Greater Norwich Green Infrastructure Strategy
Supplementary
Evidence and Opportunities Report

for

Greater Norwich Growth Board

by

Natural Capital Solutions

on behalf of

CBA

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Version: Final

Broadland District Council   NORWICH City Council   South Norfolk Council   Norfolk County Council

Executive Summary

In 2024, CBA was commissioned by the Greater Norwich Growth Board to develop a refreshed Green Infrastructure (GI) Strategy for Greater Norwich, working in collaboration with the Greater Norwich GI Delivery Group and Steering Group.

As part of the CBA Consultant Team, Natural Capital Solutions (NCS) has undertaken supplementary Natural Places analysis to complement the existing Natural Places (GI for nature) and Active Places (GI for people) evidence and opportunities analysis for the Greater Norwich Area developed by the Natural Norfolk Team at Norfolk County Council. This work will be used in combination to inform the new GI Strategy.

The report details the results of the supplementary Natural Places opportunities modelling and mapping work undertaken by NCS for the Greater Norwich Area in line with the client brief. A summary of the key findings is highlighted below.

SUPPLEMENTARY NATURAL PLACES ANALYSIS: HABITAT NETWORK/BIODIVERSITY OPPORTUNITY MODELLING & MAPPING (SECTION 2)

This work identifies opportunities for creating and restoring new habitats to strengthen the connectivity of existing habitat networks within the Greater Norwich Area in support of biodiversity and nature recovery goals.

A baseline habitat map created for the entire Greater Norwich Area (encompassing 150,274 hectares) revealed that it is currently dominated by cropland (56.3%), grassland (20%) and woodland (9.1%) habitat. The area also contains designated sites of national and local nature conservation value, including Sites of Special Scientific Interest (SSSIs) and Local Nature Reserves, as well as habitats of nature conservation interest including fen, floodplain wetland mosaic, heathland and scrub.

The habitat opportunity maps (**Figures 4-8**) revealed that there are many opportunities for creating woodland, grassland and heathland spread across the Greater Norwich Area. The maps highlight three levels of priority, and there are a number of high priority opportunities for these habitats, with opportunities to connect and buffer ancient woodlands, SSSIs and Local Nature Reserves. The opportunities for enhancing fen and wet grassland are concentrated around the rivers and floodplain areas, although other significant opportunity areas (especially for wet grassland) were also identified. These habitats are particularly good for biodiversity, and there are large high priority areas for both habitats. There will be overlap in opportunities identified between the broad habitats (grassland, woodland, and heathland) and further prioritisation with local stakeholders to determine the most practical opportunities, which can also complement other initiatives and strategies in the area as necessary.

SUPPLEMENTARY NATURAL PLACES ANALYSIS: ECOSYSTEM SERVICES OPPORTUNITY MODELLING & MAPPING (SECTION 3)

This work identifies opportunities within the Greater Norwich Area where potential new habitats can contribute to the supply of multiple ecosystem service benefits (e.g. carbon sequestration, air quality regulation, water quality regulation) in areas with demand for these services.

The supply and demand of a sub-set of ecosystem services were modelled and mapped across the Greater Norwich Area. These showed the importance of semi-natural habitat in urban areas and along major roadways for carbon sequestration, air quality, noise and local climate regulation. These maps (**Figures 9-30**) were used to create opportunity maps for each ecosystem service.

The air purification, noise and local climate regulation maps all displayed highest priority areas in or close to densely urbanised areas (e.g. Norwich), as these areas have increased demand for these services. The water quality opportunity map, on the other hand, had the highest priority opportunities in areas dominated by arable habitat, as arable land has high soil erosion rates.

The carbon sequestration and storage capacity maps displayed the capacity for these services across the Greater Norwich Area. The carbon sequestration analysis revealed that the Greater Norwich Area currently emits approximately 93,600 tonnes of CO_2 equivalent per year from the land. This is mainly due to the dominance of arable agriculture and a fragmented semi-natural habitat network inbetween. To move to net zero and sequester as much carbon as is being emitted across the strategy area, about 10,000 ha of the woodland opportunities mapped would need to be put in place.

Air pollution was further analysed across the Greater Norwich Area by creating emission maps for different air pollutants from transport and industry based on data from the National Atmospheric Emissions Inventory. These maps revealed that the highest concentrations of ammonia were localised around livestock farms (poultry) and a sugar beet factory. The area around the sugar beet factory also had high concentrations of carbon dioxide and nitrogen oxides. The carbon dioxide and nitrogen oxides concentrations were both concentrated around urban areas and major roadways with high concentrations above a car manufacturing plant and chemical factories. Methane emissions were concentrated primarily around sewage treatment plants and livestock farms (cows and pigs). Planting woodland around livestock farms and major roads would take up pollutants and provide ecosystem services, such as noise, air quality and local climate regulation.

Areas that would be most effective at “slowing the flow” of water runoff and providing natural flood risk mitigation were investigated using water flow regulation opportunity models. These models revealed that high priority areas are concentrated around rivers and floodplain areas, especially those near urban areas, with large high priority areas along the Rivers Yare and Bure. Creating habitat in biodiversity opportunity areas which overlap with water flow regulation opportunity areas would deliver benefits for biodiversity and act as natural flood risk mitigation measures.

COMBINED NATURAL PLACES & ACTIVE PLACES ANALYSIS: MULTIFUNCTIONAL GREEN INFRASTRUCTURE OPPORTUNITY MODELLING & MAPPING (SECTION 4)

This work combines the supplementary Natural Places analysis set out above with the existing Natural Places and Active Places analysis. This approach was used to identify opportunities for multifunctional GI within the Greater Norwich Area in terms of delivering multiple biodiversity, ecosystem services and greenspace provision benefits for nature and people.

The combined opportunity maps (**Figures 31**-**34**) overlaid ecosystem service opportunities across the Greater Norwich Area. There are two versions of these maps, the constrained and unconstrained versions. In the constrained map, the results were constrained by whether these areas also fell in an area identified as a biodiversity opportunity. Both the constrained and unconstrained maps revealed that the highest priority opportunities were within or close to urban areas, especially Norwich, as these areas have greater ecosystem service demand.

Layers from the Active and Natural Places map were then added to the combined opportunities map to create a GI multifunctionality opportunities map for meeting the needs of people and nature in the Greater Norwich Area. Again, the areas that had the greatest overlap between provision of ecosystem services, biodiversity and greenspace benefits were in the Norwich urban area. This model highlights areas that could provide multiple benefits, and simultaneously meet GI standards.

APPLICATIONS

The report is intended to provide a decision-making tool to inform strategic GI planning/strategy development work. It can also be used to inform site-scale GI delivery work, subject to ground truthing. The habitat basemap (**Figure 3**) is based on existing data and it 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 consider 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.

As well as providing evidence for informing the Greater Norwich Area GI Strategy, the opportunity maps can be used to inform the emerging Norfolk Local Nature Recovery Strategy work. The habitat network/biodiversity and ecosystem services modelling and mapping approaches are intended to be applicable for rolling out across the rest of the county.

ACCESSIBILITY CONFORMANCE STATEMENT

This PDF document conforms with the Norfolk County Council guidelines for accessible online content[1]. The source Word document was manually checked using the Microsoft Office Accessibility Tool.

[1] www.norfolk.gov.uk/article/44492/How-to-create-accessible-content

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1. Introduction

1.1 Background

In 2007, CBA was commissioned by Greater Norwich Development Partnership to produce the first Green Infrastructure (GI) Strategy for Greater Norwich.

In 2022, the Natural Norfolk Team at Norfolk County Council was commissioned by the Greater Norwich Growth Board to develop the evidence base to inform the update of the Greater Norwich GI Strategy.

In 2024, CBA was commissioned by the Greater Norwich Growth Board to develop the refreshed GI Strategy, working in collaboration with the Greater Norwich GI Delivery Group and Steering Group.

As part of the CBA Consultant Team, Natural Capital Solutions (NCS) has undertaken supplementary Natural Places analysis to complement the existing Natural Places (how GI interacts with the natural environment and provides ecosystem service benefits, e.g. carbon sequestration, and increased biodiversity) and Active Places (how GI interacts with residents and visitors, providing e.g. recreational opportunities and improved wellbeing) evidence and opportunities analysis for the Greater Norwich Area developed by the Natural Norfolk Team at Norfolk County Council.

The existing Natural Places and Active Places evidence and opportunities analysis included:

- An assessment of irreplaceable habitat (Section 5.1, Evidence and Opportunities Report January 2024) that mapped valuable areas of biodiversity both inside and outside of locally and nationally designated sites
- An assessment of landscape connectivity (Section 5.2) that included mapping hedgerows
- A nature network (permeability) mapping that identified which areas of the landscape can promote species movement (high permeability e.g. woodland and semi-natural grassland) and those that do not (low permeability e.g. arable and urban areas)
- A hotspots mapping that identified statistically significant clusters of high permeability (hot spots) and low permeability (cold spots) areas across Greater Norwich
- A mapping of habitats that have long temporal continuity (Section 5.3) including ancient woodlands, veteran trees outside of woodland, long established grassland and ponds and ghost ponds
- A map of multifunctional spaces (Section 5.4) showing where greenspaces exist that provide access to people and are of biodiversity importance, combining the Natural and Active Places approaches

The supplementary Natural Places analysis outlined in this report complements the analyses already completed, and in particular extends the nature network (permeability) mapping to identify areas where habitat can be created to buffer and connect up with the existing broad habitat networks (e.g. broadleaf woodland, semi-natural grassland, heath etc). This Geographic Information System (GIS) approach (Habitat Opportunity Mapping) builds on the permeability analysis using a least cost, focal species approach, along with average dispersal distances of typical species for each broad habitat to map habitat patches that are ecologically connected to each other, and removes constraints (e.g. historic sites, infrastructure, overhead lines and cables, good quality habitats) to produce a map of opportunities that will expand the size of the existing habitat network across Greater Norwich, increase connectivity and resilience. The opportunity map is also prioritised according to whether opportunities will buffer and/or connect up sites already of national or local biodiversity value.

The supplementary analysis also builds on the Evidence and Opportunities Report by mapping opportunities for enhancing the ecosystem service benefits of carbon sequestration, flood risk reduction, increasing water quality, reducing air pollution, local temperatures in built-up areas and noise pollution. The opportunities for carbon sequestration and flood risk reduction were prioritised further by mapping greenhouse gas emissions (GHG) and flood risk. The resultant maps build on the original multifunctional spaces mapping by identifying areas where habitat can be created to deliver both biodiversity (rather than just existing sites of biodiversity importance) and a range of ecosystem service benefits. These have also been combined with the Active Places priority areas for meeting greenspace provision standards and opportunities for urban greening. The work in this report and the existing Evidence and Opportunities Report will be used in combination to inform the new GI Strategy.

1.2 Report structure and scope

In line with the brief agreed with the Greater Norwich GI Delivery Group (see **Appendix A1**), the scope of supplementary work set out in this report includes:

- **Supplementary Natural Places Analysis: Habitat Network/Biodiversity Opportunity Modelling & Mapping (Section 2)** – this work identifies opportunities for creating and restoring new habitats to strengthen the connectivity of existing habitat networks within the Greater Norwich Area in support of biodiversity and nature recovery goals
- **Supplementary Natural Places Analysis: Ecosystem Services Opportunity Modelling & Mapping (Section 3)** – this work identifies opportunities within the Greater Norwich Area where the supply of existing and potential new habitats can contribute to the supply of multiple ecosystem service benefits (e.g. carbon sequestration, air quality regulation, noise regulation, climate regulation, water quality regulation and water flow regulation) in areas with demand for these services
- **Combined Natural Places & Active Places Analysis: Multifunctional Green Infrastructure Opportunity Modelling & Mapping (Section 4)** – this work combines the supplementary Natural Places analysis set out in **Sections 2-3** with the existing Natural Places and Active Places analysis to identify opportunities for multifunctional GI within the Greater Norwich Area in terms of delivering multiple biodiversity, ecosystem services and greenspace provision benefits for nature and people.

This supplementary report should be read in conjunction with the analysis already completed in the Greater Norwich Green Infrastructure Strategy Baseline Report (March 2023) and the Evidence & Opportunities Report (January 2024) produced by the Natural Norfolk Team.

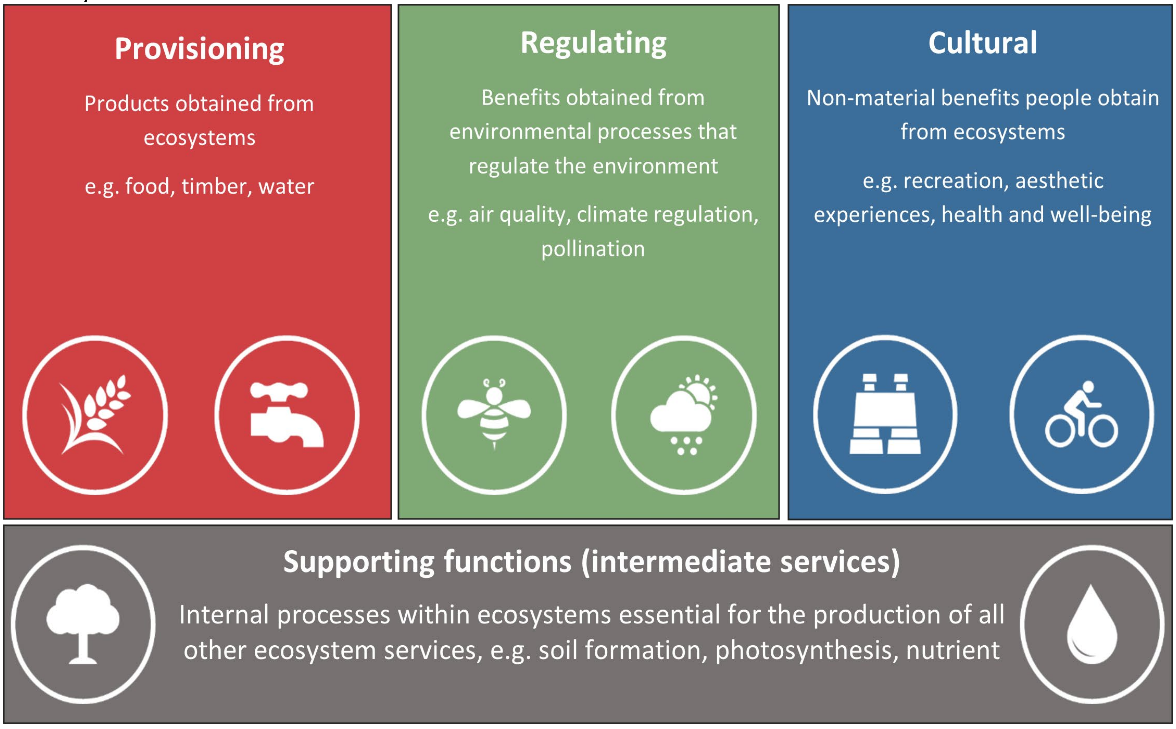
1.3 The natural capital and ecosystem services framework

The natural environment underpins our 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[2]). It is the stock of natural assets (e.g. soils, water, biodiversity) that produces a wide range of ecosystem services that benefit people. These benefits include food production, regulation of flooding and climate, pollination of crops, and cultural benefits such as aesthetic value and recreational opportunities (**Figure 1**).

[2] Natural Capital Committee (2014) The state of natural capital: Restoring our natural assets. Second report to the Economic Affairs Committee. Natural Capital Committee, March 2014.

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.

Figure 1. Key types of ecosystem services (based on MA 2005[3]). Note that supporting or intermediate services are now categorised as ecological functions (CICES[4]). They are the underpinning structures and processes that give rise to ecosystem services.



[3] Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: Synthesis. Island Press, Washington D.C. https://www.millenniumassessment.org/en/index.html

[4] Haines-Young, R. & Potschin, M. (2018) Common International Classification of Ecosystem Services (CICES) V5.1. Guidance on the application of the revised structure. Fabis Consulting.

2. Habitat network/biodiversity opportunity modelling & mapping

2.1 Habitats basemap

The biodiversity and ecosystem services opportunity mapping for Greater Norwich (referred to as the strategy area from now on) required the baseline habitats to be mapped as a first step. The strategy area encompasses the districts of Norwich, Broadland and South Norfolk (**Figure 2**). These area boundaries appear on all of the maps in this report.

Norfolk County Council supplied NCS with a habitat map of the strategy area. Each of the habitats were classified into UK Habitat Classification (UKHab) level 2, using OS MasterMap topology layer boundaries. The habitat classification of the polygons was based on Rural Payments Agency data containing land use information, highly detailed polygon data from OS Mastermap, and habitat classification data from the Living England Habitat Map (Norfolk County Council 2024[5]). It was then necessary to add additional data to this habitat map to check the habitat classification and prepare it as a basemap for the opportunity mapping (see **Box 1**).

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

- **OS MasterMap Topography layer**
- **OS VectorMap District**
- **OS Open Greenspace data**
- **OS Open Rivers**
- **Natural England Priority Habitat Inventory (PHI)**
- **National Forest Inventory (NFI)**
- **CORINE land cover**
- **Crop Map of England (CROME)**
- **Wensum Citizen Science Group Phase 1 habitat survey**
- **1m digital terrain model**
- **Public rights of way data**

There were certain habitats that were not well classified by the Norfolk County Council map. These were the rivers and lakes, woodland, and wetland habitats. In addition, areas of Coastal and Floodplain Grazing Marsh were mainly classified as modified (improved) grassland in the habitat map, which is unlikely to be the case. The OS Open Rivers, NFI and PHI was used to deal with these issues. Habitat survey data for an area around the River Wensum was obtained so this could be integrated (converted from Phase 1 to UKHab), and to ensure that important semi-natural habitat had not been missed out, as this would impact on the accuracy of the subsequent opportunity mapping.

Polygons were classified into Phase 1 habitat types (from the UKHab data as our models currently run in Phase 1 only) and were also classified into broader habitat groups. The final basemap covers the whole of the Greater Norwich area (150,274 ha) with an additional 4km buffer to ensure that no edge effects would impact on the modelling.

[5] Norfolk County Council (2024) Greater Norwich Green Infrastructure Strategy Technical Report for Greater Norwich Growth Board. V3 Final.

The basemap prepared for the habitat opportunity mapping provides the best approximation of habitat types that can be achieved based on available data, but has not been ground - truthed (apart from a 2,604 ha area around the River Wensum surveyed by the Wensum Citizen Science Group). The basemap will inevitably contain errors and all opportunity mapping outputs will require ground-truthing before being taken forward.

Figure 3 shows the distribution of baseline broad habitat types across the site; the area and percentage cover of habitats is shown in **Table 1**.

The dominant habitat type across the strategy area is arable cropland (56.3%). Grasslands cover a further 20% (30,070 ha), including modified (agriculturally improved) grassland (9.9%), and modified (amenity) grassland (2.7%), along with floodplain wetland mosaic (5.5%) and other neutral grassland (1.8%), which are important for biodiversity. Urban habitats cover 11%, and woodland covers 9.1%. The remaining 3.6% of the site consists of heathland and shrub, standing open water and canals, fen, intertidal sediment and other miscellaneous habitats.

Table 1. Baseline broad habitats (UK Hab) for the strategy area.

Habitat	Area (ha)	Area (%)
Broadleaved woodland	12,163	8.1
Coniferous woodland	1,567	1.0
Cropland (arable)	84,586	56.3
Grassland - other neutral grassland	2,750	1.8
Grassland - floodplain wetland mosaic	8,278	5.5
Grassland - dry acid grassland	48	0.04
Heathland and shrub - mixed scrub	15	0.01
Heathland and shrub - lowland heath	948	0.6
Intertidal sediment - littoral course sediment	7	0
Mixed / other / uncertain	219	0.1
Mixed woodland	69	0.04
Modified grassland (amenity)	4,115	2.7
Modified grassland (agricultural improved)	14,880	9.9
Standing open water and canals	2,524	1.7
Unclassified	271	0.2
Urban - artificial, unvegetated, unsealed surface	189	0.1
Urban - developed land, sealed surface	8,849	5.9
Urban - vegetated garden	7,532	5.0
Wetland - Fen (lowland)	1,232	0.8
Trees / Parkland	34	0.02
Total	**150,274**	**99.8**

Figure 2. Greater Norwich area with district boundaries

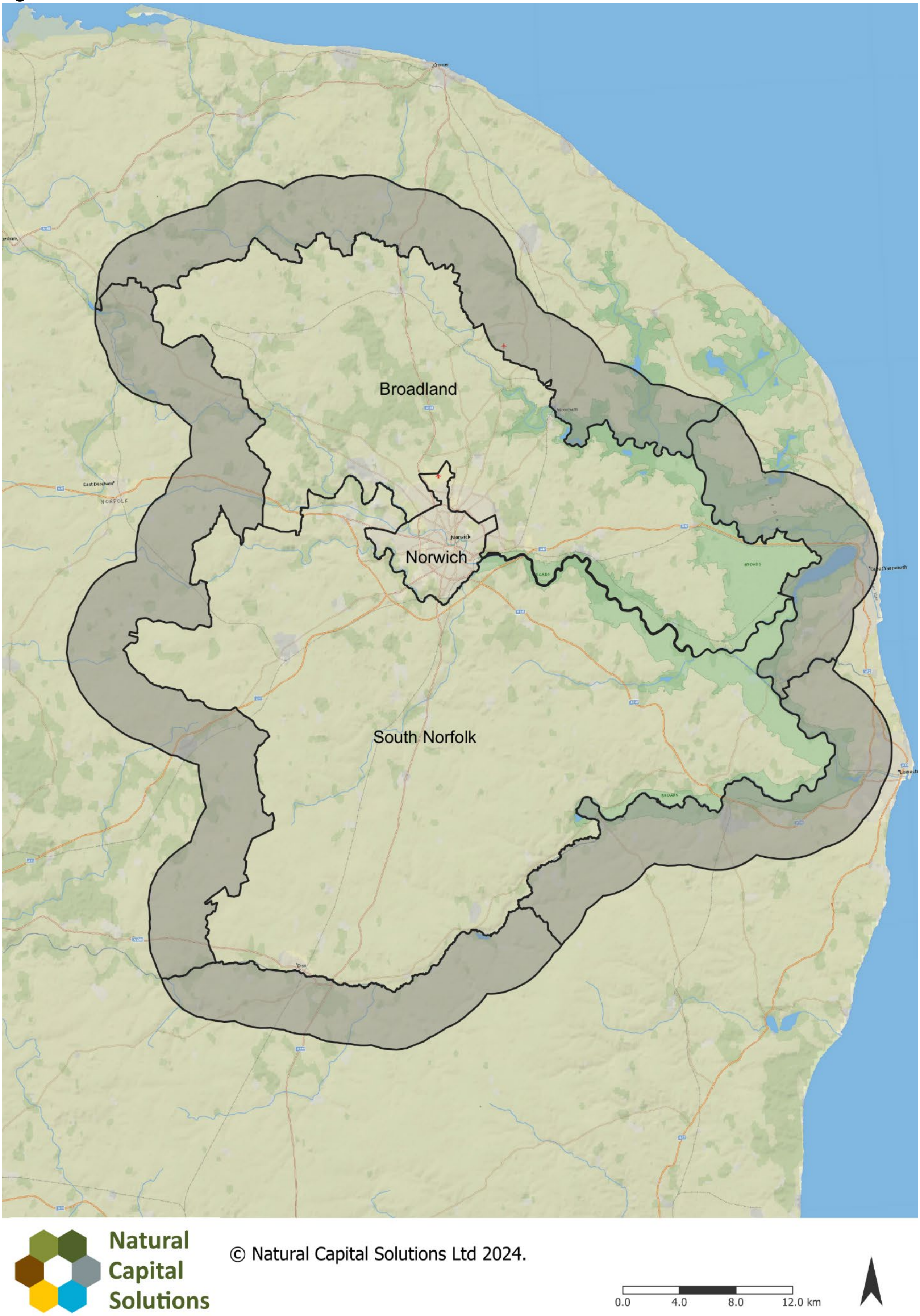
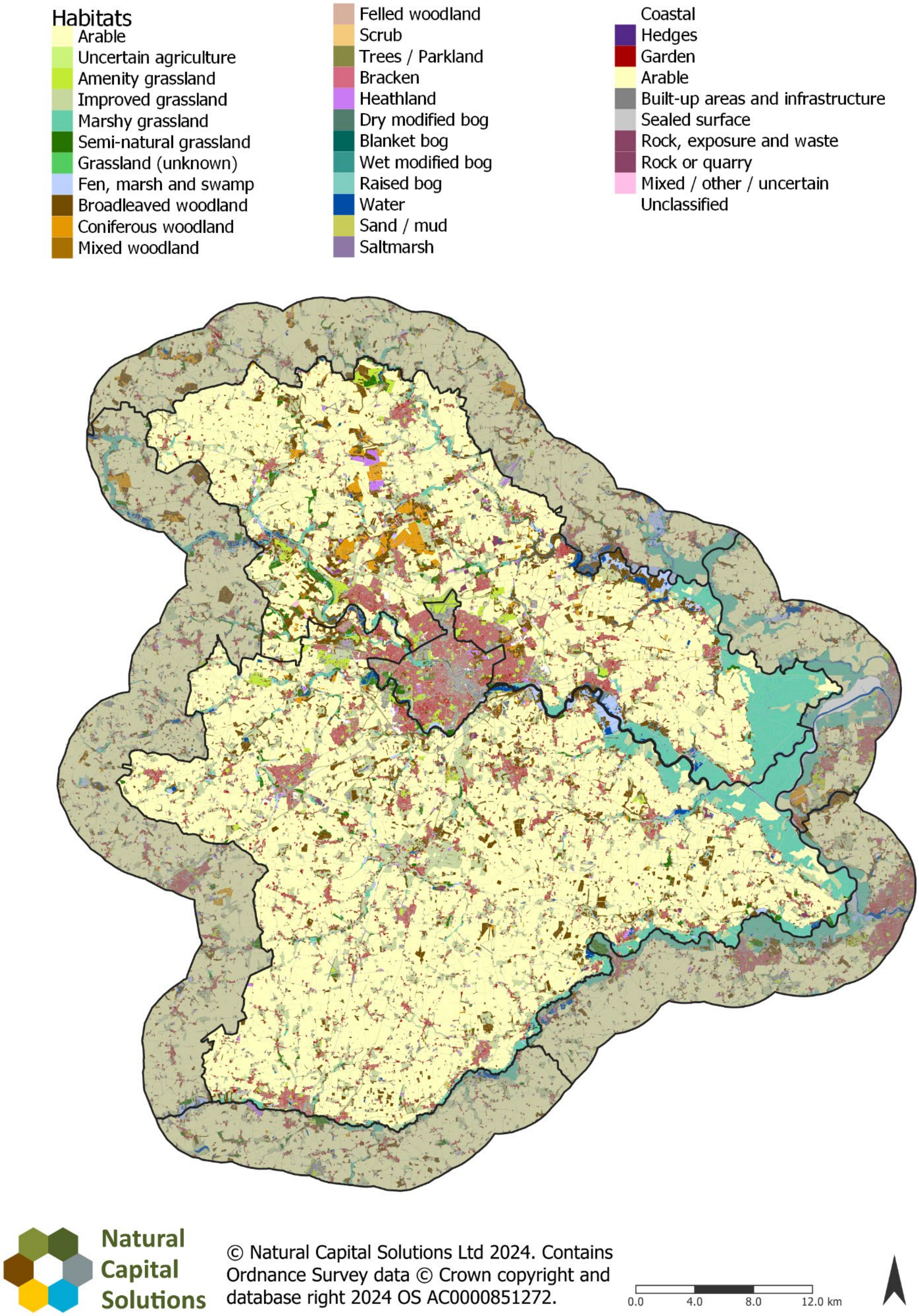


Figure 3. Baseline broad habitats for the strategy area.



2.2 Methods

Biodiversity network mapping, or habitat opportunity mapping, is a Geographic Information System (GIS) based approach used to identify potential areas for the expansion of key habitats. This approach complements but extends the permeability analysis in Section 3.5.4 of the Evidence and Opportunities Report (January 2024), which was used to measure landscape connectivity (the degree to which a particular habitat allows or facilitates the movement and dispersal of species across the landscape). The biodiversity opportunity mapping used here builds on the permeability analysis by using a least cost, focal species approach, along with average dispersal distances of typical species for each broad habitat to map habitat patches that are ecologically connected to each other, and removes constraints to produce a map of opportunities for creating new habitat.

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, can 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 five key habitat groupings, reflecting the main semi-natural habitats across the study site. The broad habitats and their constituent types are shown in **Table 2** below:

Table 2. Broad habitat types classification table.

Broad habitat	Specific habitats included
Semi-natural grassland	Acid, neutral, calcareous, rough and semi-improved grasslands.
Heathland	Includes all heathland types (including wet and dry heaths) and grass-heath mosaics.
Broadleaved and mixed Woodland	Broadleaved and mixed woodland types (excludes coniferous woodland, parkland or individual trees).
Fen	Lowland fen and swamp (reedbed)
Wet grassland	Marshy grassland, floodplain grazing marsh

Biodiversity opportunity mapping follows a four-step process, as explained below, and is based on the approach developed by Catchpole (2006)[6] and Watts et al. (2010)[7]. Note that opportunity areas for the four broad habitats often overlap, and no attempt will be made here to ascertain the most suitable habitat at a particular location.

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

[7] 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.

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 are based on expert scores compiled by Joint Nature Conservation Committee (JNCC). Once tables have been compiled showing permeability scores for each habitat, high resolution maps are 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 (**Figure 2**), 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 are obtained from JNCC, which has performed a review of the scientific literature to ascertain the dispersal distances of a range of species for each habitat type. These are typically species of small mammals, smaller birds, butterflies, and plants. The average dispersal distance for each habitat is shown in **Table 3** below:

Table 3: Dispersal distance in optimal habitats

Habitat	Dispersal Distance (km)
Semi-natural grassland	2.0 km
Heathland	1.2 km
Broadleaved and mixed woodland	3.0 km
Fen	1.0 km
Wet grassland	2.0 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 used in the mapping:

- 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 – habitats identified as being high quality, such as those identified by Natural England's Priority Habitat Inventory, as it would not make sense to destroy existing high-quality habitat to create new habitat of a different type.
- 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 all 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 fen 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.
- Large wetland habitats were not proposed as an opportunity if within 13km radius of aerodromes and MoD sites (in line with guidance on avoiding bird strikes).

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** – areas that are immediately adjacent to existing habitat patches and will usually be the priority for habitat creation.
- **Stepping stone** – areas that are slightly further away from existing habitats, but are close enough to be ecologically connected, and could potentially be used to create stepping-stone habitats that could link up more distant habitat patches.

Three different priority levels are also identified:

- **Priority 1** – buffer and stepping stones close to existing nationally designated sites (e.g. SSSI's) or ancient woodland (for woodland opportunity map only).
- **Priority 2** – areas close to existing locally designated sites (either Local Nature Reserves or Local/County Wildlife sites).
- **Priority 3** – areas close to undesignated sites in the wider countryside

The biodiversity opportunity mapping set was run at the default source patch size of 0.1 ha but it was found that for woodland and semi-natural grassland this resulted in numerous opportunities covering the whole of the strategy area. This is due to the semi-natural habitats in Norfolk generally being small in area and highly fragmented but widespread. Consequently, much of the extensive area of arable agricultural land was being identified as opportunities, and this seemed unrealistic and impractical. Therefore, the minimum patch sizes were increased for woodland (1.4 ha) and semi-natural grassland (0.28 ha) opportunities based on the average patch sizes of woodland and grassland in the area. The heathland, fen and wet grassland habitats remained at standard 0.1ha.

2.3 Results

Numerous opportunities exist for planting broadleaved woodland, semi-natural grassland, heathland, wet grassland and fen habitats across the strategy area that will ecologically connect to existing habitat (**Figures 4 to 8**). The maps show buffer and steppingstone opportunities for creating new habitat prioritised into three groups: (1 – high priority) opportunities to buffer and connect up areas of habitat with national designations (e.g. SSSI) and ancient woodland, (2 – medium priority) opportunities to buffer and connect up areas of habitat of local importance (e.g. local nature reserves and wildlife sites), and (3- low priority) all other opportunities.

Opportunity mapping for woodland

There are a number of high priority opportunities for woodland creation in Norwich urban area (red and orange, **Figure 4**). For example, there are opportunities to buffer and extend woodland around Lion Wood in east Norwich, which encompasses ancient woodland, and on the west side of St James' Pit, a SSSI in northeast Norwich (**Figure 4).** There are many more high priority opportunities in the rural areas surrounding Norwich urban area. For example, buffering and connecting up existing woodland at Cawston and Marsham Heaths SSSI in the north of the strategy area, and the ancient woodland in Spring Wood, southwest of Topcroft, south of Norwich urban area (**Figure 4**).

There are fewer medium priority opportunities (in dark and light purple, (**Figure 4**) than top priority ones, and they tend to occur on the outskirts of Norwich urban area. For example, Earlham Park Woods on the western edge of the city. However, there is one medium priority site further out to the south of Norwich where there are opportunities to create woodland to buffer and connect up Smockmill Common.

The lower priority opportunities for creating woodland (in dark and light green, **Figure 4**) are numerous and occur within Norwich urban area and extensively around the outskirts of the city. There are slightly fewer of these opportunities in the south and east of the strategy area.

Opportunity mapping for grassland

Opportunities to create semi-natural grassland are spread evenly around the strategy area (**Figure 5**) due to the widespread and fragmented nature of the existing semi-natural grassland (see habitat basemap, **Figure 3**). The majority of these opportunities are low priority (in dark and light green, **Figure 5**). Some high priority opportunities have been identified and lie mainly in the rural areas to the south of Norwich urban area (red and orange areas, **Figure 5**). For example, there are opportunities to buffer and connect up existing semi-natural grasslands around Fritton Common to the east of Morningthorpe.

There are two locations of medium priority semi-natural grassland opportunities in the strategy area (dark and light purple, **Figure 5**). One is in the east on the outskirts of Norwich buffering and connecting up existing habitats around Bowthorpe Marsh. The other is around Broome Heath on the very edges of the strategy area, northeast of Bungay.

Opportunity mapping for heathland

Similar to semi-natural grassland, opportunities to create heathland are spread evenly around the strategy area (**Figure 6**) due to the widespread and fragmented nature of the existing semi-natural grassland (see habitat basemap, **Figure 3**). The majority of these opportunities are low priority (in dark and light green, **Figure 6**). There are a few high priority sites (red and orange areas, **Figure 6**), two of the most visible in the north of the strategy area where there are opportunities to create heathland to buffer and connect up existing heathland habitat at Cawston and Marsham Heaths and Buxton Heath. There are three medium priority opportunity areas (dark and light purple, **Figure 6**), around Mousehold Heath in northeast Norwich, Broome Heath on the very edges of the strategy area, northeast of Bungay, and around South Walsham Fen in the east of the strategy area.

Opportunity mapping for wet grassland

The opportunities for wet grassland (**Figure 7**) are restricted to the floodplains of the main rivers running through the strategy area (Rivers Wensum, Tud, Yare, Tiffey, Tas, Chet and Bure). There are, therefore, fewer opportunities for the creation of this habitat than the previous three, although the total area of land identified is still high. The opportunities are mainly of low priority (dark and light green, **Figure 7**), however, there are a number of high priority opportunities (red and orange, **Figure 7**), particularly in the very east of the strategy area on the Rivers Bure and Yare. These opportunities are to create wet grassland to buffer and connect up to areas of wet grassland on the Upton Broad and Marshes SSSI adjacent to the River Bure, and the Halvergate Marshes SSSI adjacent to the River Yare.

There are two medium priority opportunity areas (dark and light purple, **Figure 7**). These show opportunities to create wet grassland to buffer and connect up to areas of wet grassland on the River Wensum in Wensum Valley Local Nature Reserve. The other is on the southern edges of Norwich urban area adjacent to Marston Marshes.

Opportunity mapping for fen / lowland wetland

The opportunities for fen creation (**Figure 8**), as with wet grassland, are restricted to the floodplains of the main rivers running through the strategy area (Rivers Wensum, Tud, Yare, Tiffey, Tas, and Bure). The opportunities are mainly of low priority (dark and light green, **Figure 8**), however, there are a number of high priority opportunities (red and orange, **Figure 8**), particularly towards the east of the strategy area on the Rivers Bure and Yare. These opportunities are to create fen to buffer and connect up areas of fen on the Bure Broads and Marshes SSSI, and the Yare Broads and Marshes SSSI.

There are three medium priority opportunity areas (dark and light purple, **Figure 8**) that all fall on the River Yare in the middle of the strategy area on the edges of Norwich urban area. These opportunities to create fen to buffer and connect up to areas of existing fen habitats are adjacent to Eaton Common, Earlham Park Woods and Whitlingham Marsh Local Nature Reserves.

Figure 4. Opportunities for broadleaved and mixed woodland across the strategy area.

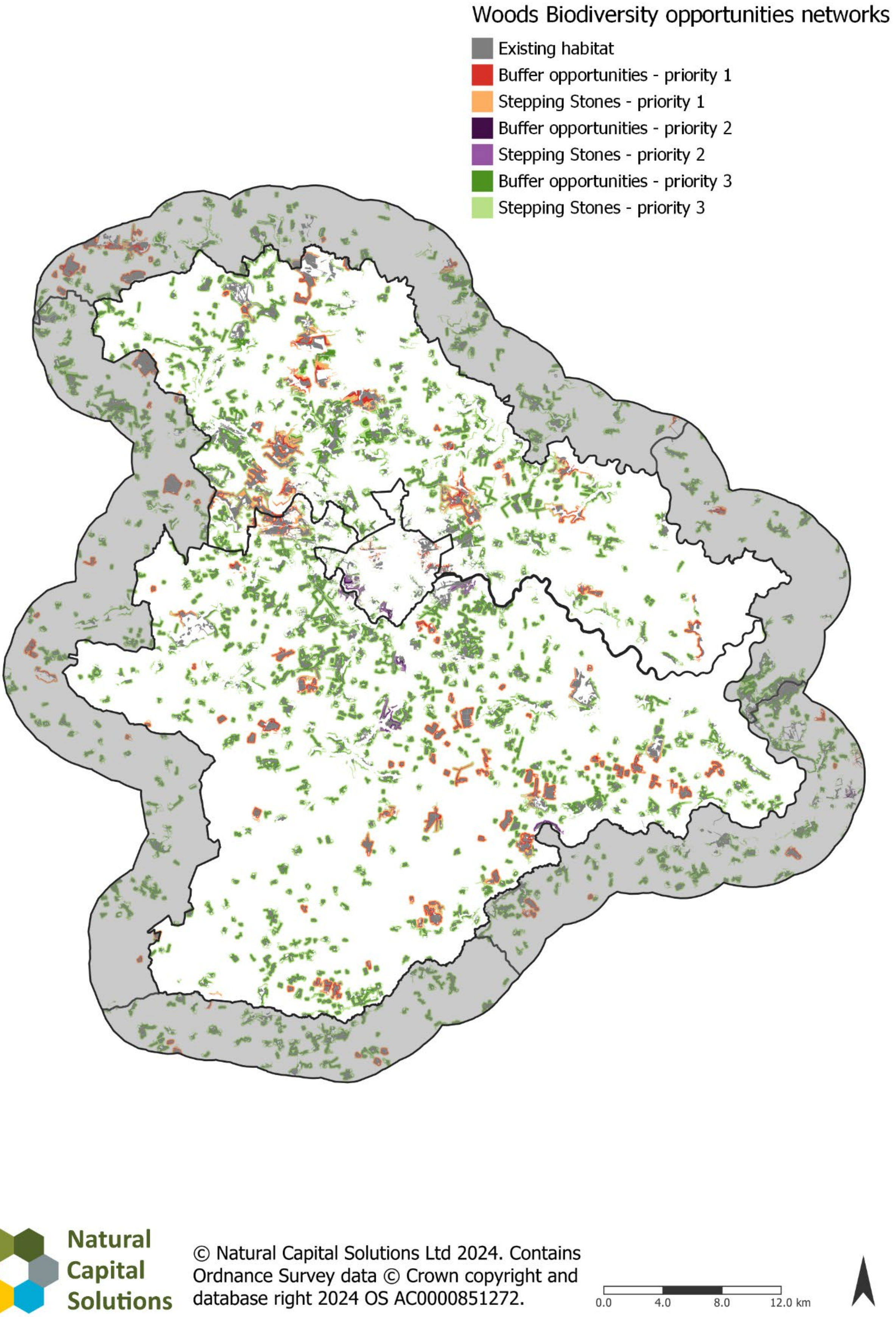


Figure 5. Opportunities for semi-natural grassland across the strategy area.

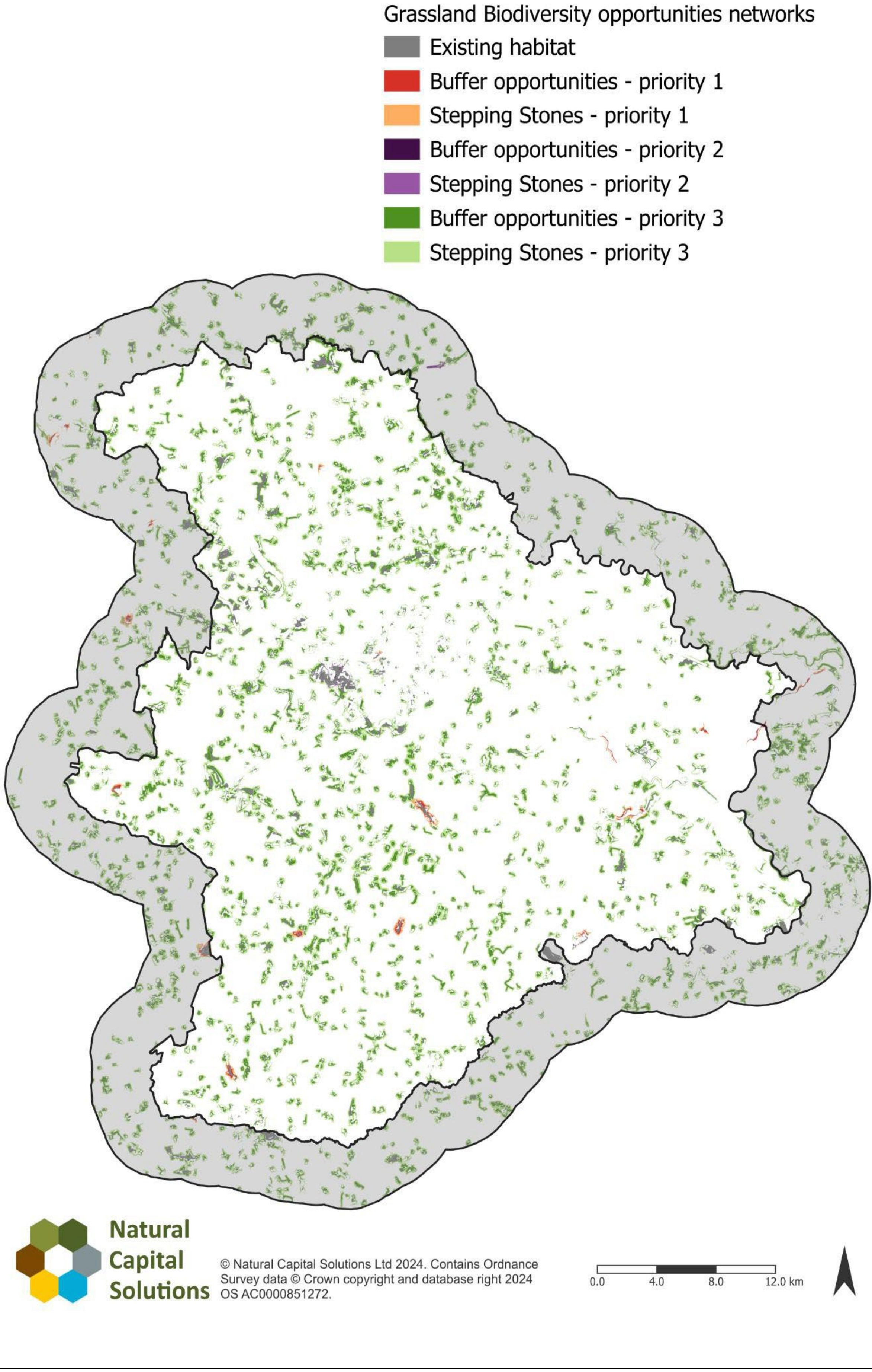


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Figure 6. Opportunities for heathland across the strategy area.

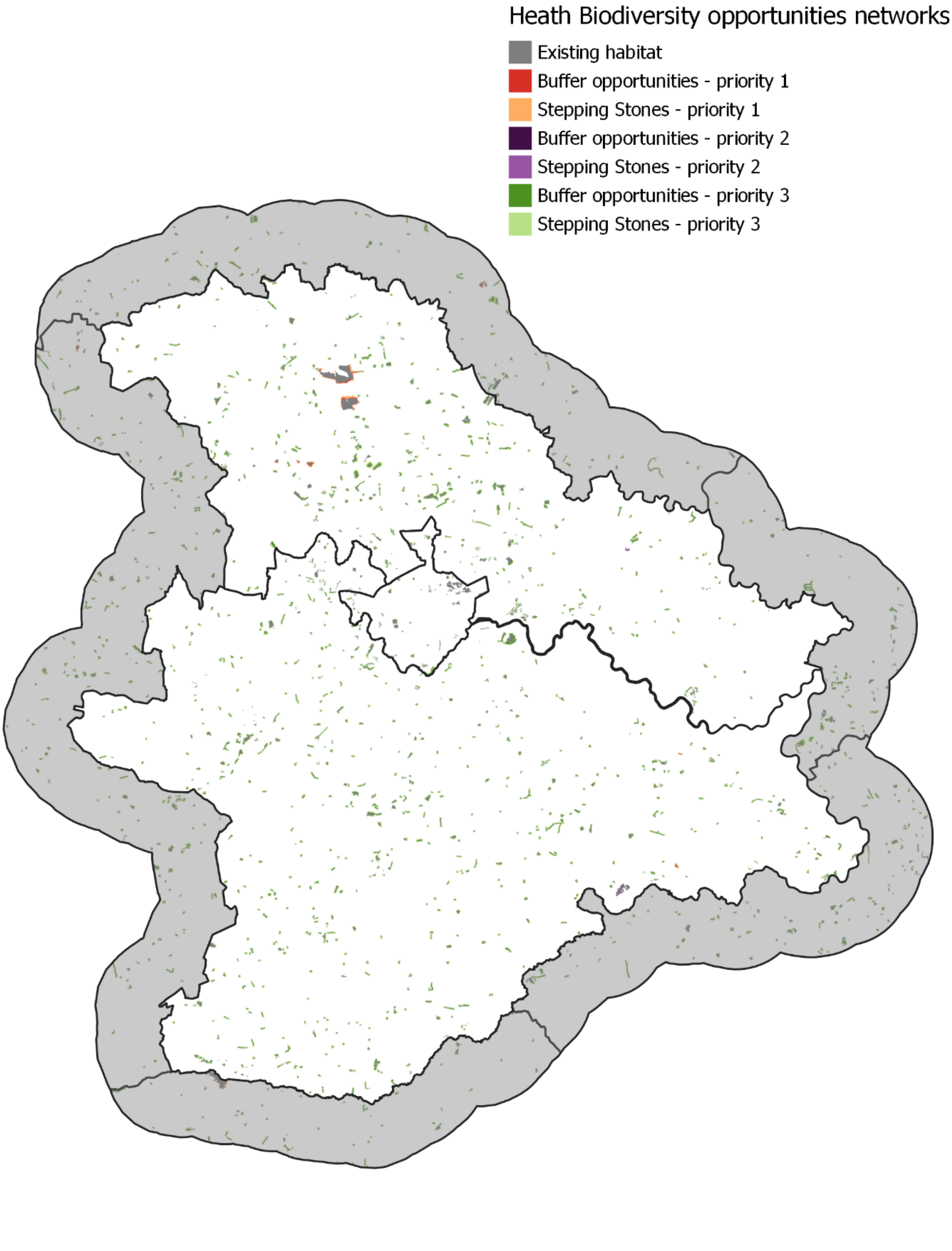

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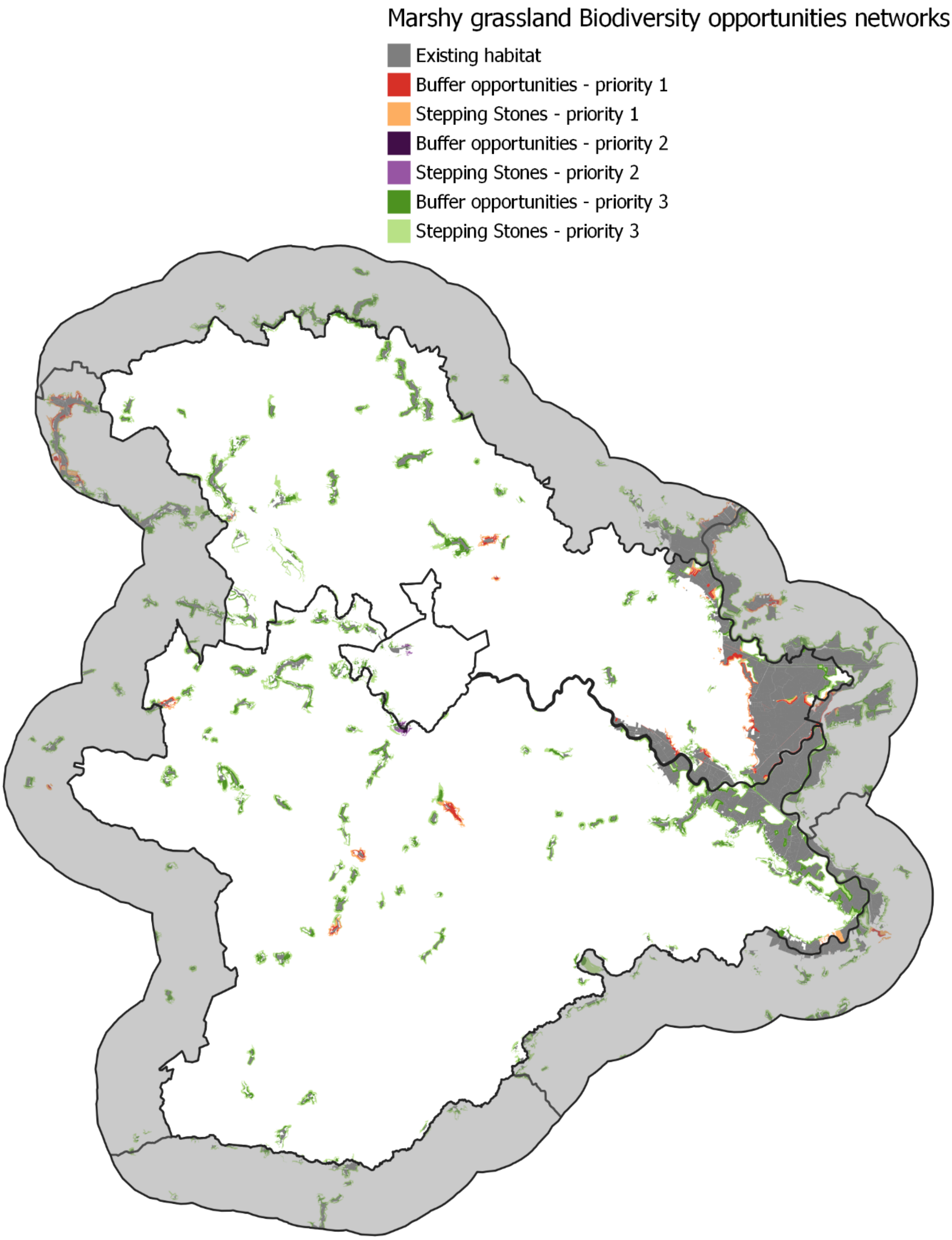
Figure 7. Opportunities for marshy grassland across the strategy area.



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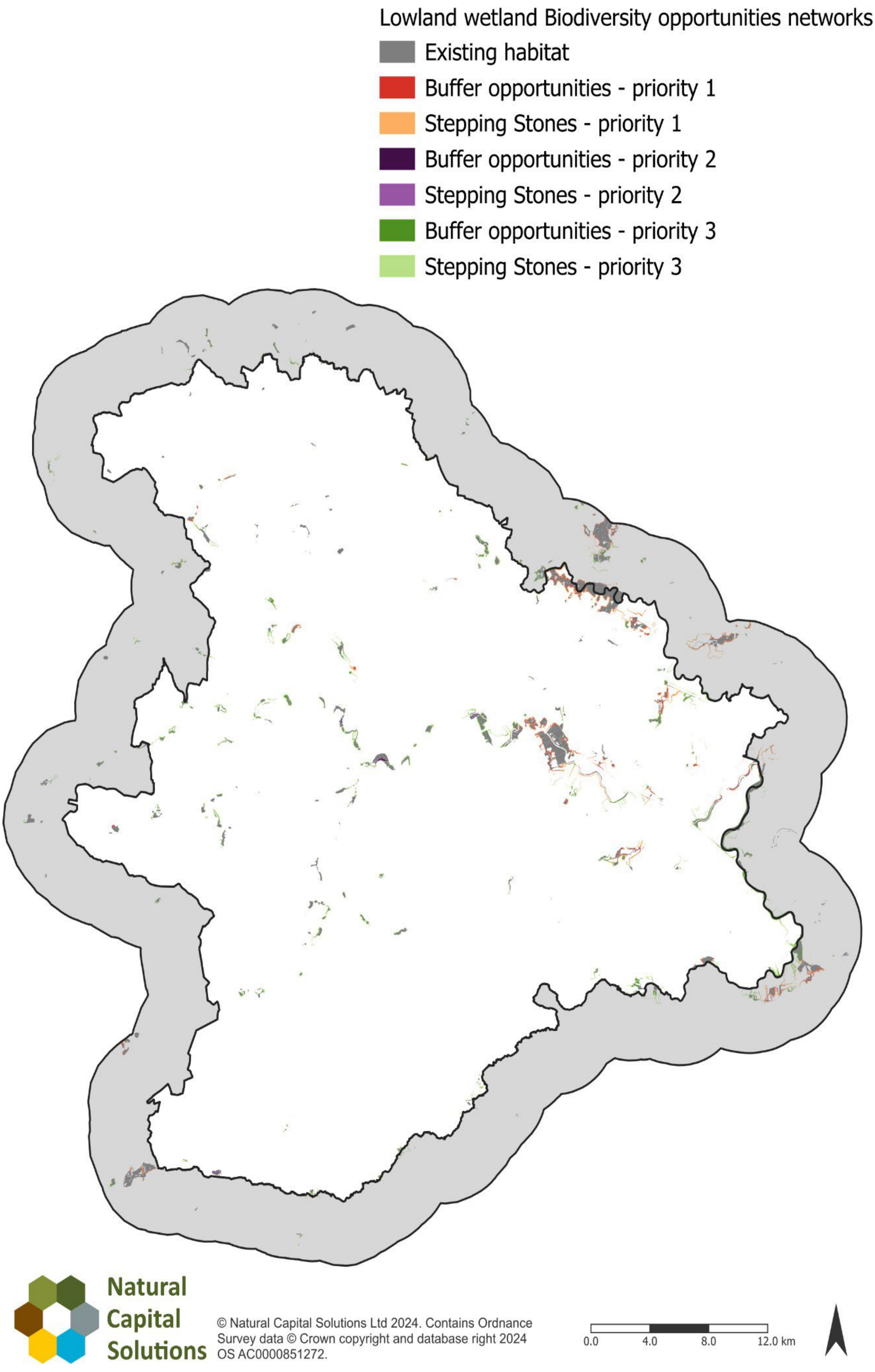
0.0 4.0 8.0 12.0 km

Figure 8. Opportunities for lowland wetland habitat across the strategy area.



3. Ecosystem services opportunity modelling & mapping

A subset of ecosystem services needed to be mapped to provide the foundation for the ecosystem service opportunity analysis.

3.1 Methods

The first step of the ecosystem services opportunity mapping was to quantify and map the benefits that the strategy area's habitats (natural capital) provide to people, using the basemap created in **Section 2.1**. The following benefits (ecosystem services) were assessed:

- Carbon sequestration and storage capacity
- Air purification capacity and demand
- Noise regulation capacity and demand
- Local climate regulation capacity and demand
- Water flow regulation
- Water quality (soil erosion) regulation

The list of services assessed was considered to capture all of the most important services provided by the natural capital assets within the strategy area. A variety of methods were used, and these are summarised for each individual ecosystem service in the sections below, with a more detailed methodology supplied in **Appendix A2**. The models were applied at a 5m-by-5m resolution, with the exception of the demand models, which were applied at a 10m-by-10m resolution. 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. In all cases the capacity and demand for an ecosystem service is mapped relative to the values present within the study area.

Opportunity mapping to reduce surface runoff

There is a growing interest in working with natural processes 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 using the water flow model (see **Figure 17**) and highlights areas across the whole area where changing land-use would have the greatest impact on reducing runoff.

Constraints were identified and mapped in the same way as for the biodiversity opportunity mapping outlined above. These locations were then erased from the water flow regulation map to leave a map showing water flow regulation in all unconstrained locations. This is then classified into percentiles and the top 50% extracted into another map. This map shows the top 50% of areas of land across the study area, broken down into three classes - 10%, 11-25%, and 26-50% - where surface water runoff is currently highest and where there are no constraints on potentially altering land use.

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, 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 were 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.

Opportunity mapping to reduce soil erosion and improve water quality

Agricultural and diffuse urban pollution have a major impact on water quality in lowland areas in the UK. Hard engineered solutions such as water treatment plants are much less effective in these circumstances than when dealing with point source pollutants, and 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 the highest risk of sedimentation and soil erosion based on catchment land use characteristics, distance to a 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 agriculture, and built-up areas are not as well accounted for in the existing model.

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 percentiles and the top 50% extracted into another map. This map shows this top 50% of areas of land across the study area, broken down into three classes - 10%, 11-25%, and 26-50% - where sedimentation risk and soil erosion are currently highest and where there are no constraints on potentially altering land use.

As for water flow, the final opportunity map identified 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.

Opportunity mapping to ameliorate air pollution, reduce noise pollution and urban heat

When mapping these services a slightly different approach is used compared to water flow and water quality. Air and noise pollution, along with the impacts of increased temperatures are often highly localised, and vegetation is most effective at mitigating these issues when planted close to pollution sources, or where temperatures are likely to be highest. Opportunities to ameliorate air and noise pollution and high urban temperatures are, therefore, focussed around areas with the greatest demand. Demand is assumed to be highest in areas where there are likely to be high air and noise pollution levels and high temperatures, and where there are lots of people who could benefit from the air quality, noise and climate regulation services. The opportunity maps, therefore, highlight areas that currently have no trees or structural vegetation or water, but where it would be most beneficial to plant them.

The constraints identified (as in biodiversity network mapping and services above) were erased from the demand maps for these services to leave a map showing demand in all unconstrained locations. This was then classified into percentiles and the top 50% extracted into another map. This map showed this top 50% of areas of land across the study area, broken down into three classes - 10%, 11- 25%, and 26-50% - where demand for these services was greatest and where there are no constraints on potentially altering land use.

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 urban tree in very small plots of land.

Carbon emissions and sequestration

The habitat opportunity mapping in **Section 2** has identified opportunities for the creation of woodland across the strategy area (**Figure 4**). These are also opportunities for increasing the sequestration of carbon. The extent to which these opportunities will offset the emissions from the region are considered here, both from land and other sectors, and where in the strategy area it would be best to focus woodland creation, given the location of the emissions sources. A map was created that shows the carbon sequestration and emissions associated with the habitats in the strategy area and how they are managed. Then, the emissions and sequestration by habitat in tonnes of CO_2e are presented, giving an overall carbon balance for the region. The concentration of GHG gasses in the atmosphere across the strategy area from all sector sources (agriculture, commercial, domestic, industry, public sector, transport, waste management and land use, land-use change and forestry (or LULUCF)) were also mapped.

Prioritised flood risk reduction opportunities

The habitat opportunity mapping to reduce surface runoff, as described above, identifies opportunities for creating habitats that will slow the flow of water, thereby reducing flood risk. Here, these opportunities are prioritised further using the Risk of Flooding from Multiple Sources data from the Environment Agency.

3.2 Results

Carbon storage

Carbon storage capacity indicates the amount of carbon stored naturally in soil and vegetation that gradually accumulates, or is lost, over long periods of time. Carbon storage and sequestration are seen as increasingly important as the UK moves 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.

This model estimates the amount of carbon stored in each habitat type. It applies average values (tC/ha) for each habitat type taken from Natural England (2019)[8]. A multiplier[9] is then applied to habitat carbon storage values depending on which soil type the habitat occurs on. As such, it does not take into account habitat condition or management, which can cause variation in amounts of carbon stored.

Most of the strategy area is on mineral soil but there are areas along the rivers (River Bure, Yare and Waveney) that have deep peat and shallow peat soils. In these areas, the broadleaved woodland, coniferous woodland and fen habitats have higher carbon storage capacity, (between 280-300 tC/ha, pink areas) because peat soils have greater carbon storage capacity than mineral soils. Comparatively, broadleaved woodland areas on mineral soil have a carbon storage capacity of 200 tC/ha (cream areas). Within the Norwich urban area, in the centre of the map, the urban gardens on mineral soil have a carbon storage capacity of 107 tC/ha, and appear light blue (see **Figure 9**). The majority of the area is covered by arable land on mineral soil, which has an average carbon storage capacity of 73 tC/ha (blue areas). The dark blue areas have no capacity for carbon storage and include water areas (standing open water and canals, intertidal) and urban habitats (sealed surfaces and rock, exposure and waste).

Carbon sequestration

Carbon is sequestered (captured) from the air by growing plants, and carbon sequestration typically refers to the annual flow (or change) in carbon concentrations between the atmosphere and different carbon-sequestering systems (vegetation, soils, oceans, bedrock). Sequestration rates vary with habitat type, how those habitats are managed and on the soil type on which the habitat lies (many habitats on deep peat soils emit greenhouse gases if they are in a degraded state). This model applies average values (tCO_2/ha/year) for each habitat type taken from various sources including Natural England (2021)[10] and the RSPB's Accounting for Nature report[11].

[8] Sunderland T, Waters RD, Marsh DVK, Hudson C, Lusardi J. (2019) Accounting for National Nature Reserves: A natural capital account of the National Nature Reserves managed by Natural England. Natural England Research Report, No. 078.
[9] Lagas and Sweep (2020) Ecosystem service – carbon storage and sequestration.
[10] R Gregg, J. L. Elias, I Alonso, I.E. Crosher and P Muto and M.D. Morecroft (2021) Carbon storage and sequestration by habitat: a review of the evidence (second edition) Natural England Research Report NERR094. Natural England, York.
[11] The RSPB. (2017) Accounting for Nature: A Natural Capital Account of the RSPB's estate in England. Annex 7.

Broadleaved woodland on mineral soil has the highest carbon sequestration capacity of the habitats in the area (9.42 $tCO_2/ha/yr$, red areas, **Figure 10**), even greater than the coniferous woodland on mineral soil (6.97 $tCO_2/ha/yr$, pink areas). The vegetated gardens in the Norwich urban area have a moderate carbon sequestration capacity (1.55 $tCO_2/ha/yr$) and in the southeast, there is a floodplain with other neutral grassland (or marshy grassland) around the River Yare, which has a carbon sequestration capacity of 2 $tCO_2/ha/yr$ (cream areas). The majority of the site is arable habitat, which has a negative carbon sequestration capacity (-1.5 $tCO_2/ha/yr$, dark blue areas) due to emissions from agricultural practices. Other habitats that have no capacity for this service include urban habitats and water areas.

Figure 9. Carbon storage capacity across the strategy area.

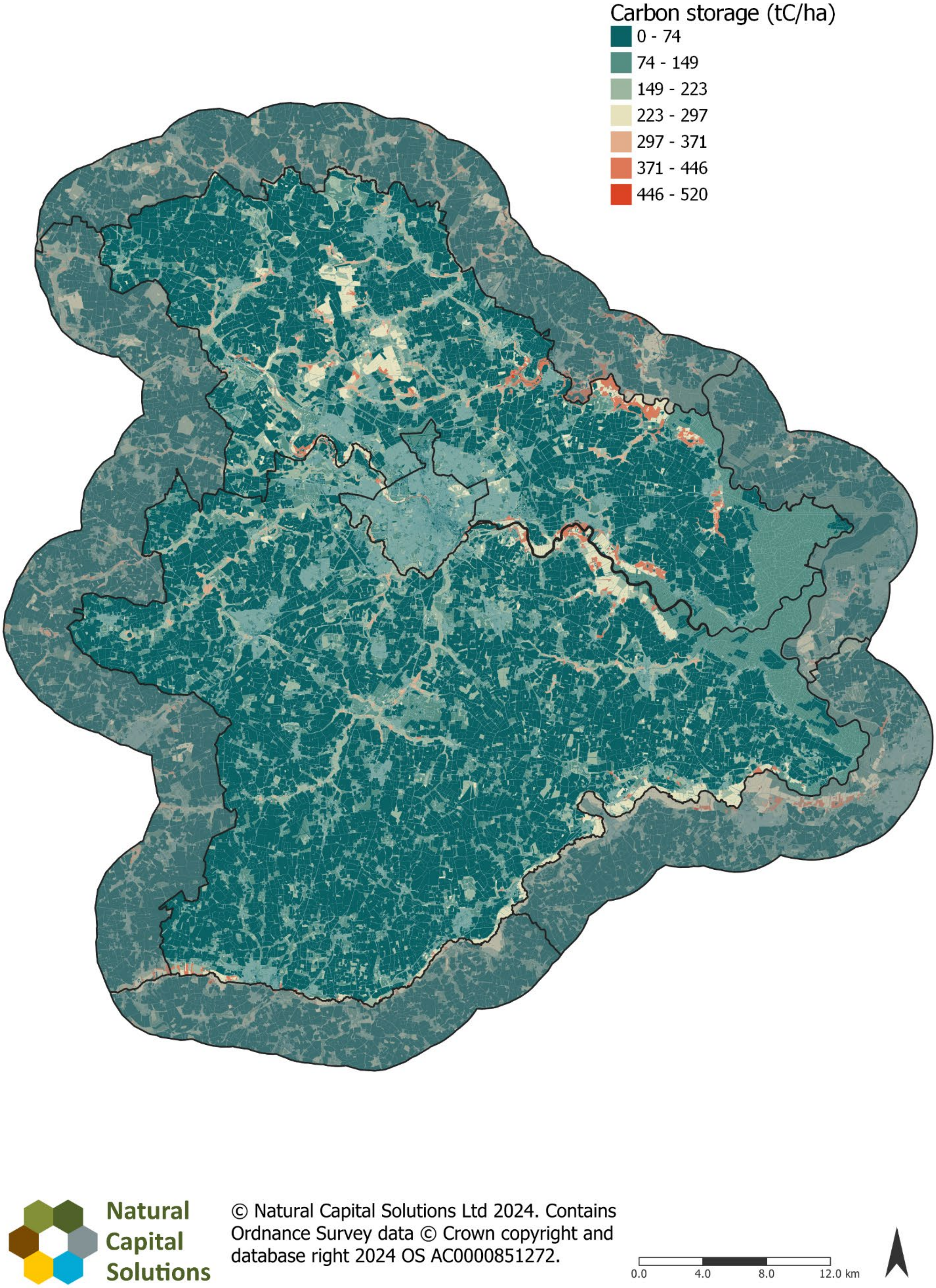
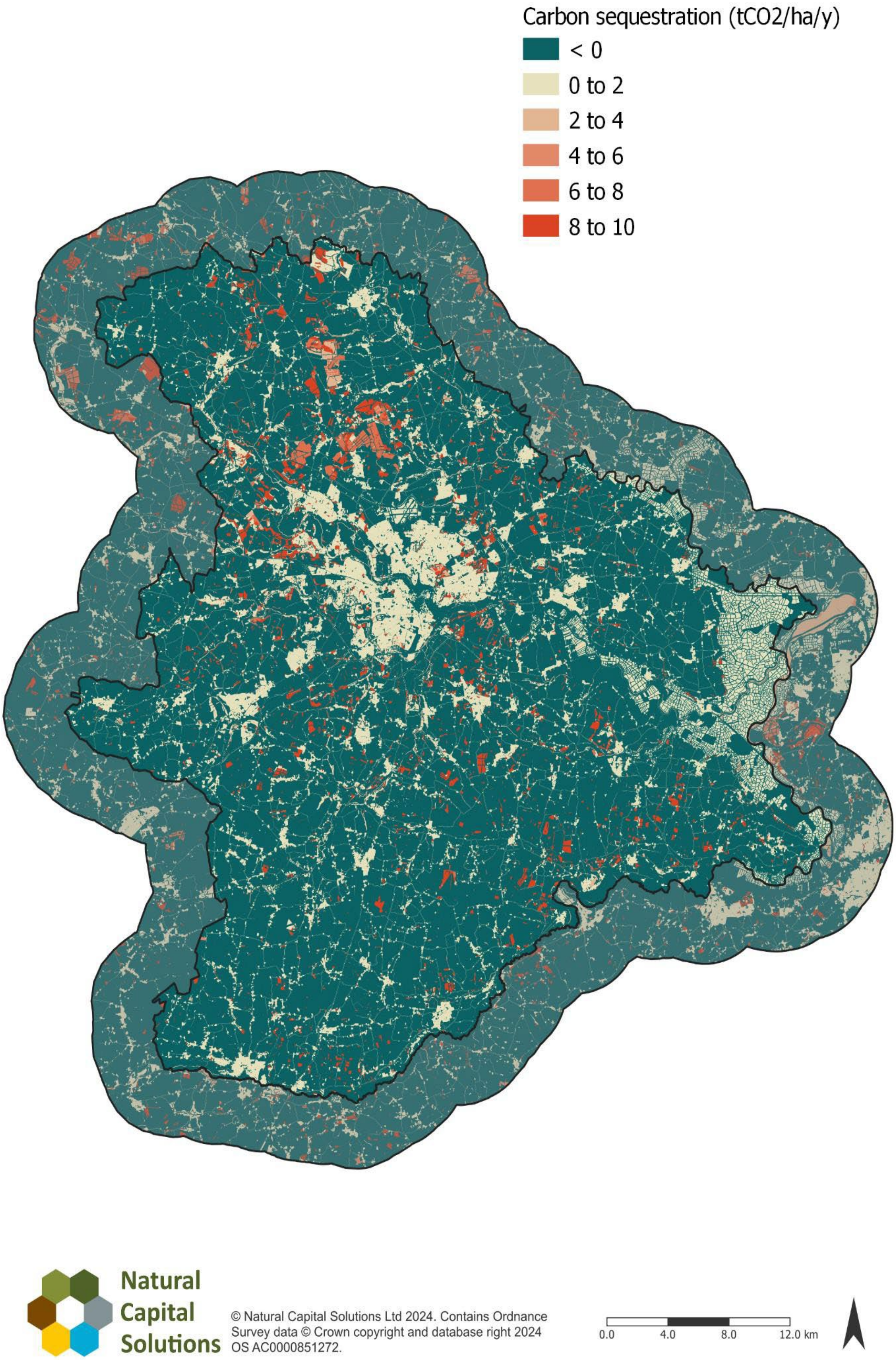


Figure 10. Carbon sequestration capacity across the strategy area.



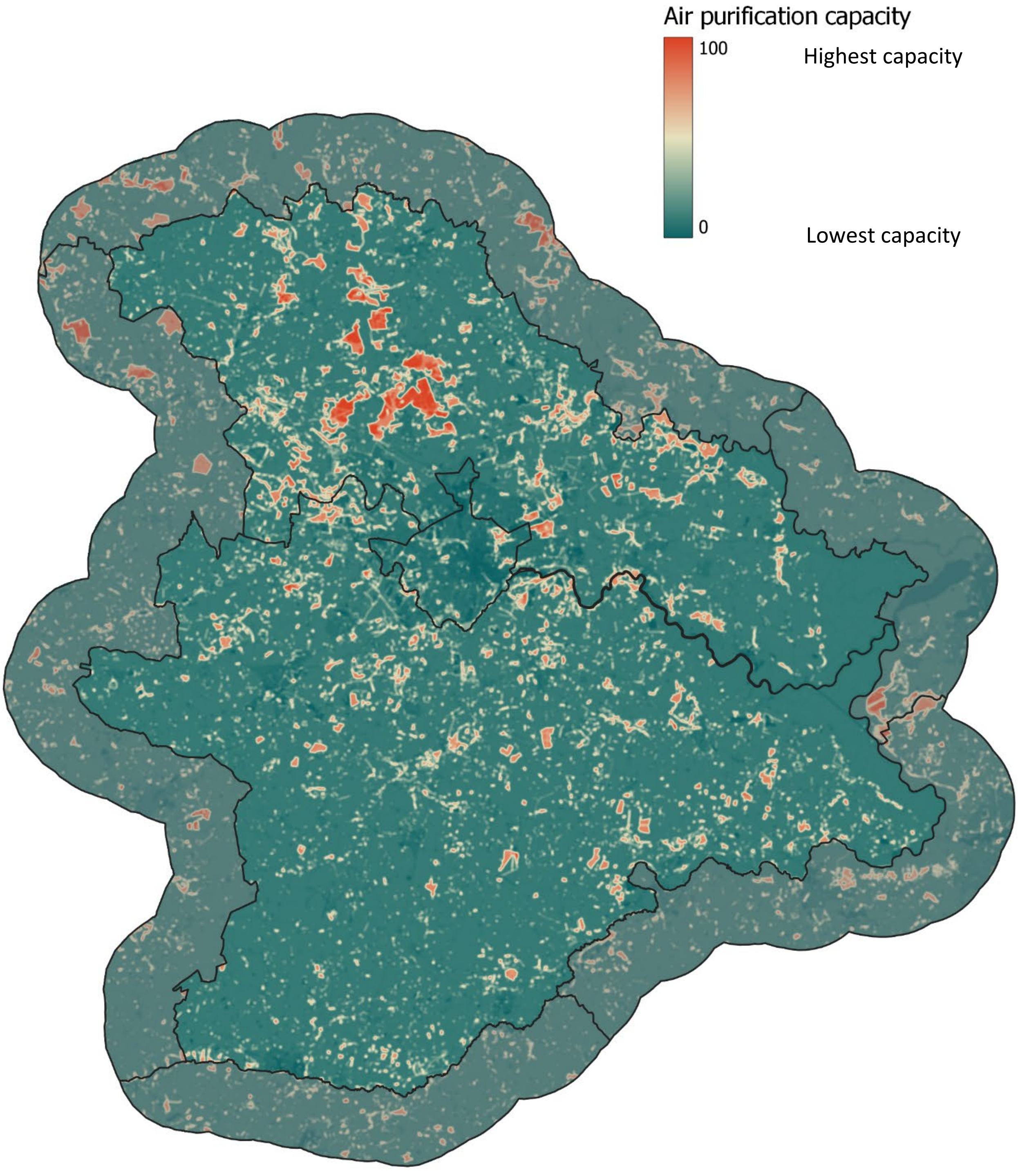
Air purification capacity (air quality regulation)

Air purification capacity estimates the relative ability of vegetation to trap airborne pollutants or ameliorate air pollution. 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. Air purification is generally low across the strategy area (blue area, **Figure 11**), with the greatest capacity in areas with coniferous woodland (red areas, **Figure 11**) and broadleaved woodland (pink areas, **Figure 11**).

Air purification demand

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. Air purification demand is highest in the central urbanised area of the city of Norwich (pink areas, **Figure 12**) and along the major roadways fanning out from the city (A47, A1067, A140, A1151, A146, A11). Apart from the Norwich urban area, towns and roadways, the majority of the strategy area is covered by arable land, and has low air purification demand.

Figure 11. Air purification capacity across the strategy area.



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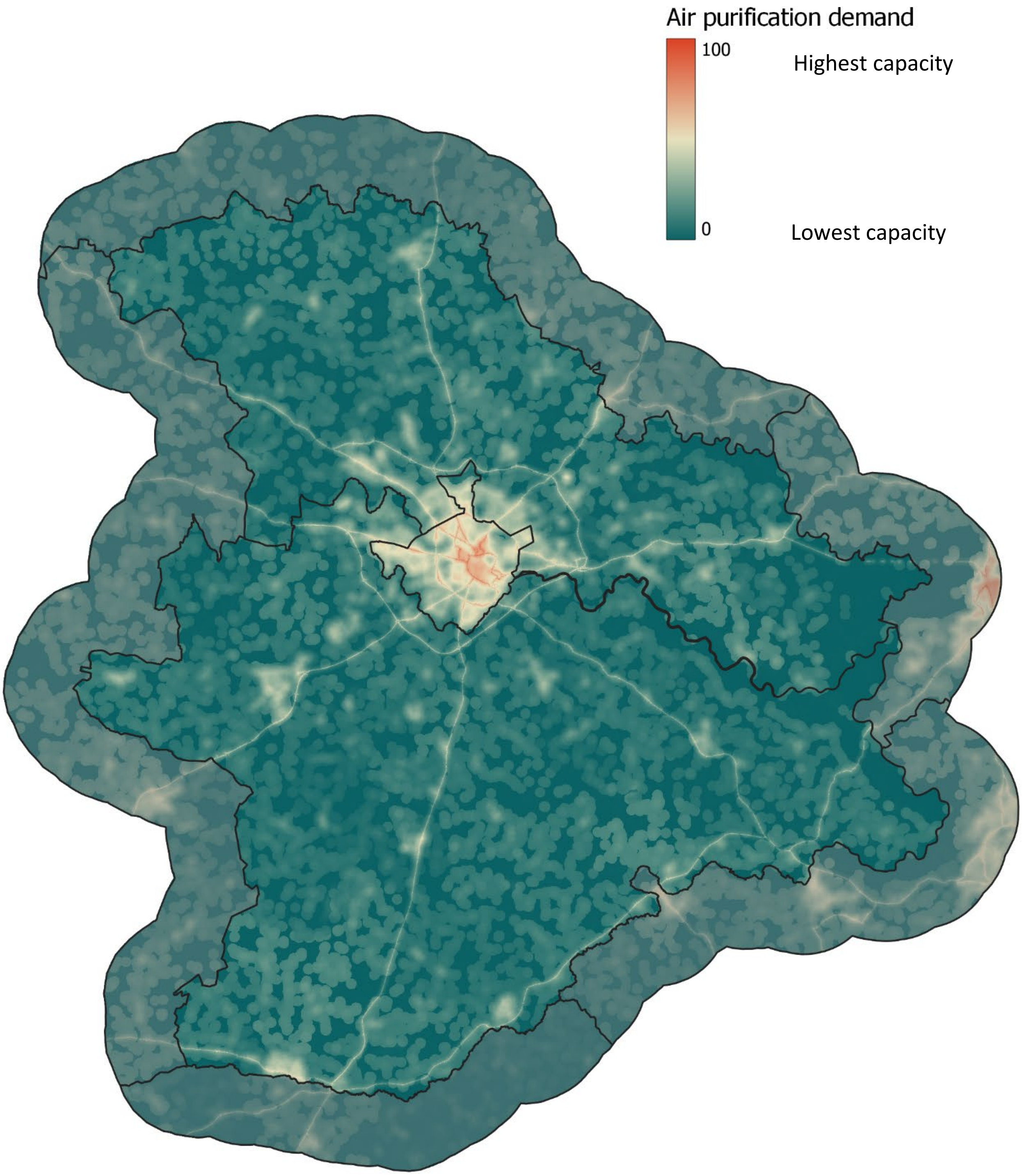
0.0 4.0 8.0 12.0 km

Figure 12. Air purification demand across the strategy area.



0.0 4.0 8.0 12.0 km

Noise regulation capacity

Noise regulation capacity is the capacity of the land to diffuse and absorb noise pollution. Complex vegetation cover, such as woodland, trees and scrub, is considered to be most effective, and the effectiveness of vegetation increases with width. Noise regulation capacity is highest in the areas of coniferous woodland (red areas, **Figure 13**) and broadleaved woodland (pink areas, **Figure 13**). Overall, this strategy area has a low capacity for noise regulation (blue areas, **Figure 13**) likely because of the majority arable habitat, which is not very effective at noise pollution amelioration.

Noise regulation demand

Noise regulation demand estimates societal and environmental need for ecosystems that can absorb and reflect anthropogenic noise. Noise regulation demand is similar to air purification demand in that it is highest in the central urbanised area of the city of Norwich (pink / cream areas, **Figure 14**) and the major motorways that surround it. To the north of the city, the area around Norwich Airport also has a moderately high noise regulation demand (cream / pink areas, **Figure 14**). Outside of these major urban hubs, the majority of the strategy area has low noise regulation demand (blue areas, **Figure 14**).

Figure 13. Noise regulation capacity across the strategy area.

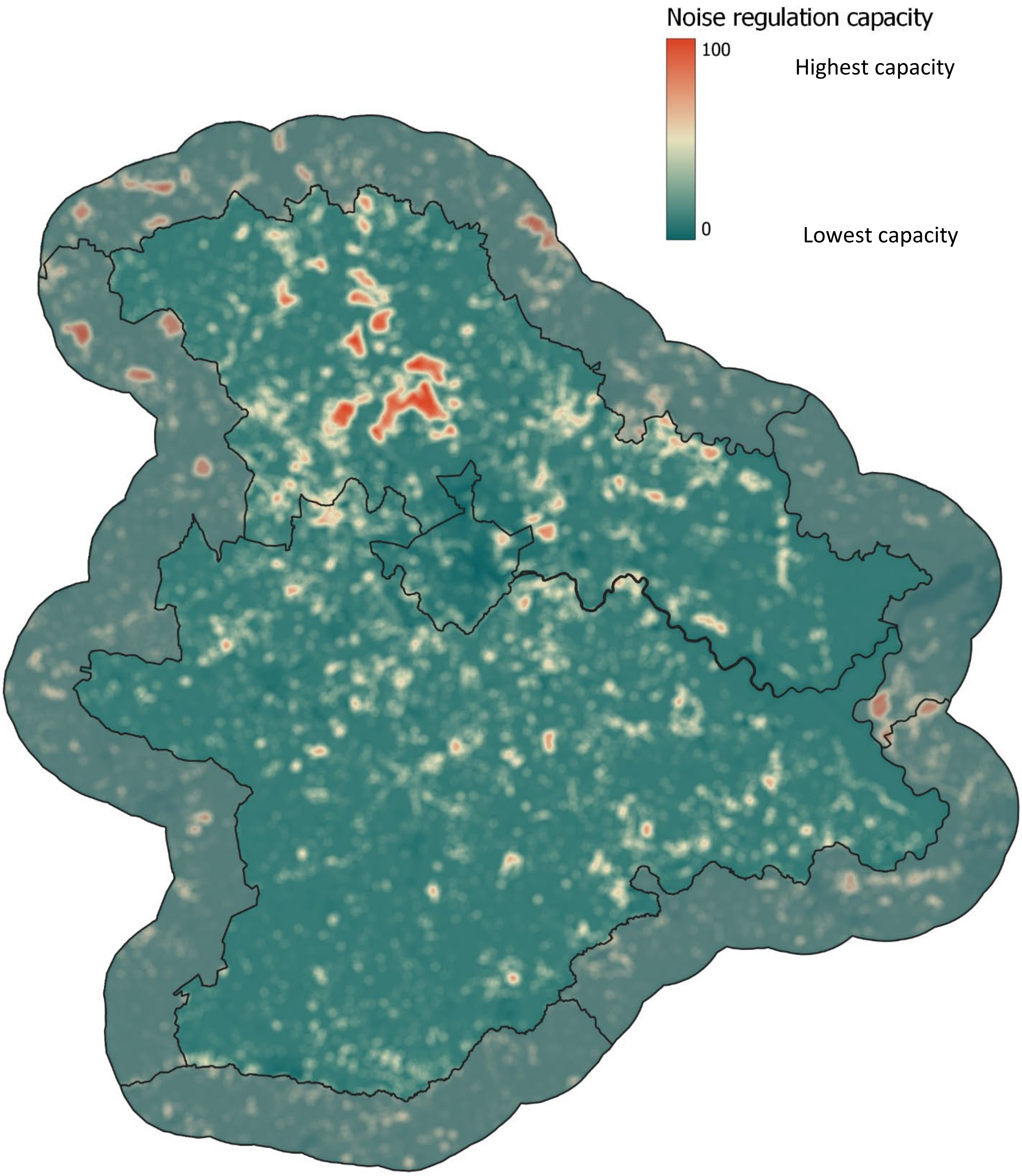


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Figure 14. Noise regulation demand across the strategy area.

Local climate regulation capacity

Land use can have a significant effect on local temperatures. Local climate regulation capacity estimates the capacity of an ecosystem to cool the local environment and cause a reduction in urban heat maxima. Natural vegetation, especially trees / woodland and rivers and lakes, are able to have a moderating effect on local climate, making nearby areas cooler in summer and warmer in winter. Across the strategy area, the coniferous woodland, broadleaved woodland and fen habitats have the highest capacity for local climate regulation (red areas, **Figure 15**). Large, connected areas of these habitats have greater capacity for this service than smaller, disjointed habitats. Arable areas have a low capacity for this service (light blue area**s, Figure 15**). Urban areas have no capacity for this service (dark blue areas, **Figure 15**).

Local climate regulation demand

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. These urban heat islands can be clearly seen in **Figure 16**, as demand for this service increases in the urbanised areas such as Norwich, Wymondham, Diss, and Aylsham (cream / pink areas). Densely urbanised areas have increased demand for this service (pink areas). However, across the majority of the strategy area, the demand for this service is low (blue areas).

Figure 15. Local climate regulation capacity across the strategy area.

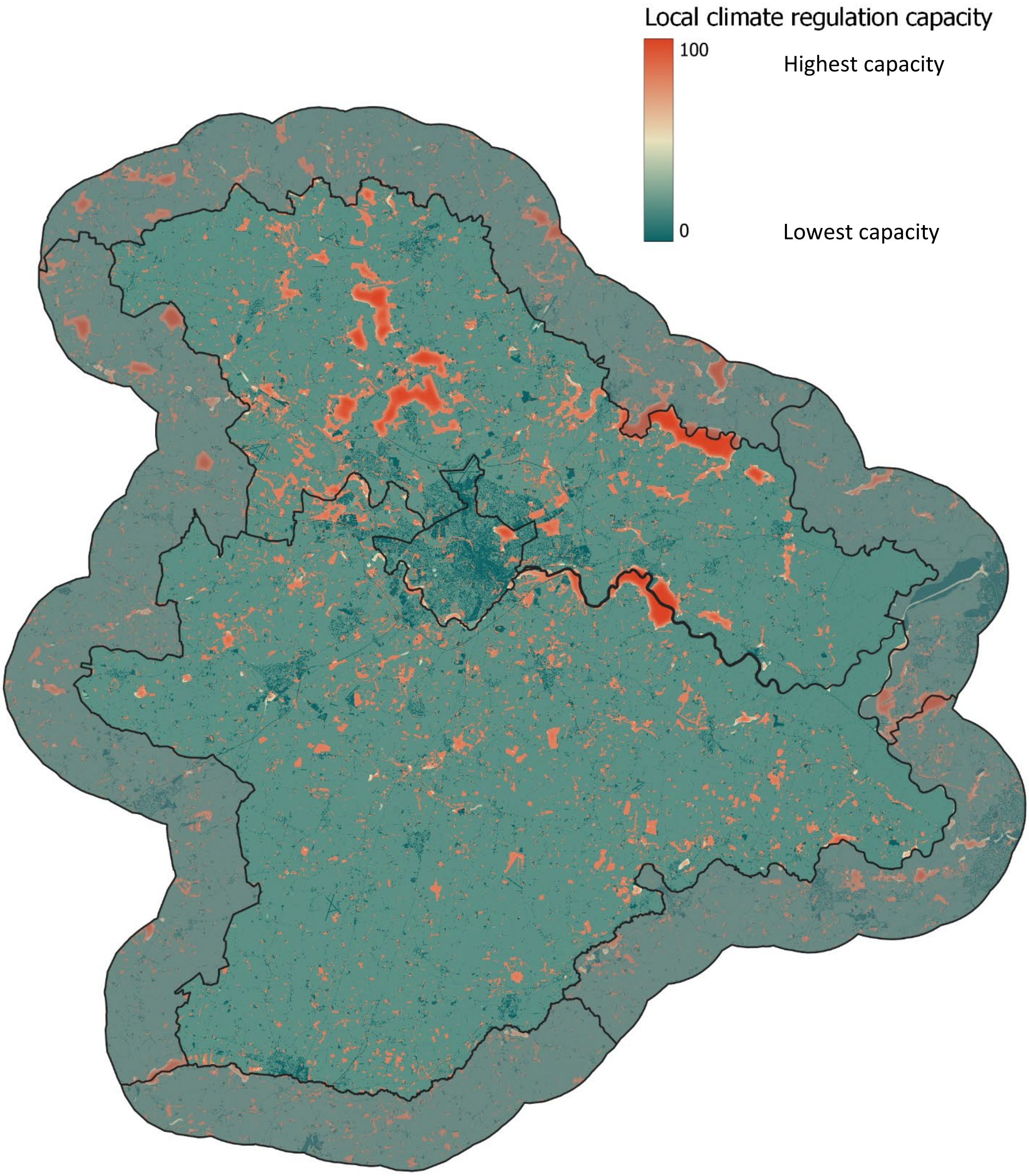
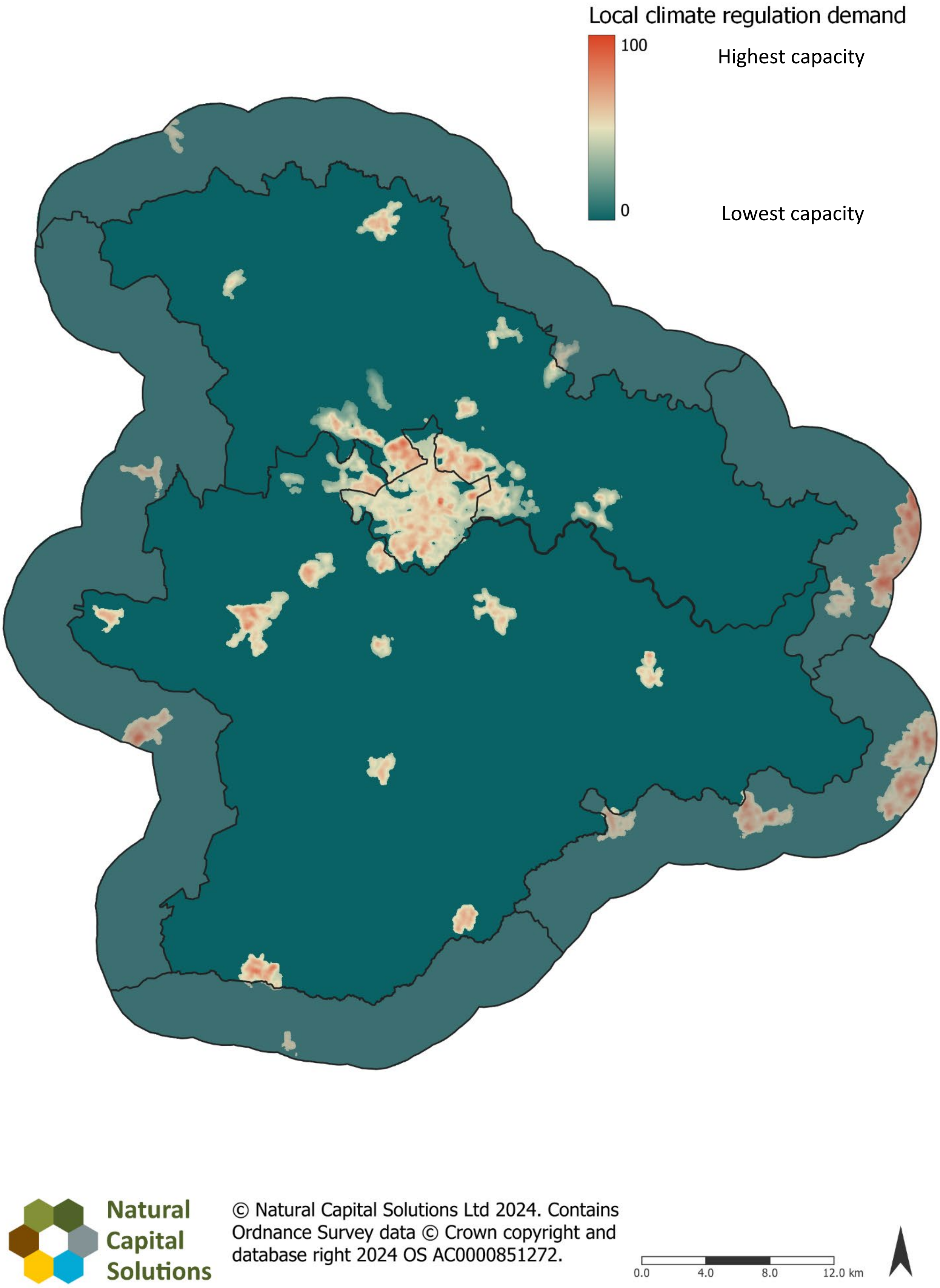


Figure 16. Local climate regulation demand across the strategy area.



Water flow regulation capacity

Water flow regulation capacity is the ability of the land to slow water runoff and thereby potentially reduce flood risk downstream, based on land use and slope. The best locations for slowing water runoff are areas of woodland on flat land. The worst areas tend to be impermeable surfaces and slopes. The scheme area is quite flat in terms of relief, so most of the influence will be from the vegetation and land use. Water flow capacity across the scheme area is highest in areas of coniferous woodland, broadleaved woodland and fen (shown in red, **Figure 17**). Areas of grassland (including arable land) and scrub have a moderate capacity (shown in pink, **Figure 17**). Sealed surfaces and houses have a low capacity (shown in cream), and water areas are excluded (shown in white, **Figure 17**).

Water quality regulation capacity (soil erosion)

Water quality regulation capacity models the risk of surface runoff becoming contaminated with high pollutant and sediment loads before entering a watercourse, with a higher water quality capacity indicating that water is likely to be less contaminated. The majority of the area is arable land, which has high erosion rates (blue areas, **Figure 18**). Marshy grassland and fen have moderate capacity for this service (cream areas, **Figure 18**) and woodland areas have a high capacity (red and pink areas**, Figure 18**). The model is focussed on agricultural erosion so urban areas with sealed surfaces tend to have higher capacities in this model (pink areas, **Figure 18**).

Figure 17. Water flow regulation capacity across the strategy area.

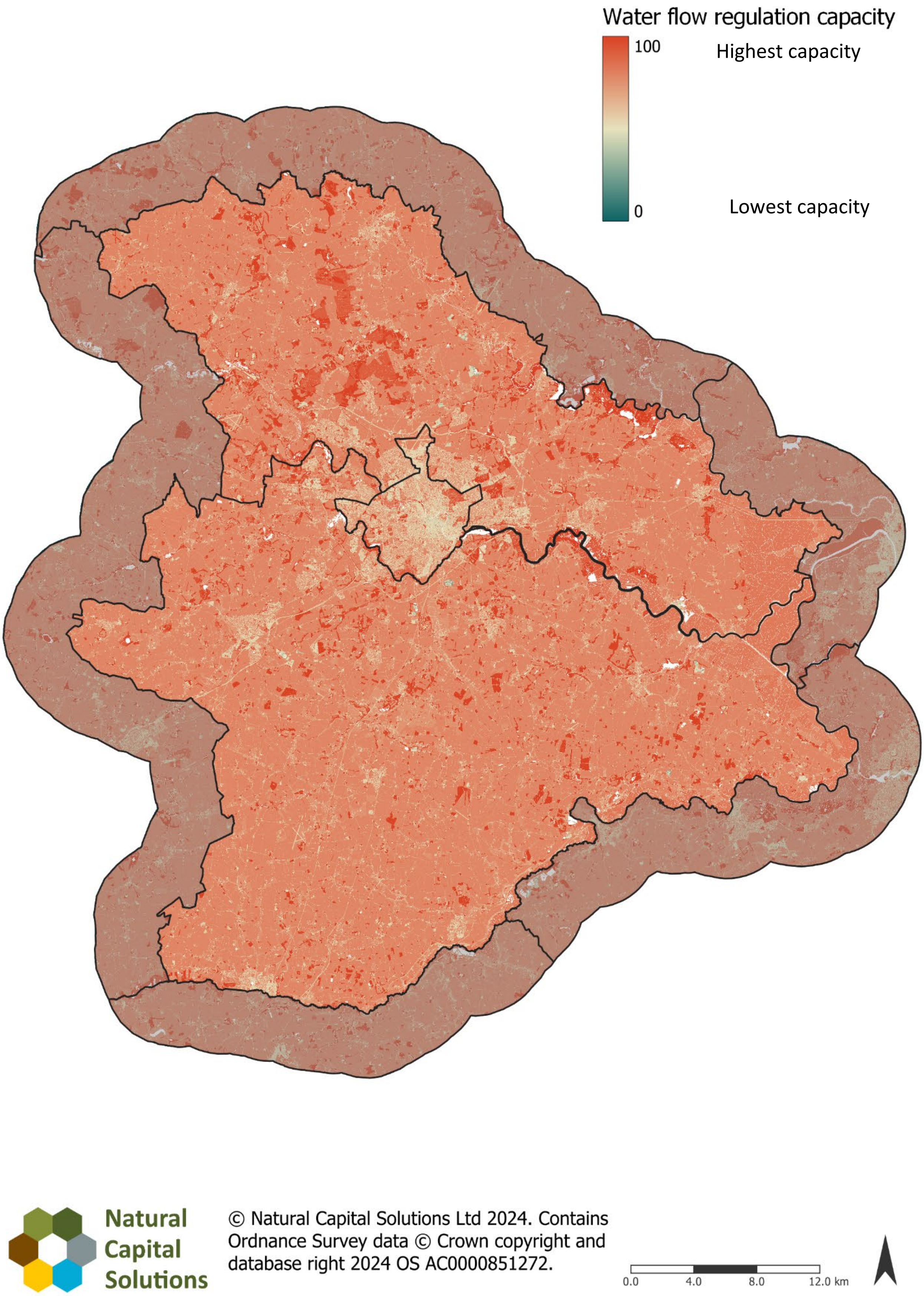
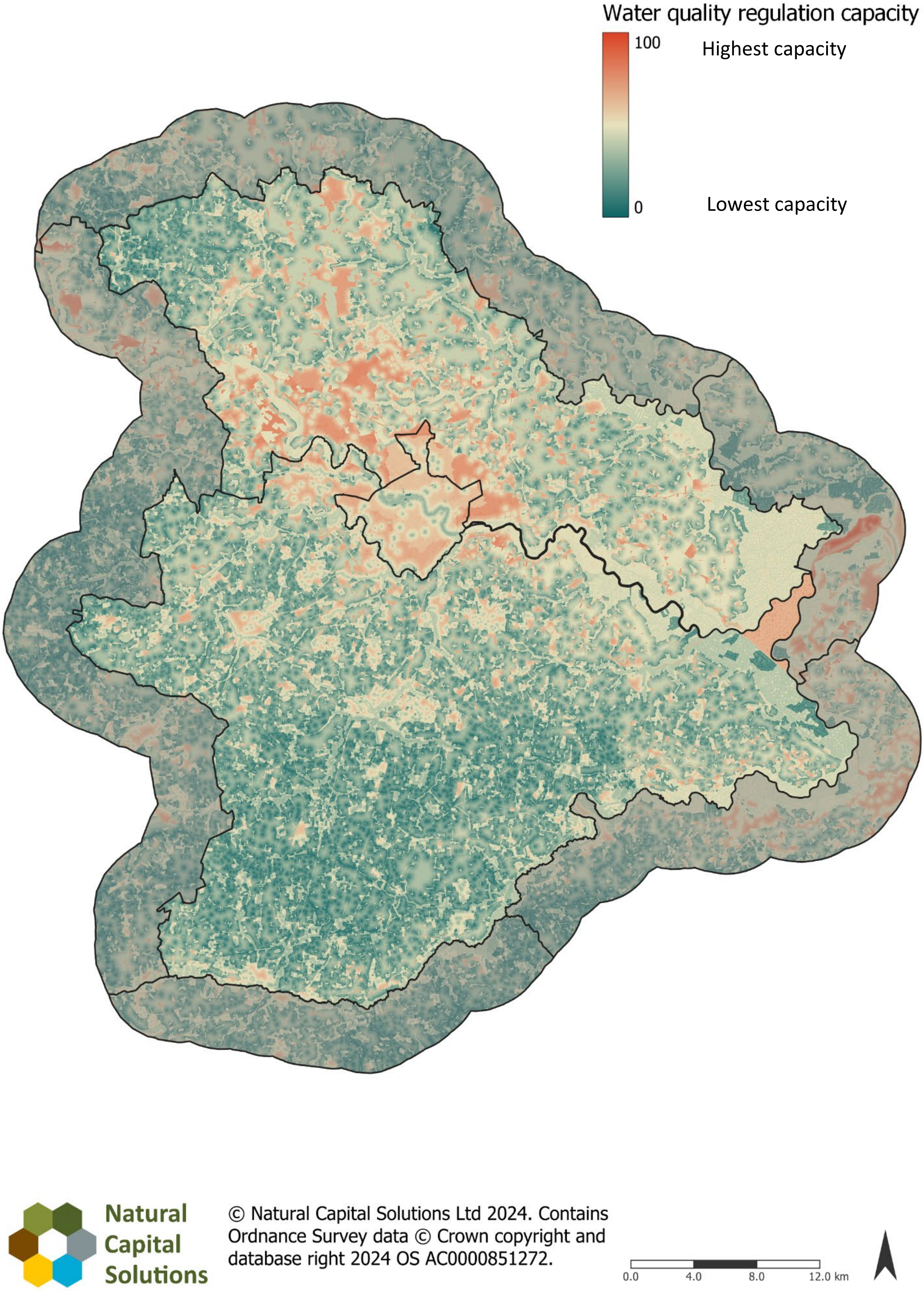


Figure 18. Water quality regulation capacity across the strategy area.



3.3 Ecosystem service opportunity maps

Opportunity mapping to reduce soil erosion and improve water quality

Opportunity mapping to improve water quality focussed on identifying areas at highest risk of sedimentation and soil erosion, based on the water quality model (**Figure 18**) and described in **Appendix A2**. **Figure 19** shows the opportunities to create habitat to improve the provision of this service. There are a significant number of highest priority locations (top 10%) within the strategy area, mainly concentrated in the southern end of the area and in the northwest, which are both currently areas of arable habitat. High (top 25%) priority locations are also found in these areas of arable habitat. Medium priority (top 50%) locations are spread over a wider area and throughout remaining areas of arable habitat. Existing good quality habitats were removed as a constraint so as not to remove areas where good quality habitat currently exists.

Opportunity mapping to enhance local climate regulation

Local climate regulation is very highly localised and effects of vegetation on urban cooling are often only felt within 100m of planting. Consequently, there are few opportunities to enhance this service, with most being in central urban areas, primarily in Norwich urban area but also in smaller urban areas such as Wymondham, Loddon and Long Stratton (**Figure 20**). The level of priority for this map is influenced by the density of urban sealed surfaces, and the highest priority (top 10%) are all within available green spaces surrounded by densely urbanised areas.

Figure 19. Opportunities for creating habitat to improve water quality regulation across the strategy area.

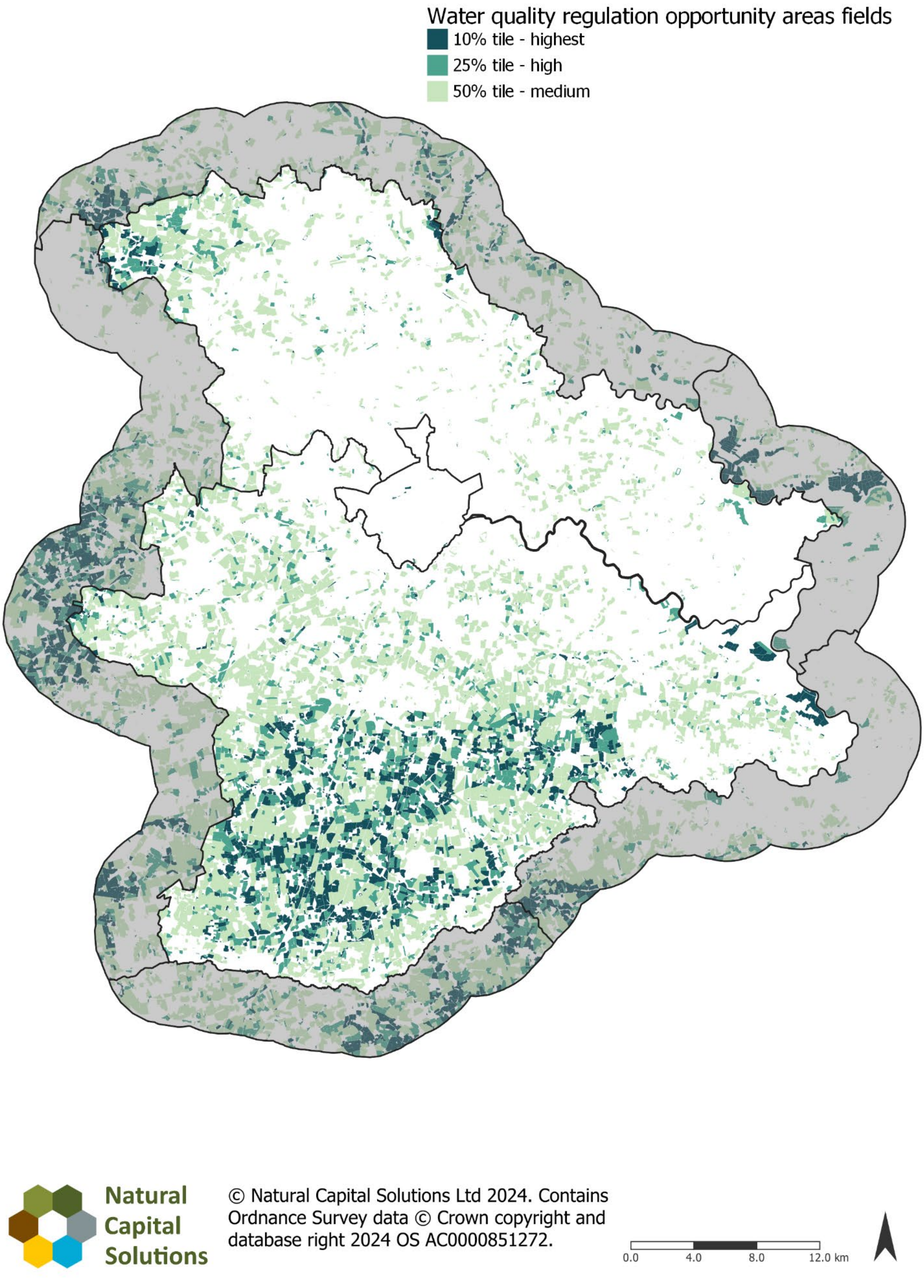
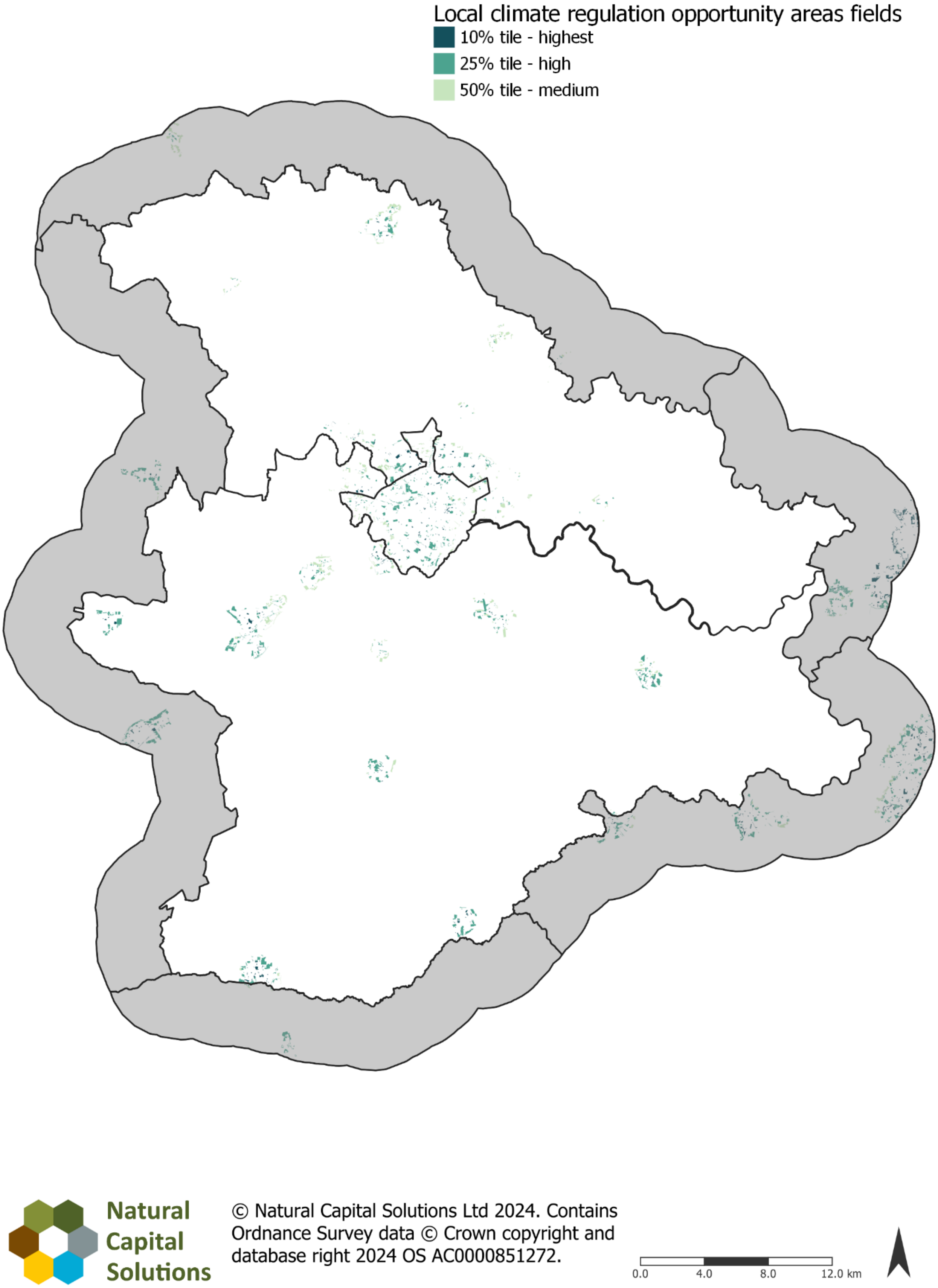


Figure 20. Opportunities to create habitat to enhance local climate regulation across the strategy area.



Opportunity mapping to ameliorate noise pollution

Similarly, to local climate regulation, noise pollution is often highly localised, and vegetation is most effective at mitigating noise when planted close to noise sources. The opportunity maps highlight areas that currently have no trees, but where it would be most beneficial to plant them (**Figure 21**). There are a number of opportunities in the study area along major roadways which would benefit from noise pollution amelioration (see blue / green and light blue areas, **Figure 21**). However, the area that would most benefit from noise pollution mitigation measures is the area surrounding Norwich airport, especially areas where there are currently amenity grasslands and arable land.

Opportunity mapping to ameliorate air pollution

Air pollution, like noise pollution, is localised, and vegetation is most effective at mitigating pollutants when planted close to pollution sources. Opportunities to ameliorate air pollution are focussed around areas with greatest demand. The opportunity maps highlight areas that currently have no trees, but where it would be most beneficial to plant them. As the strategy area is dominated by cropland and livestock farming areas, there are a lot of opportunities for air pollution amelioration across the area. Highest priority areas (top 10%) are concentrated around densely urban areas and the main road network, with high concentrations of air pollutants and large populations that could benefit from enhanced air quality (see **Figure 22**). Areas with high and medium priority opportunities (mid and light shading) follow this same general trend, but in areas with slightly lower demand, slightly further away from urban centres and major roads.

Figure 21. Opportunities to create habitat to ameliorate noise pollution across the strategy area.

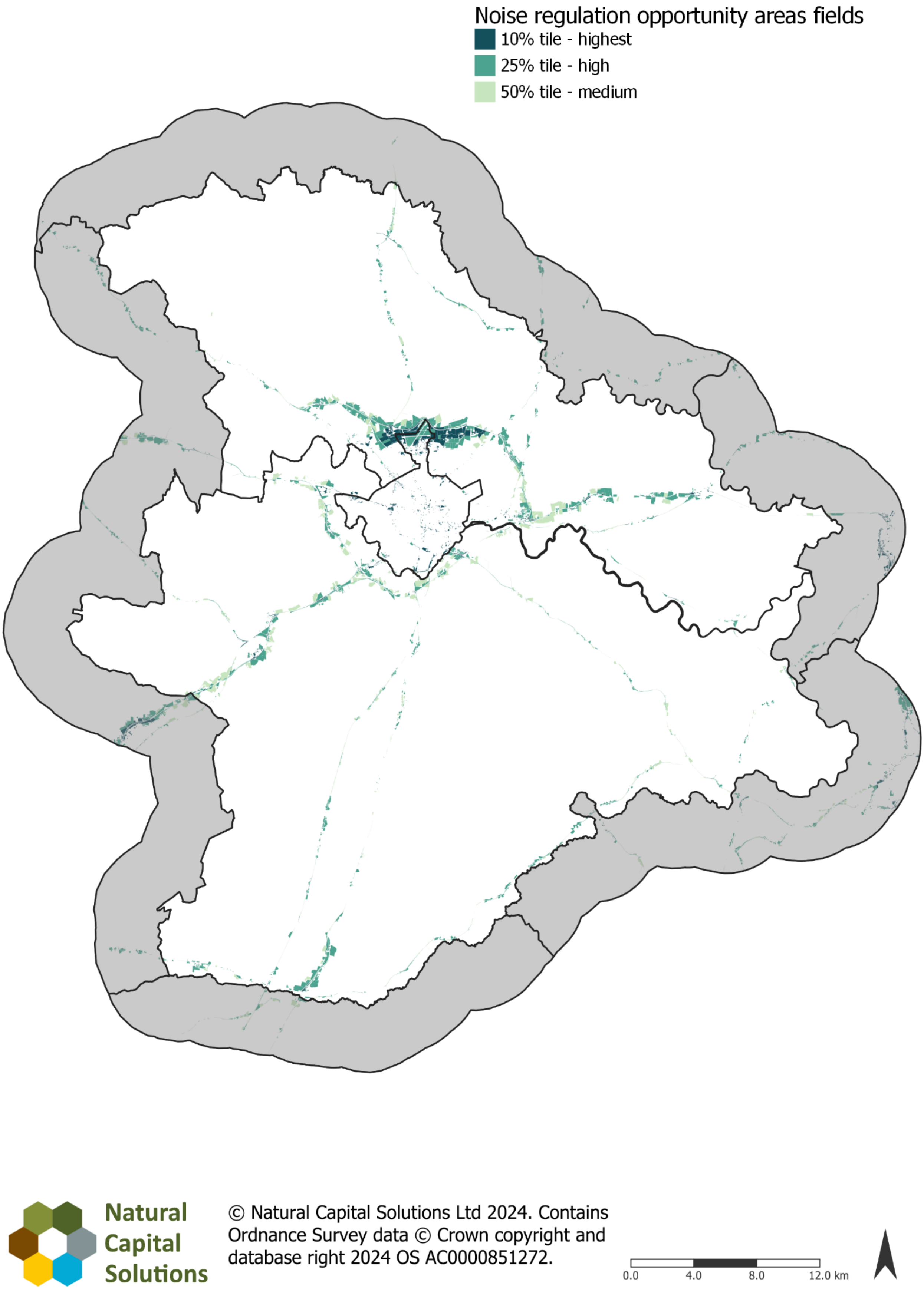
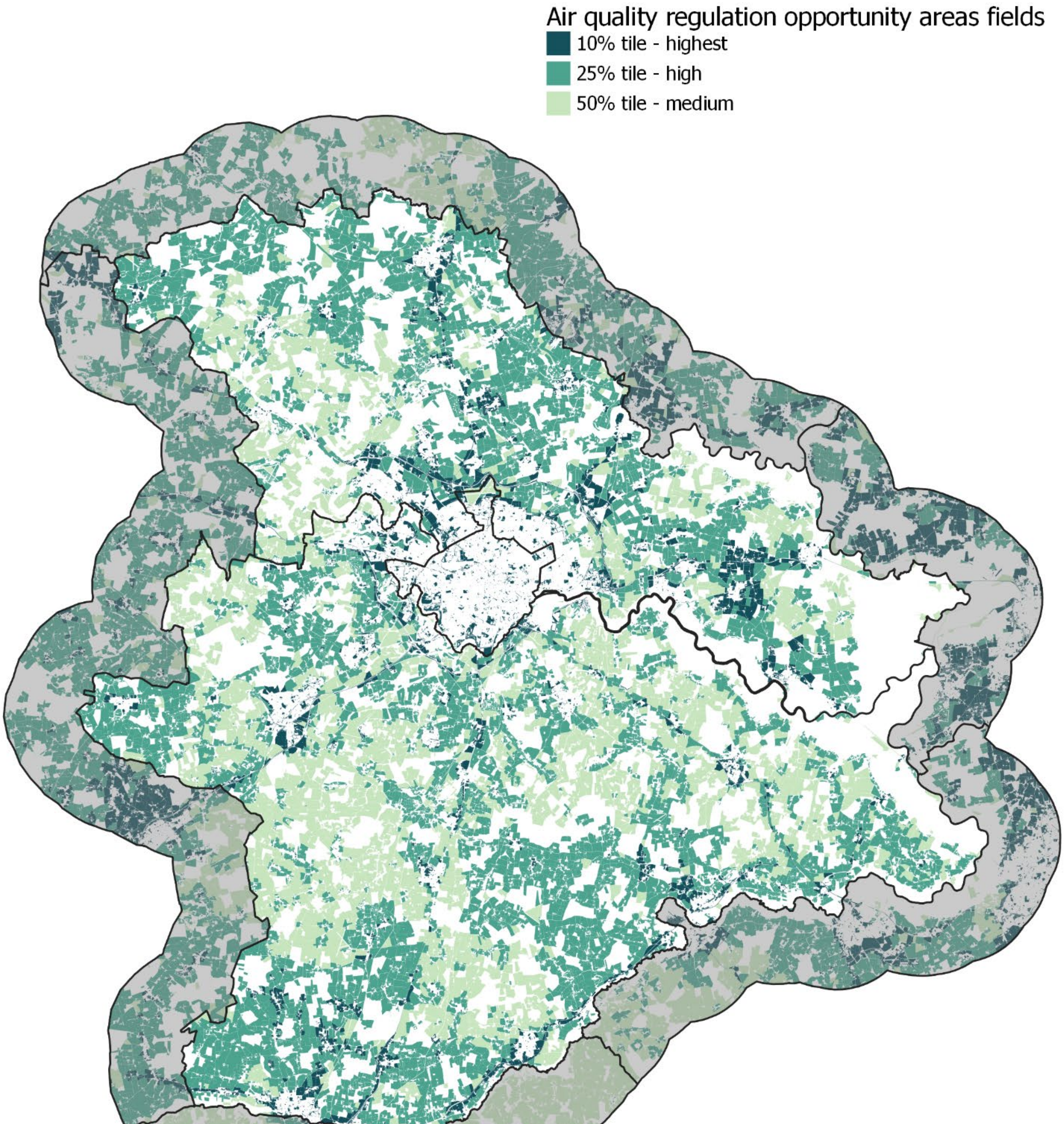


Figure 22. Opportunities to create habitat to ameliorate air pollution across the strategy area.



3.4 Carbon emissions sequestration

The carbon sequestration and emissions associated with the land and how it is managed are described above and shown in **Figure 10**. When the carbon balance is calculated across habitats (sequestration and emissions across the habitats of the strategy area are summed), the area is emitting c.93,600 tonnes of CO_2e per year (see **Table 4**). Despite the woodland and grassland habitats taking up carbon, the dominance of agriculture in the strategy area (66% of the area) pushes the balance into emissions.

Table 4. Carbon sequestration (in tonnes CO_2 per year) by habitat type across the strategy area associated with the land only. Note this does not include emissions from any livestock. Note that negative numbers in the table represent carbon emissions, and positive numbers represent carbon sequestration.

Habitat	Carbon sequestration/emissions per year (tonnes CO_2e/year)	Area (ha)	Area (%)
Agriculture (arable and improved grassland)	-186,236	99,466	66.2
Built-up	-2,686	20,766	13.8
Grasslands	11,701	11,250	7.5
Other	2,795	4,899	3.3
Woodland	80,784	13,893	9.2
Total	**-93,643**	**150,274**	**100**

The GHG emissions maps of ammonia (**Figure 23**), carbon dioxides (**Figure 24**), methane (**Figure 25**), and nitrogen oxides (**Figure 26**), based on data from the National Atmospheric Emissions Inventory, although at a relatively coarse scale, show that concentrations are reasonably low across the area, but there are locally high emissions. These take into account emissions across a broad range of sectors including agriculture, commercial, domestic, industry, public sector, transport, waste management and land use, land-use change and forestry (or LULUCF).

The highest concentrations of ammonia, carbon dioxide and nitrous oxides are found above the Cantley Sugar Beet Factory near the eastern boundary of the strategy area (**Figures 23, 24 and 26**). Ammonia levels are moderately high in areas with livestock farms, particularly poultry. The carbon dioxides map has moderately high levels above Norwich urban area, especially above the Briar Chemicals plant, which also has a moderately high concentration of nitrogen oxides. Other moderately high concentration areas include Wymondham, near the Lotus Cars manufacturing plant, which also has moderate levels for nitrogen oxides emissions. Methane emissions are highest around the Norfolk Showgrounds and the farms surrounding it, and in the southeast near Gillingham, above livestock farms and waste areas (**Figure 25**). The other moderate areas for methane emissions are found above livestock farms. Nitrogen oxides emissions follow major roads, urban areas and sewage treatment facilities, with other moderate concentrations near livestock farms.

It is difficult to use the spatial pattern of GHG emissions to guide the prioritisation of opportunities for increasing carbon sequestration apart from in two instances (air pollution from roads and ammonia production from livestock). In general, an increase in sequestration from woodland creation does not need to be located in any particular area. Although in the case of ammonia emissions from livestock it can be beneficial to plant woodland around animal housing to recapture ammonia (CEH 2018[12]). The woodland opportunity map (**Figure 27**) can be used to identify areas where woodland can be created for this purpose and for enhancing biodiversity. Woodland creation can also be focused adjacent to roads, which are sources of pollution – refer to air pollution regulation opportunity mapping (**Figure 22**).

Enhancing carbon sequestration capacity would be helpful across the strategy area. If all of the woodland opportunities identified in **Figure 27** were to be taken up, this would increase carbon sequestration by 478,700 tonnes of CO_2 equivalent per year in the new woodlands. But there would also be a drop in emissions of 57,700 tonnes as arable and improved grasslands were no longer farmed, meaning that the total change would be net sequestration of 536,400 tCO_2e. This would change the overall carbon balance for the area from emitting 93,600 tonnes of CO_2 equivalent to sequestering 442,800 tonnes per year. However, to achieve this would require converting 50,800 ha, or roughly a third of the entire study area, to new woodland, which is not realistic. To sequester as much carbon as is being emitted across the total strategy area (to move to net zero), about 10,000 ha of these woodland opportunities would need to be put in place, which would appear to be a much more realistic target. Note that this would only sequester the emissions from the land, and does not include emissions from other sectors such as transport and industry, which are included in the GHG emissions maps.

[12] Centre for Ecology and Hydrology (2018) Trees can help mitigate ammonia emissions from farming. https://www.ceh.ac.uk/press/trees-can-help-mitigate-ammonia-emissions-farming

Figure 23. Concentration of ammonia in atmosphere per square kilometre across the strategy area. Source: National Atmospheric Emissions Inventory 2021.

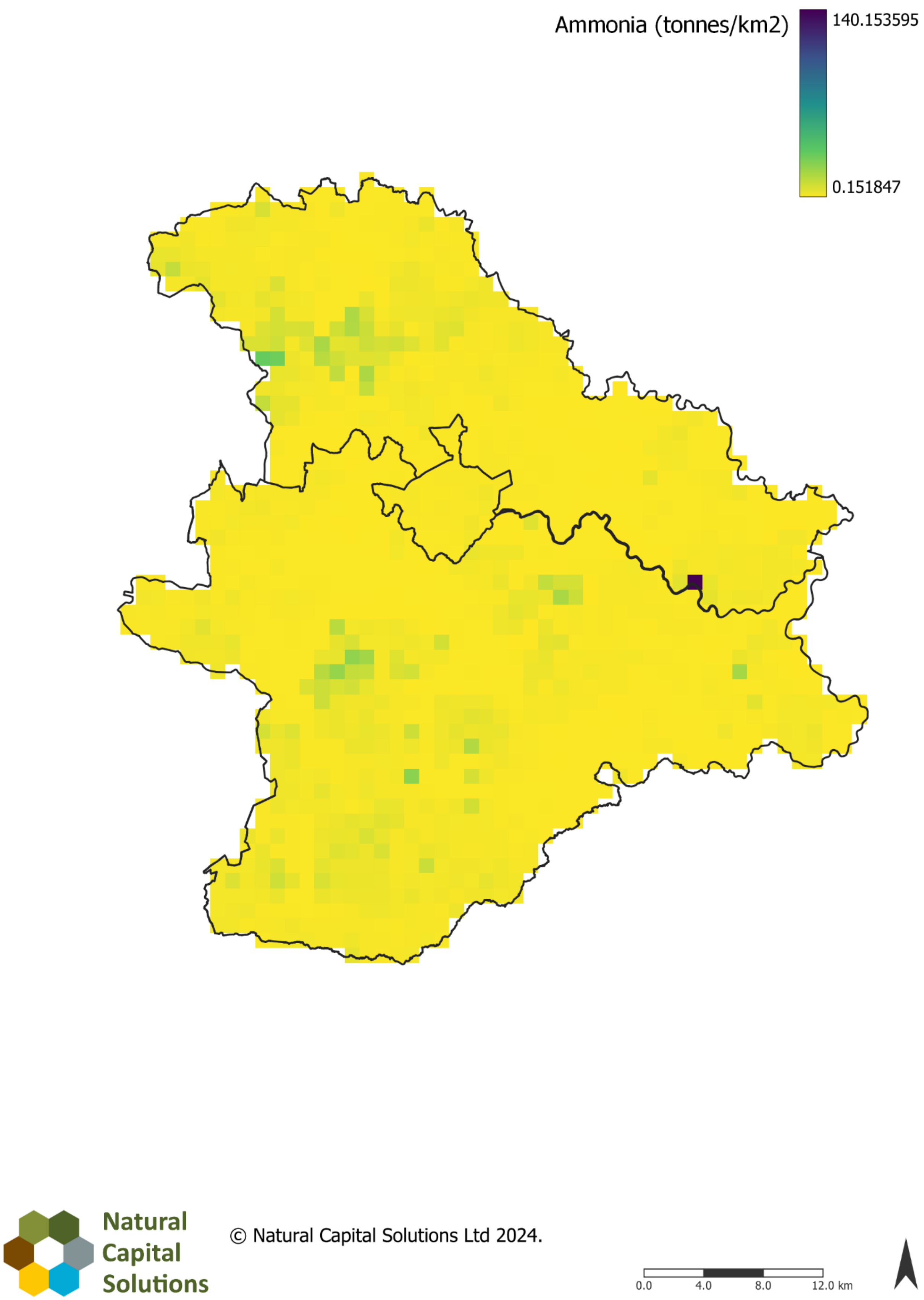


Figure 24. Concentration of carbon dioxide in the atmosphere per square kilometre across the strategy area. Source: National Atmospheric Emissions Inventory 2021.

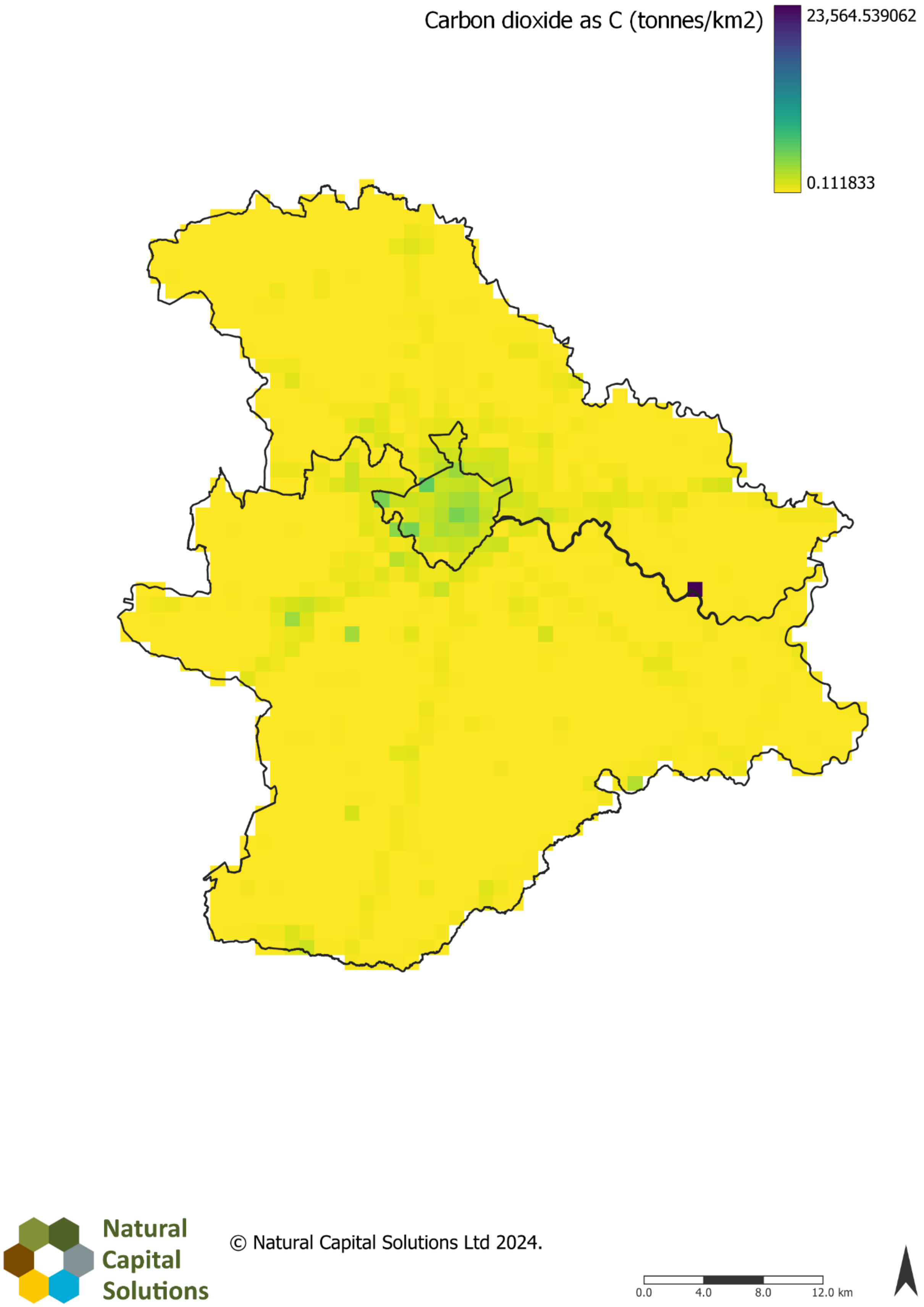


Figure 25. Concentration of methane in atmosphere per square kilometre across the strategy area Source: National Atmospheric Emissions Inventory 2021.

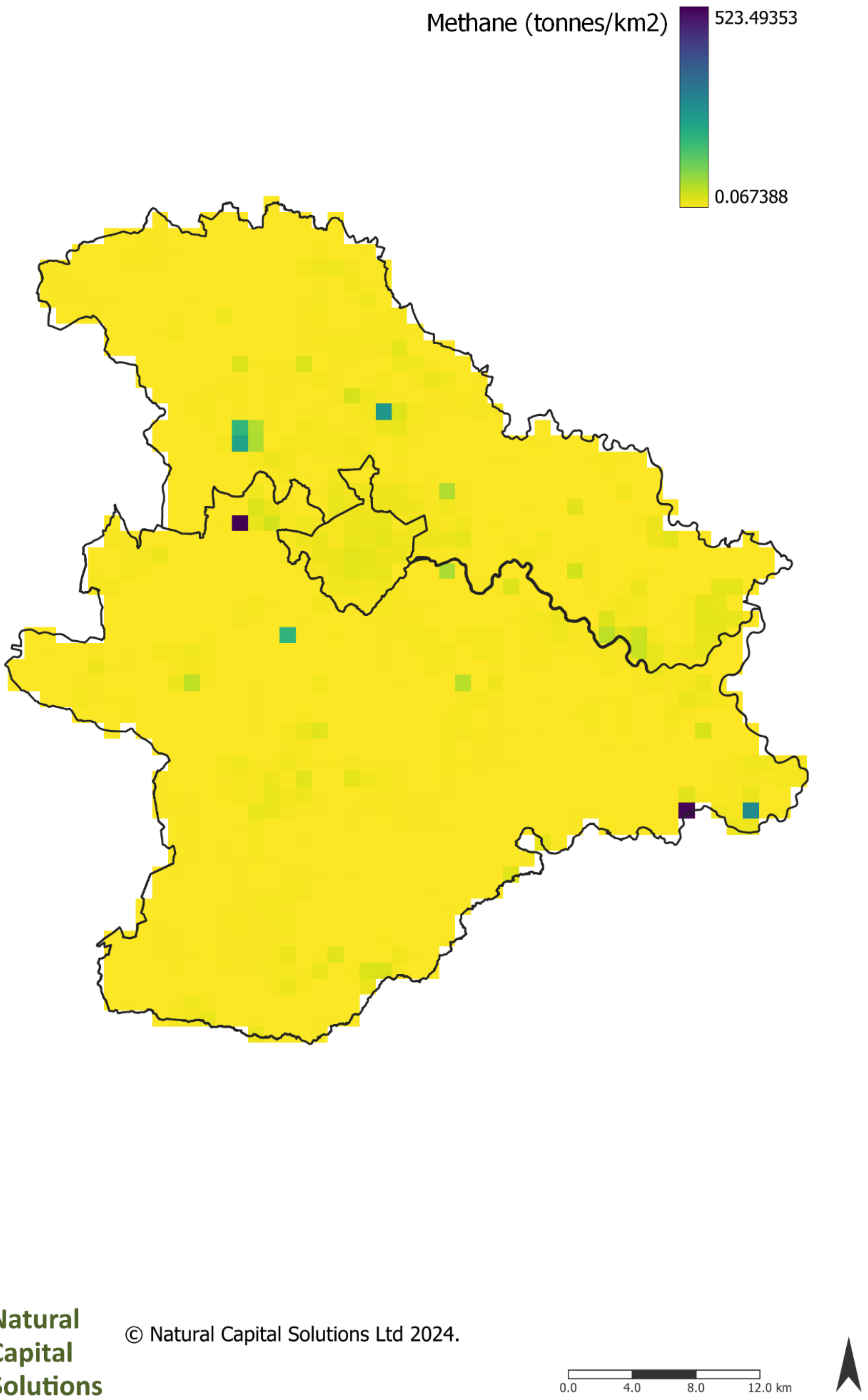


Figure 26. Concentration of nitrogen oxides in the atmosphere per square kilometre across the strategy area. Source: National Atmospheric Emissions Inventory 2021.

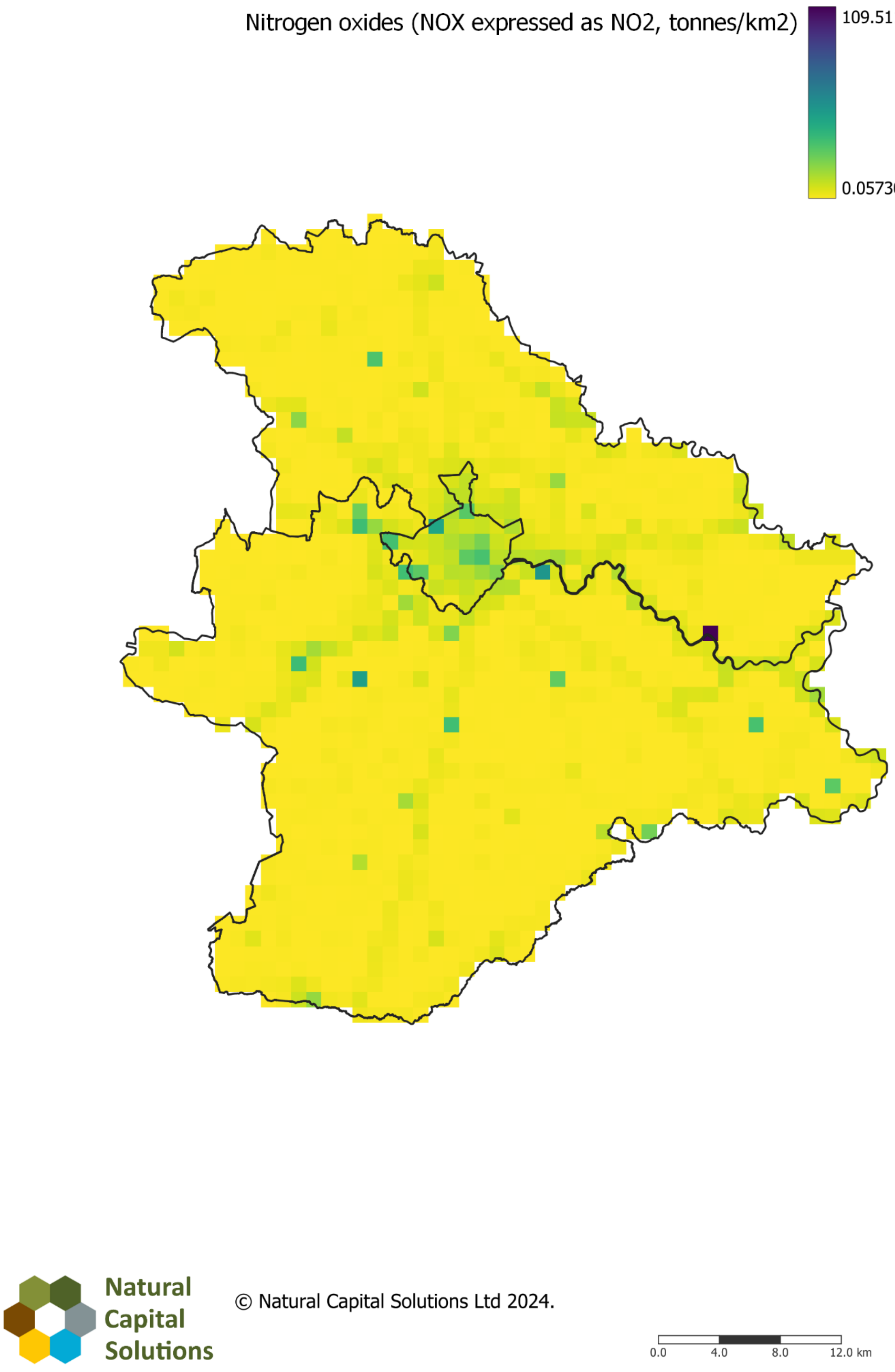
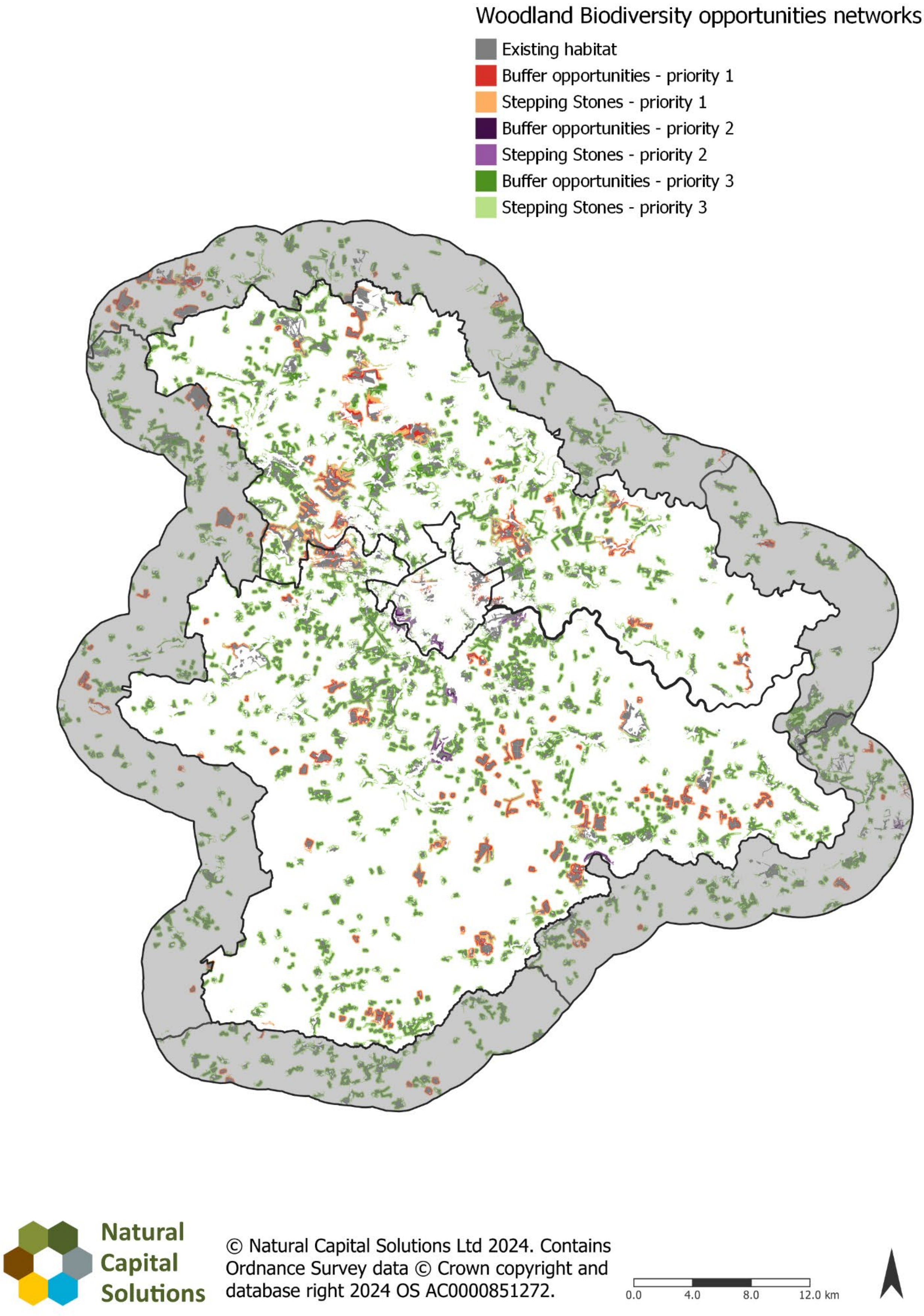


Figure 27. Opportunities for the creation of broadleaved and mixed woodland across the strategy area.



3.5 Prioritised flood risk reduction opportunities

Opportunity mapping to reduce surface runoff

Opportunity mapping to reduce surface runoff was undertaken based on the water flow map in **Figure 17** in **Section 3.2** and the model described in **Appendix A2**, and highlights the priority fields across the whole of the strategy area where surface water runoff is currently highest and where there are no constraints to potentially altering land use.

There are a number of opportunities to create habitat for slowing the flow of water across the study site (**Figure 28**) with large areas falling under the highest priority (top 10%). The main high priority location is arable land around the River Tas and the villages of Flordon, Hapton, Tasburgh and Newton Flotman. Across the strategy area, highest priority areas tend to be arable and improved grassland areas along rivers or floodplains. There are also large expanses across the strategy area that have been identified as medium priority (top 50%) for habitat creation that would slow the flow of water, covering much of the arable and improved grasslands across the area. Existing woodlands and fen have high water flow capacity (**Figure 17**) and appear blank in this model. Urban areas (sealed surfaces) also appear blank in this model because although they have low capacity for water flow regulation, there is also not enough space within the urban areas for water flow regulation habitat creation to be meaningful. This model is constrained by habitat patch size, for the conversion to semi- natural habitat to have an effect on water flow regulation, the land parcel must be at least 0.1 ha.

These opportunities for reducing surface run off were then prioritised further using the Environment Agency's Risk of Flooding from Multiple Sources (RoFMS) data (see **Figure 29**). There are four RoFMS risk categories: 1 is >3.3% chance of flooding in any year, 2 between 3.3%-1%, 3 between 1%-0.1% and 4 has <0.1%. In order to prioritise the opportunities to reduce surface runoff, the top three risk categories were used, as category 4 is low risk, and in the map (**Figure 30**) presented only the opportunities that fall within these.

In the prioritised flood risk model, the highest priority (top 10%) areas are concentrated around the arable and improved grassland habitats in the River Yare floodplain (near the eastern boundary of the map, see **Figure 30**). Other highest priority areas within the strategy area are arable and grassland (amenity and improved) habitats near rivers or in floodplains that are proximal to urbanised areas (blue areas, **Figure 30**), such as along the Rivers Tas, Yare, Tiffey and Bure.

Figure 28. Opportunities for creating habitat to reduce surface runoff across the strategy area.

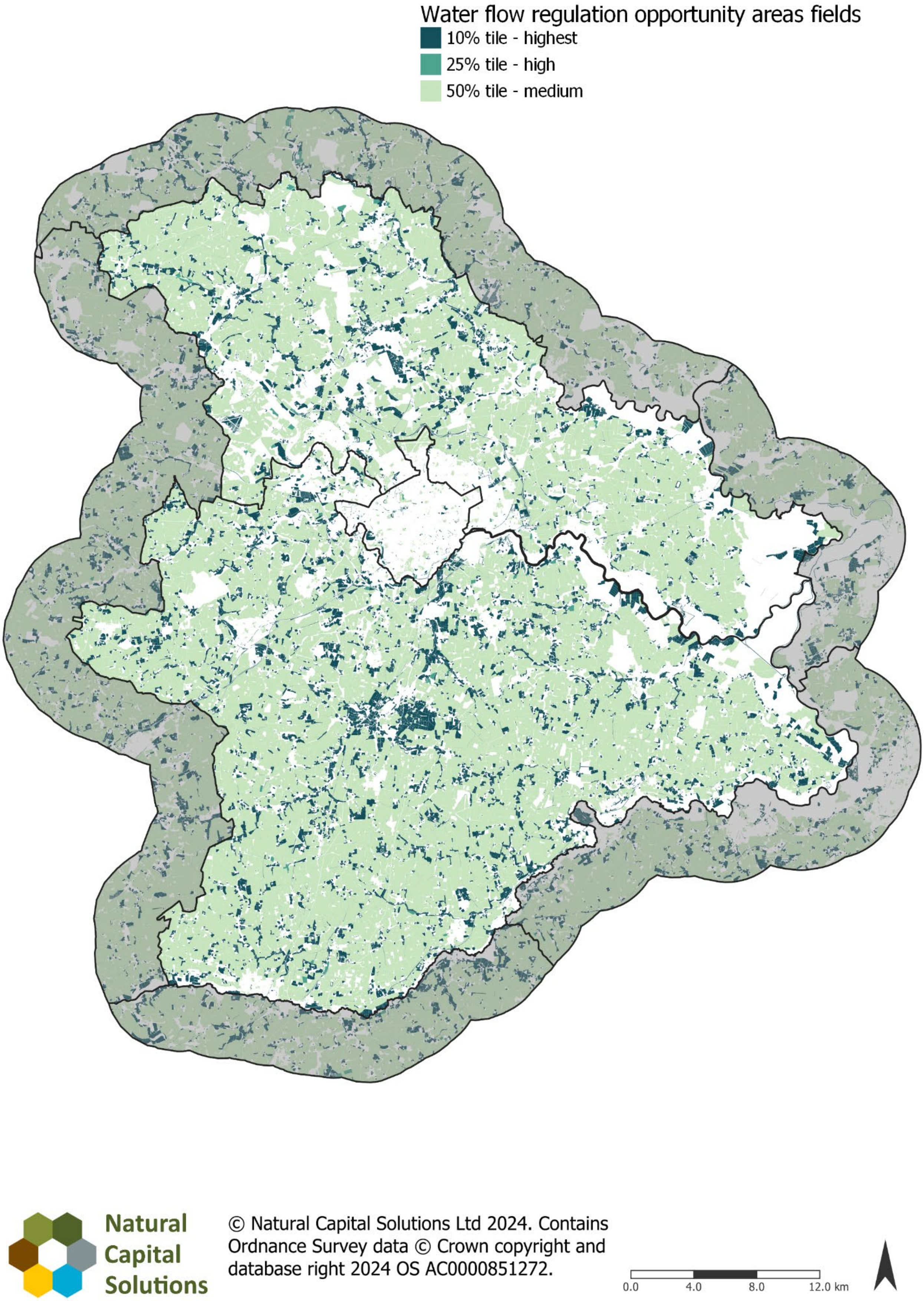


Figure 29. Risk of flooding from multiple sources as identified in the RoFMS across the strategy area. Scale of 1- 4, with 1 having >3.3% chance of flooding, 2 between 3.3%-1%, 3 between 1%-0.1% and 4 has <0.1% chance of flooding in any year.

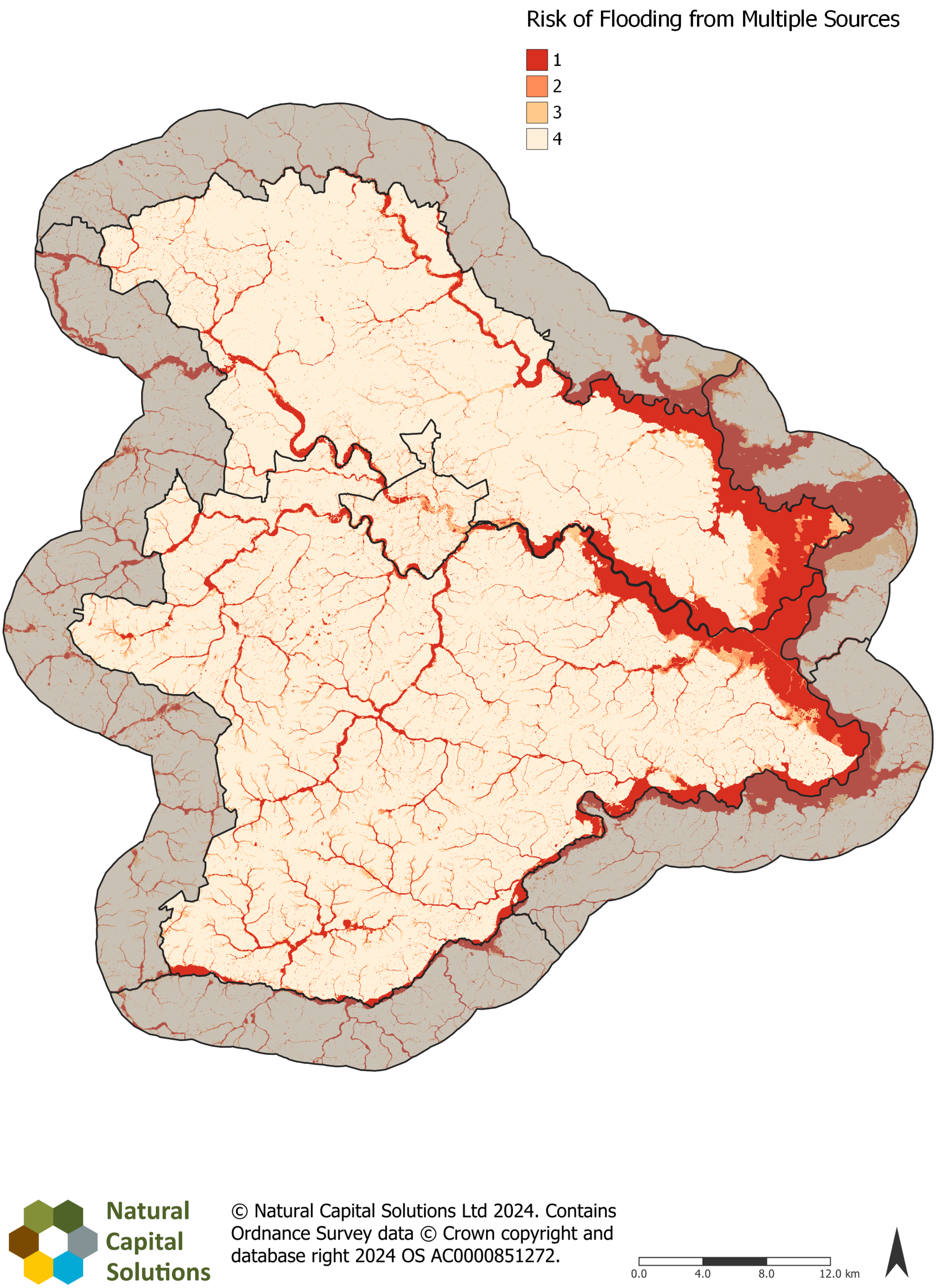
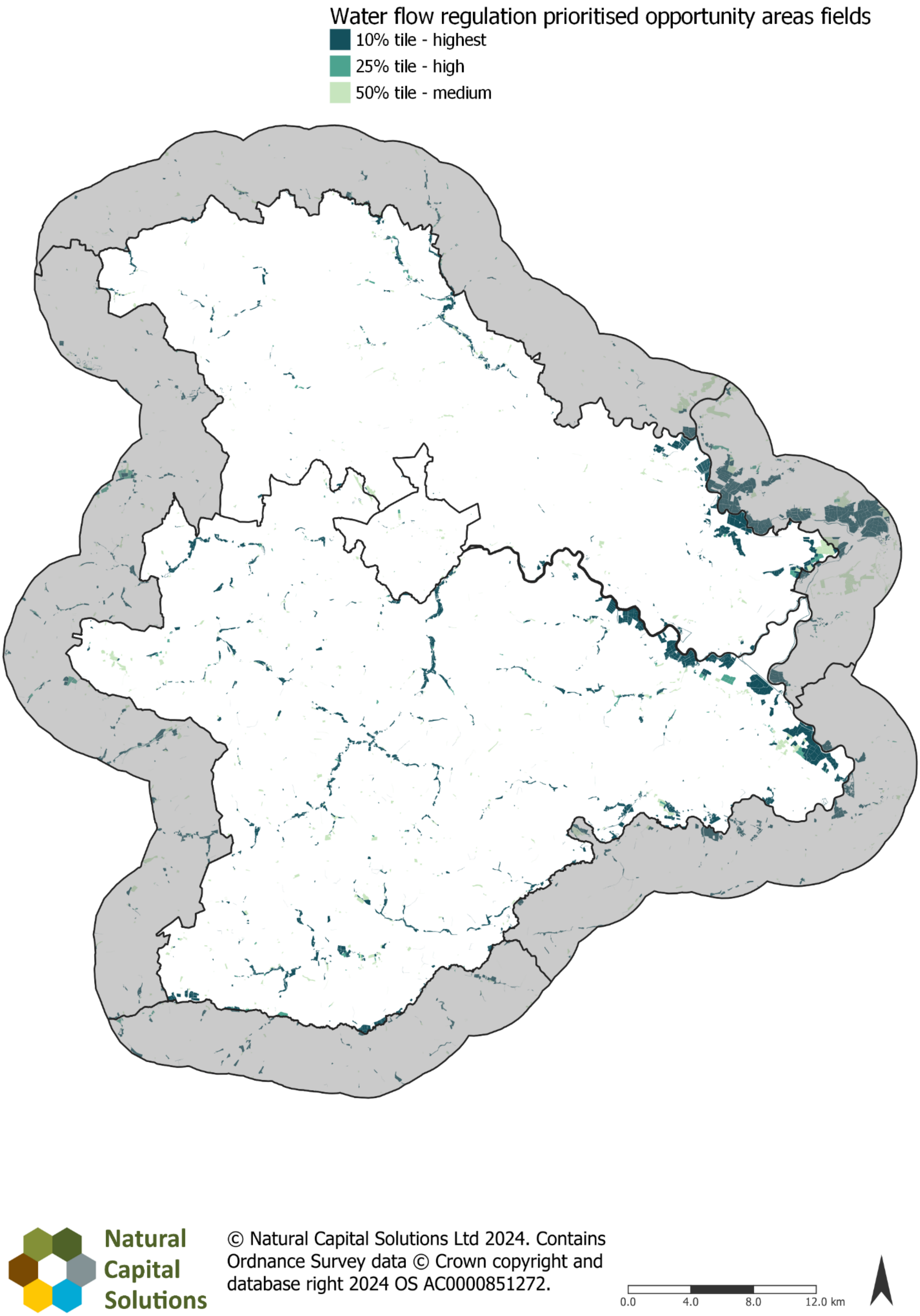


Figure 30. Opportunities for creating habitat that will slow the flow of water across the strategy area.



4. Multifunctional Green Infrastructure opportunity modelling & mapping

The habitat opportunity mapping for biodiversity in **Section 2**, and ecosystem services in **Section 3** has identified opportunities for creating new habitat to increase connectivity for biodiversity across broadleaved woodland, semi-natural grassland, heathland, wet grassland and fen habitats, and also identified where it can be created to increase water quality, slow the flow of water, increase the take up of air pollutants, noise and reduce temperatures. Here, these opportunities are brought together in one combined opportunities map (**Section 4.1**). The second step (**Section 4.2**) is to use this combined opportunities map and layer it with the Active Places priority areas for accessible greenspace provision and for increasing urban greening. This creates a multifunctional GI opportunity map highlighting areas with potential for providing multiple benefits to meet the needs of people and nature in the Greater Norwich Area.

4.1 Combined opportunities

4.1.1 Methods

In addition to mapping the individual opportunities presented above, it is also possible to examine multiple opportunities, which are areas where new habitat can be created that provides opportunities to enhance biodiversity and 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. Here, if an ecosystem service opportunity falls within the top 10% (highest) opportunities it is given a score of 3, an opportunity in the 10-25% (high) range is given a score of 2, and an opportunity in the 25-50% (medium) range is given a score of 1. Biodiversity opportunities can score between 1 and 3, with the highest priority score taking precedence where there is more than one opportunity in the same location.

All 5 ecosystem services are considered, along with each biodiversity opportunity in turn, so the maximum score that can be achieved is 18. The GIS layers produced in this opportunity mapping project can be presented in a number of different ways, for example, combined opportunities can be presented for each set of broad habitat opportunities for biodiversity. However, here the focus is on presenting all opportunities altogether in two slightly different maps, as the focus is delivering multifunctional Green Infrastructure. The first is constrained to only show multiple opportunities that will also deliver for biodiversity (**Figure 31**). This map is useful if the primary aim of habitat creation is nature recovery. The second map shows all possible opportunities, some that will also deliver for biodiversity and others that will deliver just ecosystem services (**Figure 32**). This is useful if the primary aim of habitat creation is delivering GI for ecosystem service benefits, as it also presents opportunities that will deliver benefits along, and not just where benefits are delivered alongside habitat connectivity for biodiversity. This is particularly useful in urban areas where semi-natural habitats are fragmented but it is important to incorporate GI for the delivery of air pollution, heat island effect and noise reduction where the demand is highest.

4.1.2 Results

In the constrained model, the areas with the highest scoring opportunities occur within Norwich urban area, and this is because there are opportunities to create new habitat that will deliver biodiversity benefits as well as multiple additional benefits (e.g. woodland for delivering air purification, climate and noise regulation) in relation to high demand in the city. The highest score achieved by an opportunity is 16, with some of these opportunity areas covering the Bellacre and Woodland Allotments on the banks of the River Wensum, and the Firside Junior School grounds. Creating new habitat in these areas would increase both ecosystem service provision and habitat connectivity and biodiversity, according to this assessment. The opportunities for improving both ecosystem services and biodiversity is less relevant in rural areas where there are lots of lower scores (blue colours, **Figure 31**).

The unconstrained map shows more opportunities overall, as this map highlights areas that would increase any ecosystem services provision, without the constraint of whether these areas would also benefit habitat connectivity and biodiversity (see **Figure 32**). The areas with the highest scores are also in urban areas because demand for ecosystem services increases in these areas. The areas with the greatest opportunities in this map are in Norwich urban area and Diss and Harleston.

These maps have also been reproduced to present the top 20% of opportunities (see Annex 1, **Figures 35-38**).

Figure 31. All opportunities for creating habitat that will deliver ecosystem services at the same time as connecting up existing habitat networks to enhance biodiversity.

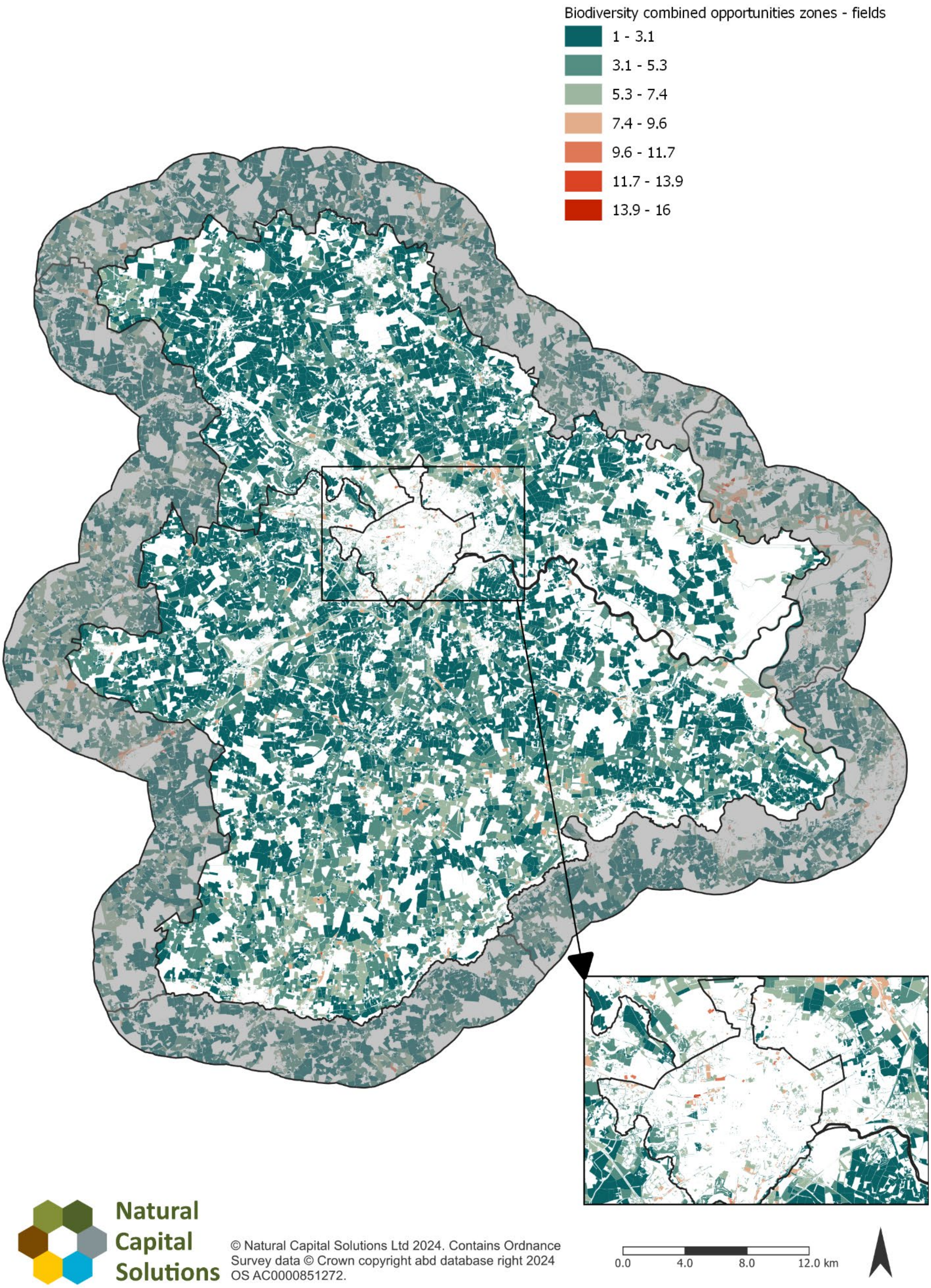
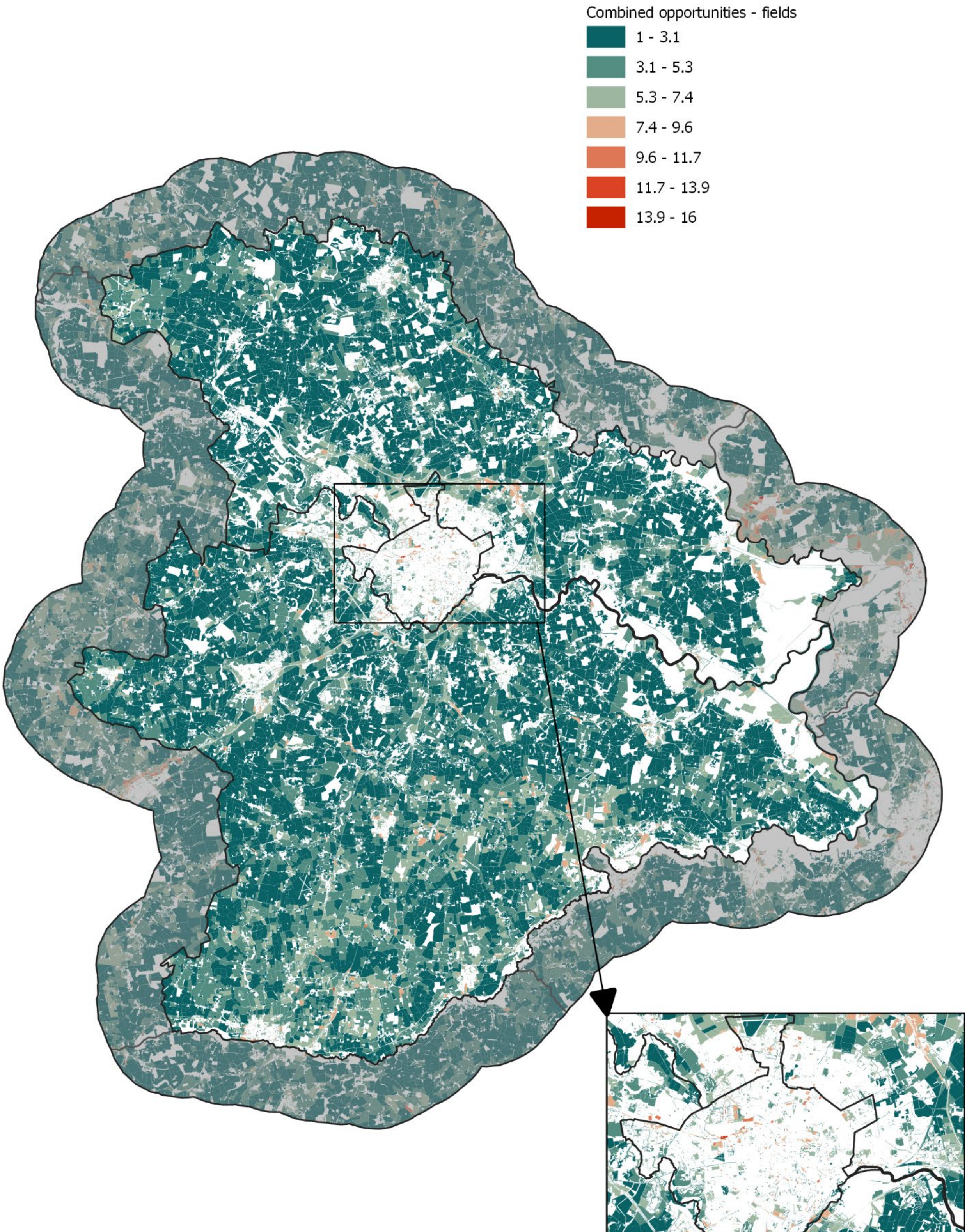


Figure 32. All opportunities for creating habitat that will connect up existing habitat networks to enhance biodiversity and deliver ecosystem services individually and at the same time.



Natural Capital Solutions

4.2 Combining with Active and Natural Places maps

4.2.1 Methods

To develop the constrained (**Figure 33**) and unconstrained (**Figure 34**) combined opportunity maps that included the Active and Natural places map, the combined opportunities maps (**Figures 31** **and 32**) were used as basemaps, and the Active and Natural Places map layers were added. Our models show all opportunities for enhancing biodiversity as well as increasing the delivery of ecosystem services, including accessible nature provision.

The following map layers were taken from the Greater Norwich Green Infrastructure Strategy Evidence and Opportunities Report (2024)[13], specifically Figure 52 of that report:

- The District Standard for Greenspace Provision, which stipulates providing at least 3 hectares of publicly accessible greenspace per 1,000 residents and no net loss, with all major residential developments included.
- The 'Close to Home' Greenspace Provision, which stipulates access to greenspace (of various sizes and conditions) within a 15 minute walk zone of people's homes.
- The Areas to Increase Urban Greening layer, which was adapted from Natural England's Urban Greening Factor tool[14]. This tool assigns scores from 0-1 for different surface types. Permeable surfaces and vegetation have the highest scores, with fully impermeable surfaces given a score of 0 (for further information on the methodology used to develop this layer, please see Section 3.4.5 Urban Greening Factor in the NCC 2024 Evidence and Opportunities report).

4.2.2 Results

This model adds three layers to the combined opportunities map (**Figure 31**), showing the priority areas for Greenspace Provision for two distinct standards, the District (pink) and 'Close to Home' (purple) standards, as well as a layer for areas to increase urban greening (yellow, see **Figure 33**). This map can be used to determine areas which would benefit biodiversity, ecosystem service provision and accessible nature demands. Special attention should be given to areas which have multiple benefits, for example, in the Norwich urban area, there are areas which would increase urban greening, 'Close to Home' greenspace provision, biodiversity and ecosystem service provision (areas with yellow, purple and green / blue layers, **Figure 33**). There are quite a few light purple areas, these are areas which meet both the 'Close to Home' and district greenspace provisioning standards. Areas with the highest opportunities for meeting multiple needs are found within the Norwich urban area, and in towns across the strategy area. The majority of the strategy area does not provide opportunity for delivering multiple benefits, as it is predominantly rural, with few people who would benefit from enhanced greenspaces. The urban greening layers take into account garden areas, whereas the greenspace provisioning standards do not, so these maps will need to be ground-truthed as some areas highlighted in these layers may not be ideal for new habitat creation.

The unconstrained map (**Figure 34**) is the same as **Figure 33** but the basemap is the combined opportunities

[13] Voisey, D., Williams, E. and Laing, K. 2024. Greater Norwich Green Infrastructure Strategy: Evidence and Opportunities Report. Norfolk County Council.

[14] Neal, P. 2023. Urban Greening Factor for England – Summary Report. NERR131. Natural England.

map that was unconstrained by biodiversity opportunities. Without constraining for areas that benefit both biodiversity and ecosystem services, this model, like **Figure 32**, has more opportunities overall, and shows areas which would benefit greenspace provisioning, urban greening and ecosystem service provisioning. This model can be used to determine areas that would deliver multiple opportunities for these provisions, if increasing biodiversity and habitat connectivity is less of a priority.

These maps have also reproduced to present the top 20% of opportunities only (see Annex 1, **Figures 37 and 38).**

Figure 33. All opportunities for creating habitat to improve greenspace provision, urban greening and ecosystem services across the strategy area, only where it will connect up existing habitat networks to enhance biodiversity (white background constitutes habitats where there are no opportunities).

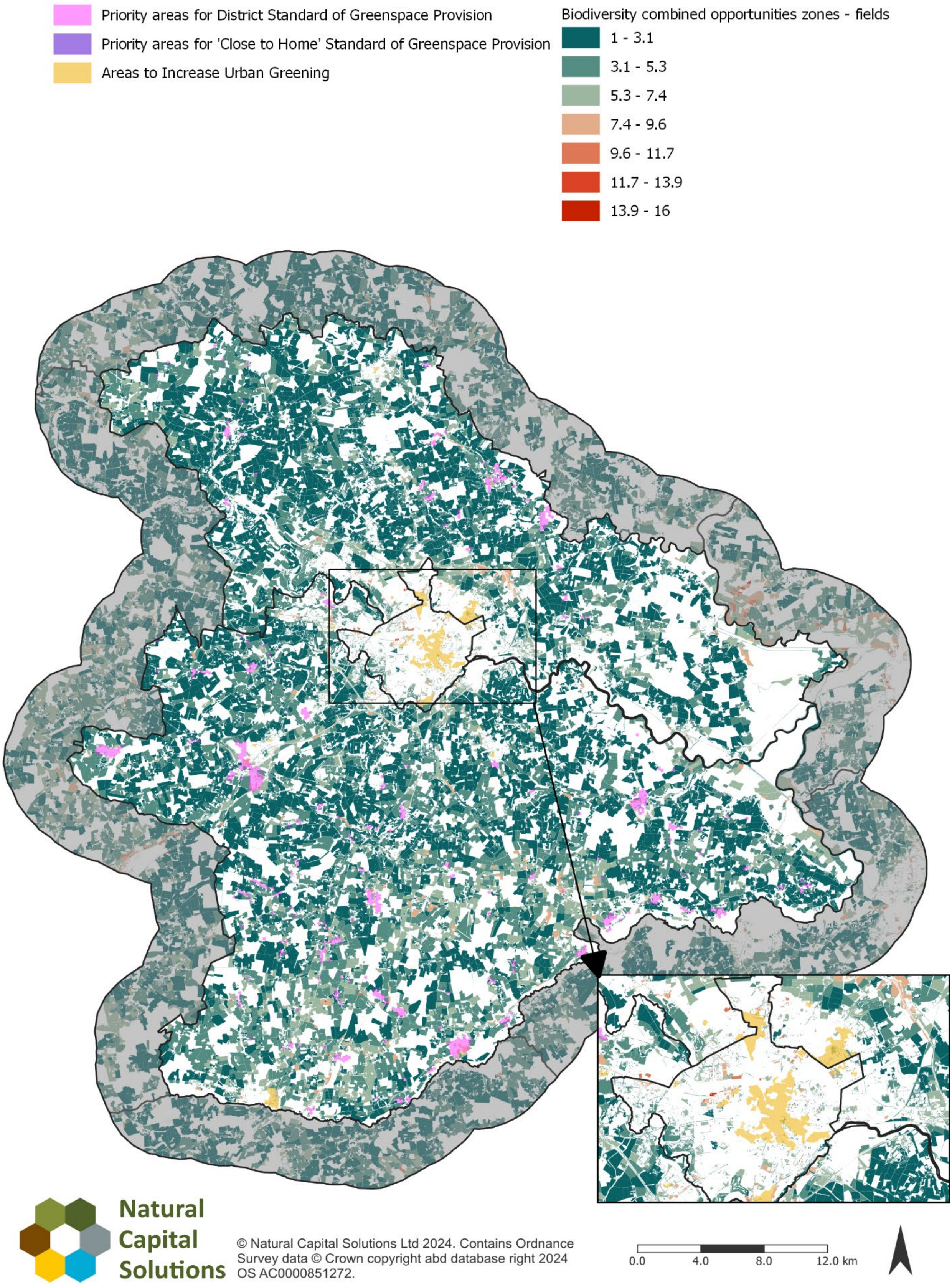
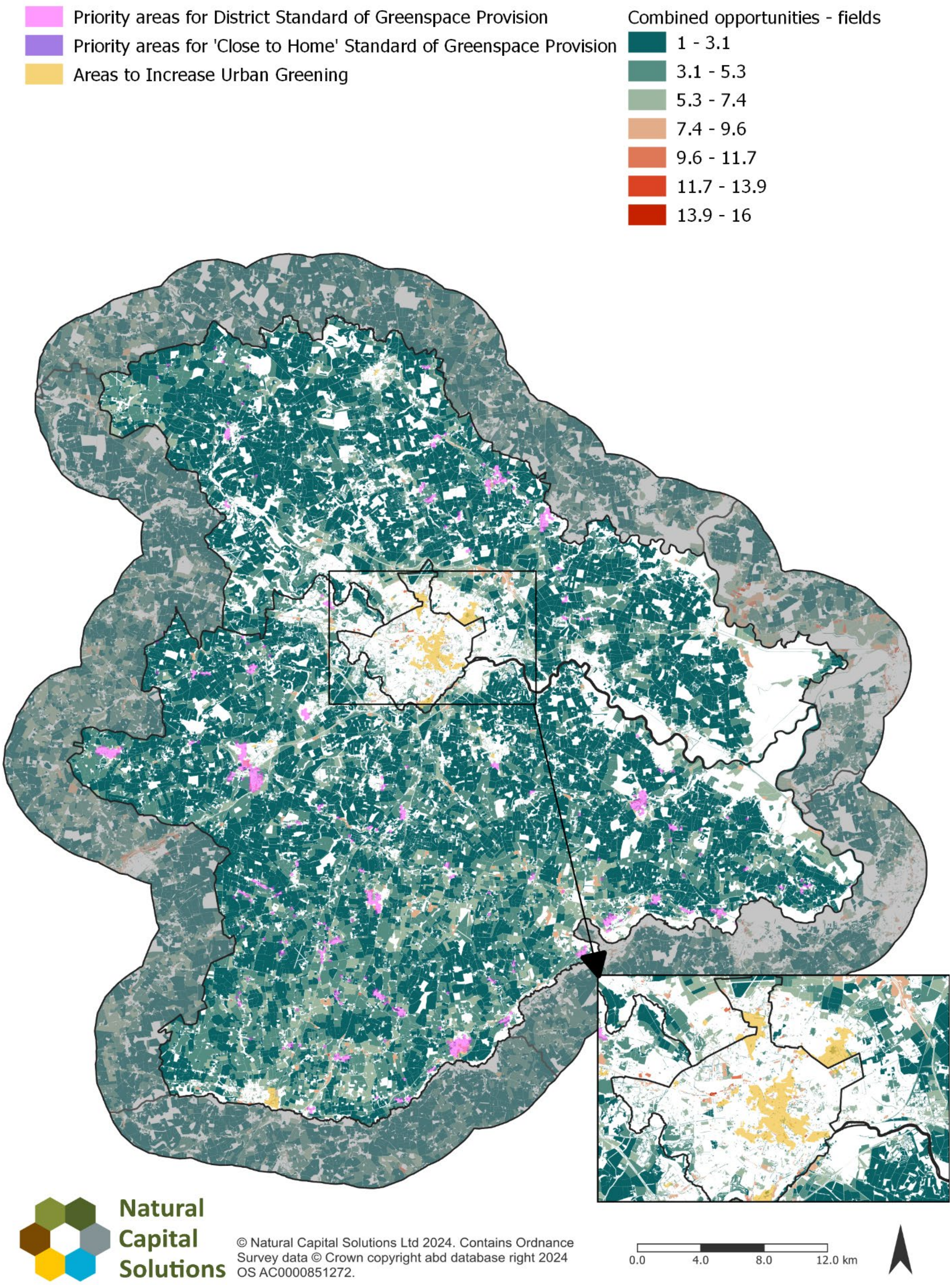


Figure 34. All opportunities for creating habitat to improve greenspace provisioning, urban greening, for connecting up existing habitat networks to enhance biodiversity and deliver ecosystem services individually and at the same time across the strategy area (white background constitutes habitats where there are no opportunities).



5. Conclusions and recommendations

5.1 Conclusions

The Greater Norwich Area is dominated by arable land (56.3%), with large areas of grassland (20%) and woodland (9.1%). Across the area, there are small fragments of semi-natural habitats, many of which are important for biodiversity, including marshy grasslands, fen and heathland habitats. There are also conservation areas of national and local significance within the Strategy Area, including Sites of Special Scientific Interest (SSSI) and Local Nature Reserves.

The habitat opportunity mapping revealed that there are many opportunities for creating woodland, grassland and heath spread right across the strategy area. The habitat opportunity maps highlight areas of high priority, and there are a number of high priority woodland opportunities which would connect and buffer ancient woodlands and SSSI's. Most of the grassland opportunities have low priority, although there are some areas where grassland can buffer and connect SSSI's. The opportunities for grassland creation occur across the strategy area because of the widespread and fragmented nature of the current grassland habitat. Most heathland creation opportunities are low priority, with the largest high priority areas in the north of the strategy area. There are not as many opportunities for enhancing fen and wet grassland, as they need to be concentrated around the rivers and floodplain areas, although significant opportunity areas (especially for wet grassland) were still identified. These habitats are particularly good for biodiversity, and there are large high priority areas for both habitats.

In this report, several ecosystem service capacities and their demands were examined for air purification, noise regulation and local climate regulation. Carbon sequestration and storage capacity and water flow and quality regulation capacity was also analysed. These maps were used to create ecosystem service opportunity maps, accounting for certain pressures and risks associated with each ecosystem service. The air purification, noise and local climate regulation maps all displayed highest priority areas in densely urbanised areas (e.g. Norwich), as these areas have increased demand for these services. The water quality opportunity map, on the other hand, had the highest priority opportunities in areas dominated by arable habitat, as arable land has high soil erosion rates.

The carbon sequestration and storage capacity maps displayed the capacity for these services across the strategy area. The carbon sequestration analysis revealed that the strategy area currently emits approximately 93,600 tonnes of CO_2 equivalent per year. Air pollution was analysed further across the strategy area by creating emission maps for ammonia, carbon dioxide, methane and nitrogen oxides, based on data from the National Atmospheric Emissions Inventory. The ammonia map showed that the highest concentrations of ammonia were localised around livestock farms (poultry) and a sugar beet factory. The area around the sugar beet factory also had high concentrations of carbon dioxide and nitrogen oxides. The carbon dioxide and nitrogen oxides concentrations were both concentrated around urban areas and major roadways, with high concentrations above a car manufacturing plant and chemical factories. Methane emissions were concentrated primarily around sewage treatment plants and livestock farms (cows and pigs). Planting woodland around livestock farms and major roads is recommended, which would take up pollutants and provide ecosystem services, such as noise, air quality and local climate regulation.

If all of the woodland habitat opportunities identified here are taken up, there is the potential for current emissions to reduce and to increase sequestration by 536,000 tonnes CO_2e per year. However, this would require about a third of the whole area to be converted to woodland. A more realistic target may be to aim for net zero, where sequestration from woodland balances emissions from farmland. This can be achieved by creating approximately 10,000 ha of woodland across the study area.

The water flow regulation opportunity maps prioritise areas which would be most effective at “slowing the flow” of water runoff and providing natural flood risk mitigation. The unconstrained map shows opportunities for water flow regulation, based on habitat type and slope. The constrained model is constrained by the Environment Agency’s Risk of Flooding from Multiple Sources (RoFMS) data, and displays the areas of highest priority for slowing the flow constrained by risk, habitat and slope pressures. These prioritised areas are concentrated around rivers and floodplain areas, especially those near urban areas, with large high priority areas along the Rivers Yare and Bure.

The combined opportunity maps combined ecosystem service provision opportunities across the strategy area, and in the constrained map, the results were constrained by whether these areas would also improve biodiversity. For both the constrained and unconstrained maps, the highest priority opportunities were within urban areas, especially Norwich, as these areas have greater ecosystem service demand. The unconstrained map had more opportunities overall because in some areas, habitat creation would deliver ecosystem service benefits but would not connect or buffer habitats (and increase biodiversity).

In the final step, layers were added from the Active and Natural Places map to the combined opportunities map to create a Green Infrastructure (GI) opportunities map for meeting the needs of people and nature in the strategy area. Again, the areas that had the greatest overlap between green infrastructure provisioning, ecosystem service, and biodiversity provision were in the Norwich urban area. This model highlights areas that could provide multiple benefits, and simultaneously meet GI standards. These maps highlight the best locations to provide multi-functional greenspace, subject to ground-truthing.

5.2 Recommendations

The models in this report have identified several areas where new habitats can be created to increase biodiversity. However, before these opportunities can be taken forward, further prioritisation with local stakeholders to determine the most practical opportunities, which can also complement other initiatives and strategies in the area is necessary.

The report is intended to provide a decision-making tool to inform strategic GI planning/strategy development work. It can also be used to inform site-scale GI delivery work, subject to ground truthing. The habitat basemap is based on existing data and it 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 consider 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.

Additionally, there will be overlap in opportunities identified between the broad habitats (grassland, woodland, heathland, wet grassland and fen) and careful consideration should be given to determine the best habitat to take forward in different locations.

Special attention should be given to biodiversity opportunity areas which overlap with water flow regulation opportunity areas (especially the highest priority areas in the constrained map, see **Figure 30**). Creating habitat in these areas will deliver benefits for biodiversity and act as natural flood mitigation measures. Those invested in this project need to take time to review all of the GIS layers that make up the combined map, and determine the areas which are practical and deliver the most benefits. Local site based factors and land ownership will also need to be taken into account.

This report has shown that there are extensive areas where carbon can be sequestered through woodland planting. About 10,000 ha of new woodland would need to be created, in order to move from net emissions to net zero for carbon from land based activities. A far larger area of opportunities has been identified, indicating that there is plenty of land available to achieve this target. The creation of woodland in these areas would also deliver other ecosystem services as well, including air quality, local climate and noise regulation. Again, the opportunity maps, and especially the combined opportunity maps and the woodland creation map (**Figure 27**) should be carefully reviewed and ground-truthed in order to determine the areas that would deliver the most benefits for people and nature.

As well as providing evidence for informing the Greater Norwich Area GI Strategy, the opportunity maps can be used to inform the emerging Norfolk Local Nature Recovery Strategy work. The habitat network/biodiversity and ecosystem services modelling and mapping approaches are intended to be applicable for rolling out across the rest of the County.

Annex 1. Combined opportunities maps with priority areas of varying degrees

Figure 35. Top 20% of opportunities for creating habitat that will deliver ecosystem services at the same time as connecting up existing habitat networks to enhance biodiversity.

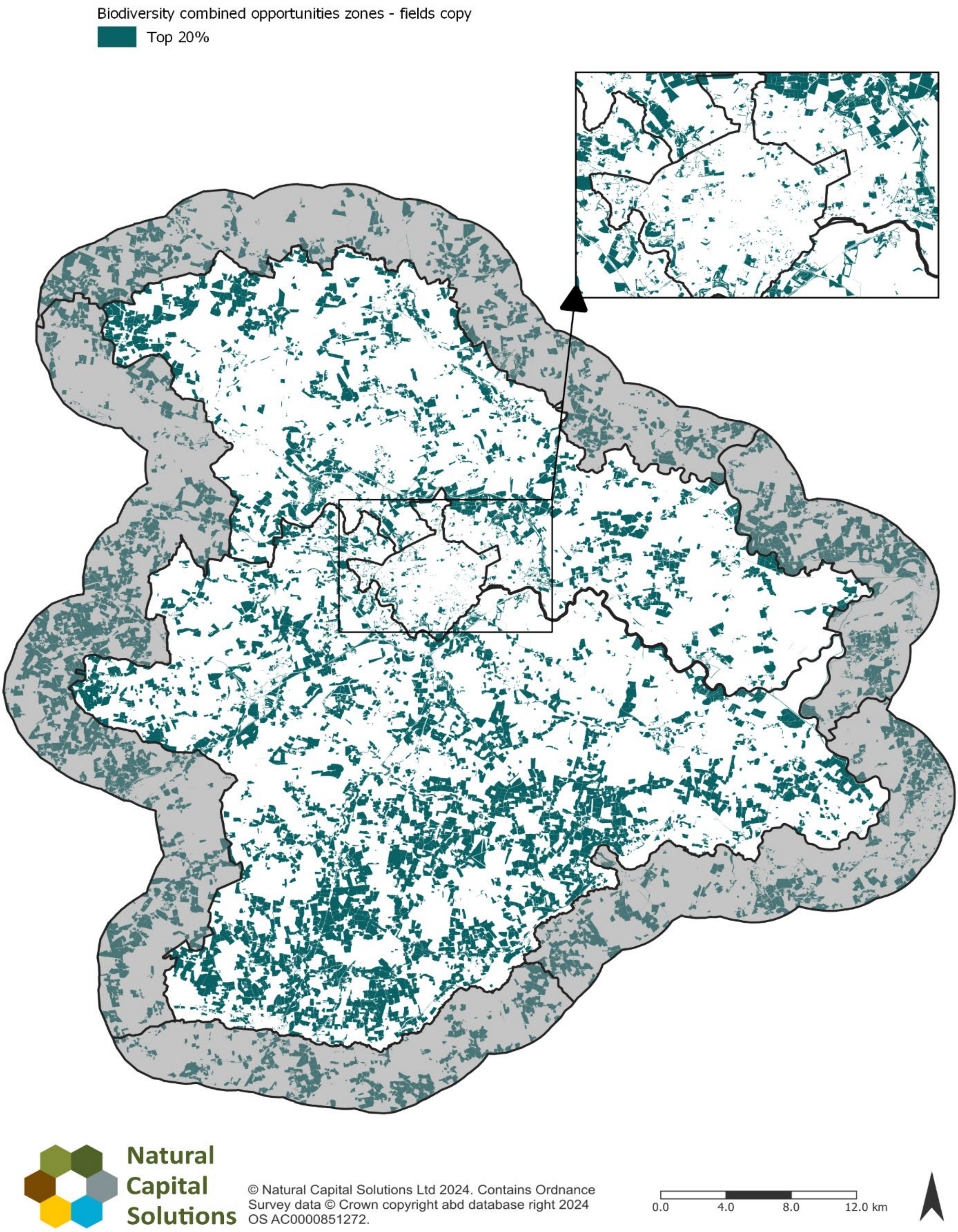


Figure 36. Top 20% of opportunities for creating habitat that will connect up existing habitat networks to enhance biodiversity and deliver ecosystem services individually and at the same time.

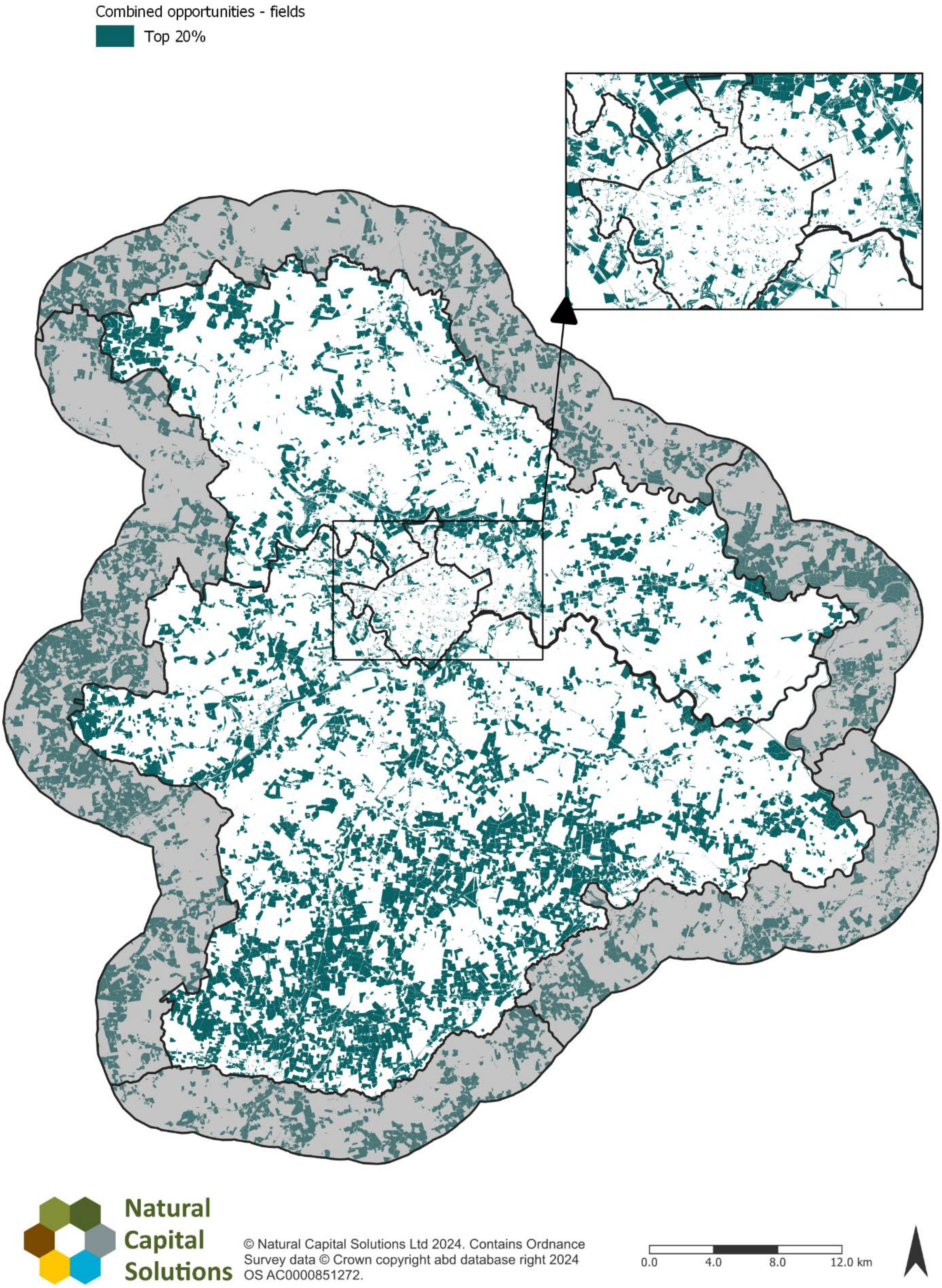


Figure 37. Top 20% of opportunities for creating habitat to improve greenspace provision, urban greening and ecosystem services across the strategy area, only where it will connect up existing habitat networks to enhance biodiversity (white background constitutes habitats where there are no opportunities).

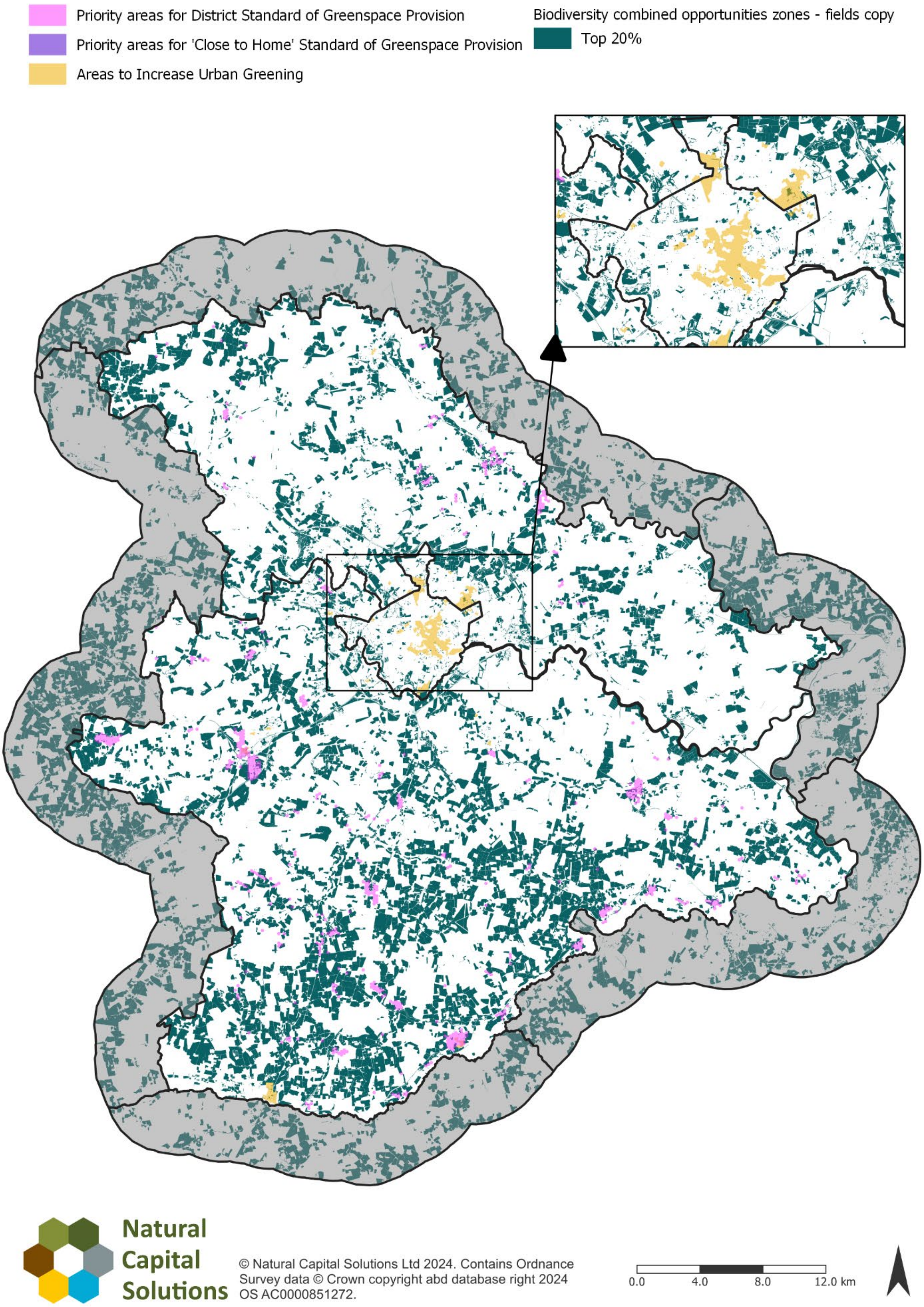
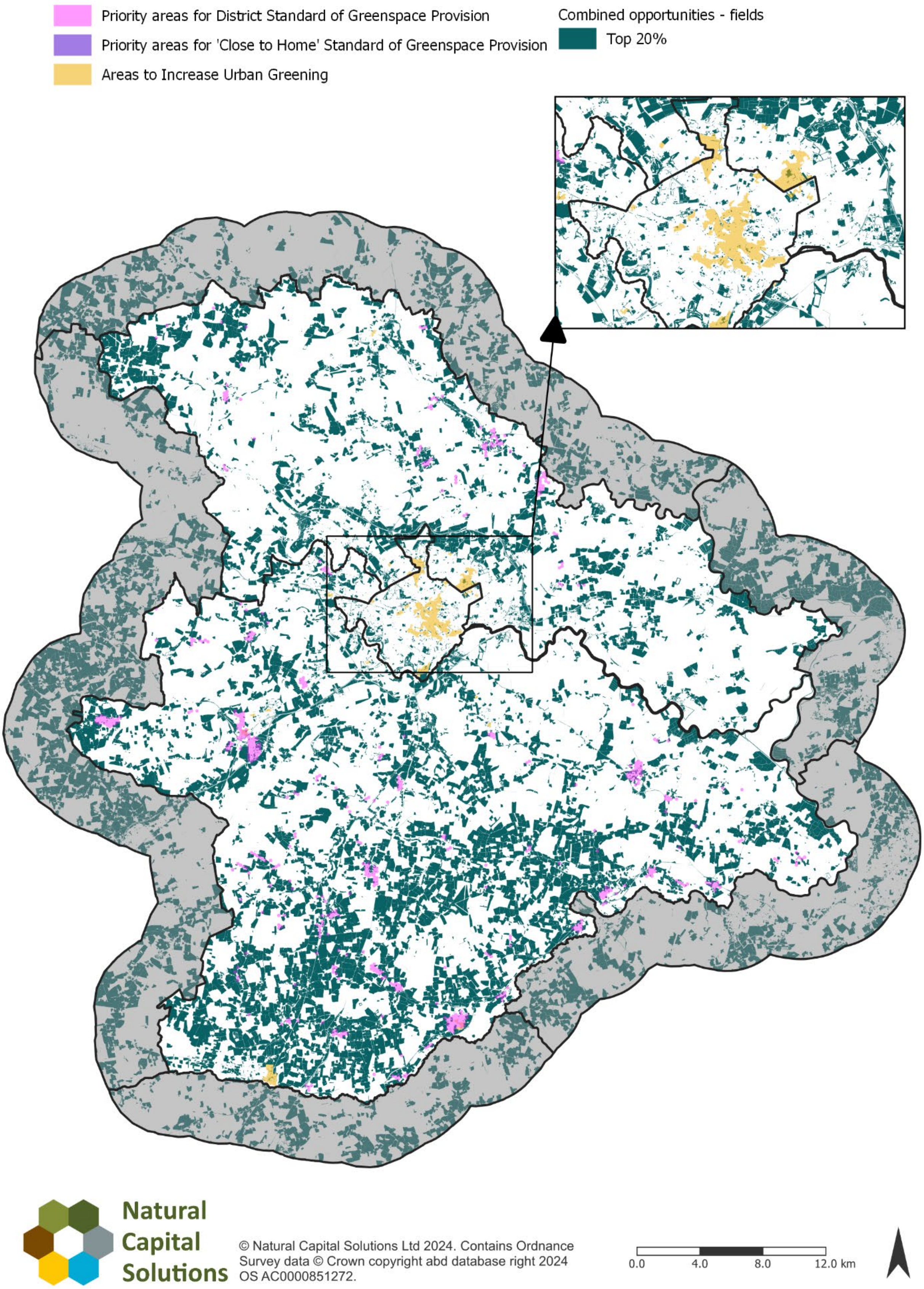


Figure 38. Top 20% of opportunities for creating habitat to improve greenspace provisioning, urban greening, for connecting up existing habitat networks to enhance biodiversity and deliver ecosystem services individually and at the same time across the strategy area (white background constitutes habitats where there are no opportunities).



Appendices

A1. Greater Norwich GI Strategy: Natural Places Evidence & Opportunities Supplementary Analysis – Brief

Background

This brief has been developed in liaison with the NCC Natural Norfolk Team, UEA and CBA. The approach is intended to be applicable for rolling out across the rest of the County as part of the Norfolk Local Nature Recovery Strategy work.

A review of the Greater Norwich GI Strategy was completed by Prof. Andrew Lovett at UEA. The review identified key areas that need further work, specifically in relation to evidence and opportunities for Natural Places:

1. Habitat network opportunity modelling
2. Ecosystem services opportunity modelling

The UEA review also recommended a synthesis of the Natural Places and Active Places opportunities analysis to highlight areas of greatest GI multifunctionality.

Below outlines the approach that will be used to address these gaps.

Methods

Habitat network opportunity modelling

Habitat opportunity mapping (HOM), a GIS based approach, that can be used to identify opportunities for habitat creation that will improve the existing network of habitats (and the designated areas within that network) in the region. As part of this analysis, areas of habitat that can be restored to expand and link up the existing habitat network can also be identified.

HOM identifies possible locations where new habitat can be created, that will be able to deliver particular benefits, whilst taking certain constraints into account (e.g. historic sites, infrastructure, overhead lines and cables, protected areas). HOM to enhance biodiversity uses ecological networks to identify potential areas for new habitats, using the least cost, focal species approach developed by Catchpole (2006)[15] and Watts et al. (2010)[16].

The first step is assessing landscape permeability (similar to the approach already used in the Greater Norwich GI strategy evidence and opportunities report). The second is to use the permeability map along with information on average dispersal distances, to map which habitat patches are ecologically connected and which are ecologically isolated from each other (please refer to Annex 1 at the end of this document for more details on the species and dispersal distances used).

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

[16] 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.

In the third step constraints are identified and removed from the habitat connectivity map, and the final step uses this to identify buffer (immediately adjacent to existing habitat patches and fall within the previously identified ecological network) and stepping stone opportunities (fall outside of the ecological network but are immediately adjacent to it). 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 site. Opportunities to enhance biodiversity for broad habitat groups including woodland, grassland, wetland, mire and heath will be mapped across the strategy area.

The opportunities for creating new habitat to enhance biodiversity can be prioritised into three groups: (1 – high priority) opportunities to buffer and connect up areas of habitat with national designations (e.g. SSSI) and ancient woodland, (2 – medium priority) opportunities to buffer and connect up areas of habitat of local importance (e.g. local nature reserves and wildlife sites), and (3- low priority) all other opportunities. The mapping will, therefore, highlight areas where creating new habitat can enhance the resilience of protected areas, as well as other opportunities.

Ecosystem services opportunity modelling

Using a similar approach to HOM for biodiversity, it would be beneficial to map opportunities for creating new habitat to increase the provision of ecosystem service benefits. This uses maps of ecosystem services provision and demand to guide where habitat creation would deliver the highest levels of benefits.

The following ecosystem service benefits can be mapped (please note additional ecosystem services were included to carbon sequestration and flood alleviation as they are likely to be useful for strategy development and can be included in the original budget for this work):

1. Opportunities to increase carbon sequestration (woodland and mire opportunities from (i) above).
2. Opportunities to reduce surface runoff and reduce soil erosion and improve water quality.
3. Opportunities to ameliorate air pollution, the urban heat island effect and noise pollution.

For all of the above, constraints are mapped as in (i) above, and these areas are removed from the final maps, to leave opportunity areas that are not subject to these constraints. The ecosystem service opportunities can be prioritised into the top 10, 25 and 50% for creating new habitat to increase the benefits.

Further analysis: Carbon emissions and sequestration

Whist the habitat opportunity mapping will identify opportunities for increasing carbon sequestration (key habitats being woodland and mire habitats), it will be possible to estimate and map the carbon that is being sequestered or emitted by the existing habitats (and their agricultural management) in the study area (using a range of emission/sequestration factors in the scientific and grey literature and using the Woodland Carbon Code methodology). Greenhouse gas emissions no2 for the Greater Norwich region not associated with the land (e.g. transport) can be gathered from Government statistics, but are not possible to map in a meaningful way.

Although the emissions data from Defra and the National Atmospheric Emissions Inventory are provided in a form that can be transferred to GIS, it has been set up to map across Local Authorities at the national scale. The data on emissions levels across sectors and years are supplied for one location only within each Local Authority. It is possible then to extract the total emission values for the Norfolk and Norwich area and compare these to the sequestration ability of the land covers in the project study area. However, emissions for the Greater Norwich area would be a more appropriate comparator, and it would be necessary to rely on the client to supply us with these. The potential future carbon sequestration can be estimated should the opportunities for creating new habitats be taken up (or indeed other investment priorities identified as part of the strategy).

Further analysis: Flood risk mitigation

The habitat opportunity mapping identifies opportunities for creating habitats that will slow the flow of water, thereby reducing flood risk. In addition, the high and medium flood risk areas will be mapped using Environment Agency data (the Risk of Flooding from Multiple Sources) and overlay the opportunities for slowing the flow of water to see where key opportunities are located where they are needed the most.

Combining the Natural Places and Active Places opportunities analysis to highlight areas of greatest GI multifunctionality

The outputs will be a map of prioritised opportunities for creating new habitat to enhance biodiversity across Greater Norwich. The output will cover prioritised opportunities for creating new habitat to enhance carbon sequestration, flood alleviation (also prioritised by high and medium flood risk) and a range of other ecosystem service benefits. The following synthesis maps will be created from these outputs and by integrating with the existing Active Places and Natural Places maps that have been created as part of the GI strategy process to date.

The biodiversity and ecosystem service opportunities will first be integrated to create a map of combined opportunities across the Greater Norwich area (maps will be prioritised by the number of benefits being provided). This map will show locations where habitat can be created to deliver the greatest multifunctional benefits, across biodiversity, carbon sequestration, flood alleviation, increased water quality, reduction of urban temperatures, reduction of noise and air purification.

The prioritised biodiversity opportunities layer will be integrated with the opportunity areas identified as part of the Active Places analyses: priority areas for greenspace provision and for increasing urban greening, as well as with the Natural Places layers: accessible greenspace of principal importance for biodiversity and areas of principal importance for biodiversity. This will create a GI opportunities map for meeting the needs of people and nature.

Dr Alison Holt Director
Natural Capital Solutions Ltd 18th April 2023

Annex 2. Species and dispersal distances used in HOM

A question was raised in the meeting with the NCC Natural Norfolk Team and UEA about whether the dispersal distances of locally relevant species would be used in the habitat opportunity mapping in consultation with the wider project team. Below is a more detailed explanation of which species were included, and the dispersal distances used in this approach, that are believed to be appropriate for use in the Greater Norwich context, and indeed in the context of the Norfolk LNRS.

In the habitat opportunity mapping process, a landscape permeability map, along with information on average dispersal distances, is used to map which habitat patches are ecologically connected and which are ecologically isolated from each other. The species dispersal distances originally obtained from the JNCC were used, which had performed a review of the scientific literature to ascertain the dispersal distances of a range of species for each of the broad habitat types mapped. The species considered across the habitats are small mammals, smaller birds, butterflies, and plants. Watts et al. (2010) outlines the dispersal distances for the 15 species used as the generic focal species for the broadleaved woodland habitat.

The average dispersal distances used in this approach across the generic focal species for each habitat is shown in the **Table 5** below:

Table 5: Dispersal distance in optimal habitat

Habitat	Dispersal distance (km)
Wet grassland & wetlands	2.0 km
Semi-natural grassland	2.0 km
Heathland	1.2 km
Broadleaved and mixed woodland	3.0 km
Mire	1 km

The dispersal distances used in this approach are all based on English species across the taxa outlined above. The approach has not been devised to be used on the exact species in the location on which it is being used, because information from the scientific literature on dispersal distances for a broad range of species is patchy and is a time intensive process to gather. Rather the point is that it takes a range of species that may be impacted to a high and moderate degree by a fragmented habitat, those that are rare through to those that are more common, and takes an average dispersal distance into account for the network mapping. It has deliberately been devised as a generic approach.

A2. Mapping ecosystem services (physical flows)

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 a year as the sequestered carbon is immediately released. However, there are emissions associated with the management of the agricultural land (e.g. machinery use and fertiliser application) that are included here. Sequestration rates also depend on the soil type on which the habitat lies. Many habitats on peat soils emit greenhouse gases. There is very little consistent information about sequestration across all habitats (apart from woodlands on mineral soils), but the evidence available shows that sequestration rates can be relatively low.

How is it measured?

This model estimates the amount of carbon sequestered by each habitat type. It applies average values (tCO_2e/ha/year) for each habitat type taken from Natural England (2019)[16] and the RSPB's Accounting for Nature report[17]. It is calculated for every 5m by 5m cell across the study area and takes soil type into account, although note that it does not take into account the age structure of the trees. Unlike most of the other services which are on a 0-100 scale, amounts are in tonnes CO_2e/ha/yr.

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 are seen as increasingly important as the UK moves 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 significant changes in carbon storage, as can the restoration of degraded habitats. Note that carbon storage measures the stock of carbon in the natural environment, whereas carbon sequestration (see above) measures its annual flow.

How is it measured?

This model estimates the amount of carbon stored in each habitat type. It applies average values (tC/ha) for each habitat type taken from Natural England (2019)[18]. A multiplier[19] is then applied to habitat carbon storage values depending on which soil type the habitat occurs on. 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 every 5m by 5m cell across the study area. Scores are measured in tonnes of carbon per ha.

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

[16] Sunderland T, Waters RD, Marsh DVK, Hudson C, Lusardi J. (2019) Accounting for National Nature Reserves: A natural capital account of the National Nature Reserves managed by Natural England. Natural England Research Report, Number 078.

[17] The RSPB. (2017) Accounting for Nature: A Natural Capital Account of the RSPB's area in England. Annex 7.

[18] Sunderland T, Waters RD, Marsh DVK, Hudson C, Lusardi J. (2019) Accounting for National Nature Reserves: A natural capital account of the National Nature Reserves managed by Natural England. Natural England Research Report, No. 078.

[19] Lagas and Sweep (2020) Ecosystem service – carbon storage and sequestration.

Air purification capacity

What is it and why is it important?

According to 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/m^3 reduction in $PM_{2.5}$ concentrations could prevent 50,000 new cases of coronary heart disease and 9,000 new cases of asthma by 2035 [5]. 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 PM_{10} and $PM_{2.5}$) but also by absorbing ozone, SO_2 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?

Air purification capacity was mapped using an EcoServ R 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 every 5m-by-5m 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 the prevailing wind direction. The final capacity score was calculated for every 5m-by-5m 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.

Air quality regulation demand

What is it and why is it important?

Air purification demand estimates the 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 R. The model combines two indicators of air pollution sources (log distance to roads and % cover of sealed surfaces) and two indicators of the 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.

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 health, wellbeing, productivity and the natural environment. Consequently, the World Health Organisation (WHO) has 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 2013 [6]). Major roads, railways, airports and industrial areas can be sources of considerable noise, but the 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. However, 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 every 5m-by-5m 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.

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 is mapped using a modified version on an EcoServ R 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.

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 the 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, can have a moderating effect on the 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 heat maxima.

How is it measured?

Local climate regulation capacity is mapped using an InVest model. Vegetation can help reduce the urban heat island by providing shade, modifying thermal properties of the urban fabric, and increasing cooling through evapotranspiration. The model calculates an index of heat mitigation based on shade, evapotranspiration, and albedo, as well as distance from cooling islands (e.g. parks) for each pixel. The raster generated by this process shows the capacity of each landuse to cool the air and is calculated relative to the average temperature across the summer months. The temperatures recorded in each location will differ from the index shown here since landuse would generate a given temperature which in reality is blend with the temperatures generated by the landcover of the surroundings. After the cooling capacity index is generated, an air blending factor is applied to simulate air mixing which gives a realistic estimation of temperatures on the ground. The model provides an accurate cooling capacity index, validated against satellite data (see Zawadzka et al. 2021 and Bosch et al., 2021).

Local climate regulation demand

What is it and why is it important?

Local climate regulation demand estimates the 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 R 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 the societal need for local climate abatement (population density and proportion of the population in the highest risk age categories – defined as under ten 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.

Water flow regulation 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 processes 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-R 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.

The 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 generally have 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.

Water quality regulation capacity

What is it and why is it important?

Water quality capacity maps the risk of surface runoff becoming contaminated with high pollutant and sediment loads before entering a watercourse, with a higher water quality capacity indicating that water is likely to be less contaminated. Note that although diffuse urban pollution is partially captured in the model at the catchment scale, the focus is on sedimentation risk from diffuse agricultural pollution.

How is it measured?

A modified version of an EcoServ-R 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 several risk classes. There is a strong link between the percentage cover of these land uses and pollution levels, with water quality being particularly sensitive to the percentage of sealed surfaces in the catchment.

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 a 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 generally have 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).