ in diameter ($\text{PM}_{2.5}$) was measured. Quantifying the physical flow of the air quality regulation service provided by the woodland and grassland was based on the absorption calculation in Powe & Willis (2004²⁰) and the method in ONS (2016²¹). The deposition rates for $\text{PM}_{2.5}$ in coniferous woodland, deciduous woodland, and grassland were taken from Powe & Willis (2004). Average background pollution concentrations for $\text{PM}_{2.5}$ were calculated using Defra data (Modelling of Ambient Air Quality 2018 and 2001). The surface area index of coniferous and deciduous woodlands in on-leaf and off-leaf periods was taken from Powe & Willis (2004). The proportion of dry days in 2020 (rainfall $<1\text{mm}$) for Bedfordshire was estimated using MET office regional value data for the Midlands (<http://www.metoffice.gov.uk/climate/uk/summaries/datasets>). The proportion of on-leaf relative to off-leaf days was estimated at the UK level using the average number of bare leaf days for five of the most common broadleaf tree species (ash, beech, horse chestnut, oak, silver birch) in the UK using the Woodland Trust data averages tool.

The air quality regulation service was valued using guidance from Defra that provides estimates of the damage costs per tonne of emissions across the UK (Defra 2019²²). These are social damage costs based on avoided mortality and morbidity. Therefore, it was assumed that the value of each tonne of absorbed pollutant by the woodland and grassland habitats was equal to the average damage cost of that pollutant. The $\text{PM}_{2.5}$ damage cost estimates depend on the location (urban size or rural) and source of pollution. The local authority areas were considered to fall into three different categories: urban medium, urban small, and rural, according to the Defra ONS (2016)²³ categorisation at ward level, and the damage cost levels associated with these categories were used and adjusted appropriately for each local authority area. When calculating the present value over 50 years, the absorption rate was assumed to be constant. The Defra damage cost of $\text{PM}_{2.5}$ is in 2017 prices, and so was adjusted to reflect inflation up to 2020. The value was also subject to an uplift of 2% per annum to reflect the assumption that willingness to pay for health will rise in line with economic growth, as recommended by Defra (2019). The central damage cost figures are presented in the monetary flow estimates, low and high damage costs from Defra (2019) were used in the sensitivity analysis.

A2.2 Carbon sequestration

The annual physical flow of the carbon sequestration service was calculated as in Section 4.2 above. Monetary flows were calculated using the Government's non-traded central carbon price for 2020 (DBEIS 2019²⁴). We use the non-traded carbon price because it is a better reflection of the 'real' value

²⁰ Powe, N., A., & Willis, K.G. (2004) Mortality and morbidity benefits of air pollution (SO_2 and PM_{10}) absorption attributable to woodland in Britain. *Journal of Environmental Management*, 70, 119-128.

²¹ ONS (2016) Annex 1: Background and methods for experimental pollution removal estimates. UK National Accounts.

²² Defra (2019) Air quality damage costs guidance. Crown Copyright.

²³ Defra and ONS (2016) Urban and rural classification of English local authority districts and similar geographical units in England: Methodology.

²⁴ DBEIS (2019) Carbon priced and sensitivities 2010-2100 for appraisal in HM Treasury (2018) The Green Book. Central Government guidance on appraisal and evaluation, version 3. London.

of carbon sequestration if it were to be exchanged, than market prices. Using the latter reflects the current institutional set up of carbon markets, rather than the true value of carbon sequestration. The present value (PV) of the ability of the woodland to sequester carbon into the future was calculated by summing the values for each year over a 50-year period, after discounting using the discount rate suggested in HM Treasury (2019²⁵) of 3.5%. The HM Treasury also provides low and high estimates of current and future non-traded carbon prices. These were used to provide a sensitivity analysis to the economic valuation of this ecosystem service.

A2.3 Greenhouse gas emissions from agriculture

Agricultural activities release CO₂ and other greenhouse gasses such as methane and NO₂ into the atmosphere, with emissions highly variable depending on the type of farming practices employed. These emissions can therefore negate the benefits obtained through carbon sequestration of habitats within a site.

The greenhouse gas emissions of the site were calculated by multiplying the area of each crop type and the numbers of livestock by emissions figures for each crop type and livestock type in Bateman *et al.* (2013²⁶). These emission figures are based on three types of agricultural emissions:

1. Emissions from typical farming practices (e.g. tillage, sowing, spraying, harvesting, and the production, storage and transportation of fertilizers and pesticides).
2. Emissions of N₂O from fertilizers.
3. Emissions of N₂O and methane from livestock, caused by enteric fermentation and the production of manure.

The total physical flow of greenhouse gas emissions was calculated by adding crop type and livestock emissions (in tCO₂e). These were monetised using the DBEIS (2019) non-traded central carbon price, as described for carbon sequestration above, and discounted at the standard rate. The low and high non-traded carbon prices were used for the sensitivity analysis.

A2.4 Agricultural production

The physical annual flow of agricultural production for Bedfordshire was simply measured as the area of land under agriculture derived from the asset register (Table 1). These were classified to an appropriate Defra farming system, that is the proportion of different livestock and crops, using data on the structure of the farming system in England at the county scale.

The monetary value of agricultural production was calculated as the economic value of land, net of all non-land costs. Net Farm Income (NFI), the return to farm operators once all expenses have been deducted, were obtained from Defra's Farm Accounts in England (Farm Business Survey) for the three local authority areas. This takes into account yields and farm gate prices, to give gross output, and subtracts typical variable costs (e.g. fertilizers, husbandry, feed and forage costs) and fixed costs (labour, machinery, fuel, buildings). Annual NFI estimates were obtained over 5 years for the period 2015/16 to 2019/2020. These were then adjusted to remove the effects of Basic Farm Payments (income support).

²⁵ HM Treasury (2019) The Green Book. Crown Copyright.

²⁶ Bateman, I. J. et al. (2013) Bringing ecosystem services into economic decision-making: Land use in the United Kingdom. Science 341 45-50.

to remove any charges for imputed (unpaid) rent, and to include charges for the imputed value of unpaid family labour. This gives a return (an economic rent) to the land resource itself after deducting all costs associated with production except for land ownership and rental costs, and excluding income support subsidies. The annual estimates of adjusted NFI were inflation adjusted to 2020 prices, and a mean estimate per hectare was derived for the period for each of the farming systems. Low and high estimate were also calculated. The per hectare estimates were multiplied by the area of land under each of the farming systems in the local authorities, to derive the total annual value of agricultural production. Present Value was calculated over 50 years using the standard discount rate and assumes that the mix of crops and livestock numbers stays approximately the same. The low and high production values were used for the sensitivity analysis.

A2.5 Recreation

The annual physical and monetary flows of recreation was estimated for each of Bedfordshire's local authorities using the University of Exeter's Outdoor Recreation Valuation Tool (ORVal) version 2.0:

<https://www.leep.exeter.ac.uk/orval/>

This tool uses a statistical model called a Recreational Demand Model to predict the number of visits that are made to currently accessible greenspaces by adult residents of England. The number of visits are modelled using data from the Monitor of Engagement with the Natural Environment (MENE) survey, and adjusted based on factors such as socioeconomic characteristics of people, the day of the week, attributes of the greenspace, the availability and quality of any alternative greenspaces. The model, through a welfare function, also describes the welfare an individual derives from making different recreational choices, and the welfare values are, therefore, provided by the tool. The welfare gained from a particular greenspace will depend on a number of factors (e.g. socio-economic status, month of the year) and the benefits experience at a site is traded-off against the costs of travelling to the site. The overall annual physical flow and monetary value for recreation in each of Bedfordshire's local authorities was the sum of the visit estimates and the welfare values for each accessible greenspace in those areas. For further details of the ORVal model see the advanced technical report for details: https://www.leep.exeter.ac.uk/orval/pdf-reports/ORValIII_Modelling_Report.pdf. Low and high estimates were calculated to be 0.75 and 1.25 times the central estimate respectively for the sensitivity analyses.

A2.6 Physical health

There is now a growing body of evidence to show the positive effect that the natural environment can have on human health and well-being. Physical health is more commonly valued, although methods are still being refined. The physical flow of health benefits delivered by Bedfordshire were valued using an approach developed by White et al. (2016²⁷), who analysed the implications of recreational physical activity in the natural environment on health in England. The method relies on estimates of visitors to natural environments who meet recommended activity guidelines (based on both duration and intensity of physical activities).

²⁷ White, M.P. et al. (2016) Recreational physical activity in natural environments and implications for health: A population based cross-sectional study in England. *Preventative Medicine* 91 383-388.

The first step in the calculations was to estimate the number of visitors to the publicly accessible green areas in and around each of Bedfordshire's local authorities. Visitor numbers were taken from the University of Exeter's Outdoor Recreation Valuation Tool (ORVal) version 2.0 (as above). Using this estimate we converted the visits (which includes repeat visits by the same individuals) to the number of visitors (individuals), using a visit rate calculated from the latest 5 years of national MENE survey data from Natural England. These can be translated into Quality Adjusted Life Years (QALYs) scores, with 30 minutes of moderate to intense physical activity (if taken 52 weeks a year) being equal to 0.0107 of a QALY. QALY scores have an associated monetary value through estimated savings in health care costs. This physical health benefit can, therefore, be estimated by calculating the total number of QALYs by active visitors to sites that meet guidelines, and multiplying this by the QALY value. The social value of one QALY remains under review. It has been estimated to be worth £20,000 (White *et al.* 2016). and £60,000 (HM Treasury 2019). However, the recent Defra ENCA project suggests a more conservative value of £15,000 should be used, and this is what is used here. We use the £60,000 estimate for the upper estimate of value in the sensitivity analyses, highlighting that the value of physical health could be considered to be much higher. The lower estimate was 50% of the central value.

The present value (PV) of the area to deliver physical health benefits into the future was the sum of annual values over the 50-year period, using the discount rates suggested in HM Treasury (2019). Discount rates for QALY effects are recommended at 1.5% (differing from the 3.5% rate recommended for other service indicators). Also, see amenity value below for discussion of double counting issue.

A number of assumptions are used in these calculations and the results should therefore be interpreted with caution; it is the ecosystem service with the greatest degree of uncertainty out of all those assessed.

A2.7 Timber/woodfuel production

For existing woodland, annual physical flows of timber/woodfuel production were calculated in terms of average annual yield, by multiplying the yield class of the different species by the area of each woodland type (see Section 4.2).

The annual monetary flows for the woodland areas were calculated by multiplying the yield by the standing price of timber or woodfuel. The average price for softwood in 2020 was taken from the Forestry Commissions Coniferous Standing Sales Price Index (Forestry Commission 2020²⁸). The price for broadleaved timber in 2015 ranged from £15 to high quality timber reaching £250 per m³ standing (ABC 2015²⁹). We assume the lowest value here for woodfuel, and convert this to 2020 prices using Government deflators. To convert to a present value the annual value was multiplied by the standard government discount rate (3.5%) for each respective year up to 50 years. It was assumed that the area of woodland remains static and the unit price was also assumed to be constant. Low and high estimates were calculated to be 0.75 and 1.25 times the central estimate respectively for the sensitivity analyses.

²⁸ Forestry Commission (2020) Timber price indices. Data to March 2020.

²⁹ ABC (2015) The agricultural budgeting and costing book. 81st edition, Argo Business Consultants.