Ecosystem service multifunctionality and trade-offs in English Green Belt peri-urban planning

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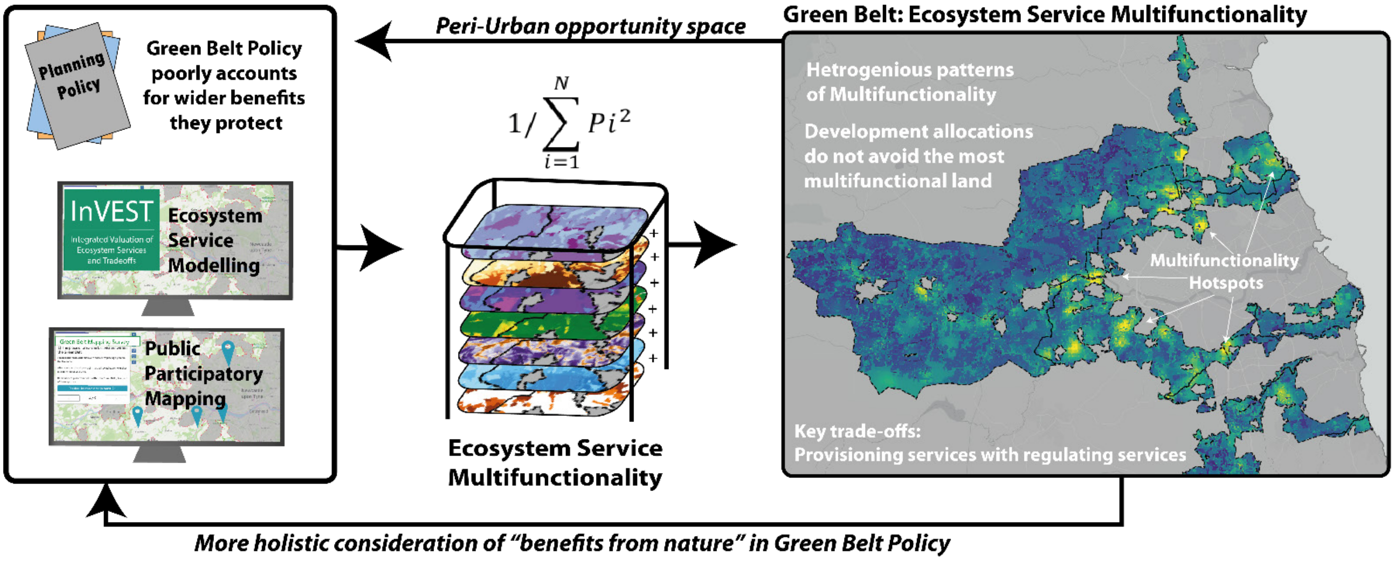
Abstract

Green Belt policies govern peri-urban landscapes globally by restricting built development. Yet, they often have little consideration for the land within them. This is especially the case in England where ecosystem services are poorly accounted for in Green Belt policy, whilst also being viewed as a development obstacle, with few environmental and social benefits; a situation mirrored in peri-urban landscapes globally. Moreover, there is a significant research gap into Green Belts through the socio-ecological lenses of ecosystem services and multifunctionality, which allows populist discourses to go unchallenged. Using modelling and participatory mapping data this paper addresses this gap by quantifying the ecosystem service supply, trade-offs and multifunctionality of the North-East Green Belt, and the wider planning and policy implications. The results show that contrary to claims, Green Belts in England can and do provide multiple benefits to people when studied through these lenses. However, levels of individual ecosystem services and overall multifunctionality differ spatially within Green Belts resulting in opportunity areas as well as potential losses of ecosystem services from development. Areas of deciduous and coniferous woodland as well as key “green wedges” close to urban populations were found to be multifunctionality “hots-spots”, whereas arable and improved grassland provide notable “cold-spots”. Trade-offs were mostly from provisioning services. We argue that Green Belt policies explicitly and holistically accounting for ecosystem services could catalyse a multifunctional opportunity space for climate, nature and people in peri-urban landscapes. Additionally, our study demonstrates the conceptual merits of ecosystem service multifunctionality for planning.

Graphical Abstract



Research Highlights

- Green Belt policy has mostly neglected the wider benefits from nature it protects.
- Green Belt zones provide important and notable supplies of ecosystem services, contrary to mainstreamed claims.
- Significant variation in multifunctionality is found, with urban edge areas some of the most multifunctional.
- Areas of higher ecosystem service multifunctionality are not protected from potential development.
- Trade-offs are found between provisioning and other ecosystem services.

Keywords: Landscape Planning; Multifunctionality; Planning Policy; Ecosystem Services; InVEST; Peri-Urban

1 Introduction

The development and operationalisation of the ecosystem service framework has significantly evolved globally in environmental disciplines since its inception (Costanza et al., 2017). Simply put, ecosystem services are material and non-material benefits we get from nature (Millennium Ecosystem Assessment, 2005), with the stocks they originate from commonly referred to as "natural capital" (Costanza et al., 2017). Despite the progress made, there has been comparatively low uptake of the ecosystem service framework outside environment disciplines, notably in land-use and spatial planning, where value perceptions of natural capital are seen to compete with other forms of capital (Scott et al., 2018; Wei & Zhan, 2023). The framework has also been critiqued due to its anthropogenic focus, and incompatibility with biodiversity goals (Spash, 2009). Yet, research has still sought to understand how to mainstream ecosystem services into other sectors, including land-use and spatial planning (Scott et al., 2021). Within this context the impacts of planning policies and decisions on the supply of ecosystem services need to be quantified (Salata et al., 2020; Scott et al., 2018), which can be gained from the application of qualitative and quantitative evaluations of ecosystem services provision (Bagstad et al., 2013). Spatially explicit approaches to modelling the biophysical flows of ecosystem services can be especially useful in supporting planning policy decisions by determining the synergies and trade-offs between different policy targets within landscapes that would be affected by such policy decisions (Maes et al., 2012).

An increasingly popular way to understand the contributions of ecosystem services from landscapes is through the lens of multifunctionality (Hölting, Beckmann, et al., 2019). Landscape multifunctionality, defined simply as "the capacity of a landscape or ecosystem to provide multiple socio-economic and ecological benefits to society" (Hölting, Beckmann, et al., 2019, p. 226), is a notable conceptual expansion from traditional landscape ecology approaches, which advocates the combined and multiple benefits natural capital can provide through bundles of ecosystem services, whilst also recognising trade-offs between services (Hölting, Beckmann, et al., 2019; Manning et al., 2018). Trade-offs refer to opposing ecosystem services, where one increases, other(s) reduce. Looking through a multifunctionality lens, not all ecosystem services can be maximised; rather groups of complementary services (bundles) can be identified which interact positively(Spyra et al., 2020). Within planning, multifunctionality has gained traction as part of green and blue infrastructure[1] as a way to understand nature's benefits more holistically through a planned and managed network (Korkou et al., 2023). Therefore, multifunctionality may be a potential "bridge[2]" concept to improve mainstreaming of ecosystem services.

The ecosystem services framework is particularly relevant in peri-urban landscapes where ecosystem services are threatened by land-use change and urban sprawl (Shaw et al., 2020). However, to date the peri-urban has been a policy blind spot, with the notable exception of urban growth management policies (UGMPs) which govern built development within these zones (Kirby et al., 2023). One way proposed to better govern these landscapes is by defining their functionality, and recognising them as important resources to urban populations (Hedblom et al., 2017). Whereas UGMPs have been shown to be effective in preventing sprawl (Pourtaherian & Jaeger, 2022), ecosystem services are rarely considered explicitly (Kirby et al., 2023). Internationally, limited research has showed UGMP's importance for ecosystems services, for example in Canadian (Ruiz-Sandoval et al., 2019) and Germany Green Belts (Zepp, 2018). However, such studies ignore cultural ecosystem services, instead favouring regulating and provisioning ecosystem services (Kirby et al., 2023). As such, current peri-urban policy responses are largely incapable of managing trade-offs between ecosystem services and land-uses which experience trade-offs within and between ecosystem services types (Spyra et al., 2020), thus limiting their ability to be holistically governed.

Such challenges are exemplified in one such UGMP: English Green Belts, which were first implemented nationally in the 1950s and today cover 12.6% of England's land. Green Belt policy seeks to prevent uncontrolled development and urban sprawl, but it does not have formal purposes to improve functionality and benefits of the land it (MHCLG, 2021). Recently, debates have refocused

[1] the "managed network of terrestrial and water spaces found across our urban and rural landscapes that help deliver socio-economic and ecological benefits supporting ecosystem functions and societal well-being" (Mell & Scott, 2023).

[2] A "linking term, concept or policy priority that is used and readily understood across multiple groups and publics" Scott et al. 2018 (pg 232).

on the purpose of Green Belt, within the backdrop of a significant housing deficit in England (Mace, 2018). Here, opponents of Green Belt argue it has a negative economic and social effect which is an obstacle to building (Koster & Zabihidan, 2019; Mace, 2018). However, these arguments fail to acknowledge or account for the wider non-market values these policies protect, including ecosystem services. Remarkably, there has been no explicit assessment of Green Belts ecosystem services in England to challenge this discourse (Kirby et al., 2023), aside from recent work showing their importance for cultural ecosystem services (Kirby, Scott, & Walsh, 2023). As such the contentious nature of the Green Belt in England is stoked by polarising debates between the need for more housing and the protection of the countryside (Dockerill & Sturzaker, 2020; Mace, 2018). The challenge of mainstreaming the benefits of nature in Green Belt is further fuelled by a neoliberal discourse that " [green belt] land is of no particular social or environmental value at all" (Fabian Society, 2023, p. 7), as well as attempts to separate the policy from its incidental benefits (Mace, 2018). Such claims are potentially misleading given that non-pristine environments supply notable ecosystem services and thus benefits to people (Honey-Rosés et al., 2014).

Whilst the fundamental aim of Green Belt policy in England is to prevent urban sprawl, secondary objectives exist to promote their beneficial planning for people and nature, including a recent policy for compensatory improvement of the environmental quality and access of Green Belt for any development within it (MHCLG, 2021). However, a recent study found a wide variation in the degree to which Green Belt policies explicitly aim to protect and increase a range of ecosystem services as secondary benefits, and diverging approaches to compensatory improvement (Kirby & Scott, 2023). Set within the current political landscape which sees diverging policies for Green Belt, including calls for wider multifunctionality (House of Lords, 2022) and a new generation of multi-goaled 21st century Green Belts internationally (Macdonald et al., 2021), there is a urgent need for evidence on the ecosystem services, and multifunctionality provided by Green Belt landscapes in England to help inform this debate and the policy direction.

More broadly, peri-urban landscapes globally, and especially in Europe, are experiencing similar political, social and environmental drivers of land-use change in their peripheries, resulting in the loss of natural capital (Shaw et al., 2020), consequently requiring a robust evidence base to demonstrate their benefits as spaces in their own right. Additionally, given the extensive implementation of UGMPs policies internationally (Amati & Taylor, 2010; Kirby et al., 2023; Pourtaherian & Jaeger, 2022), demonstrations of their interplay with ecosystem services is highly relevant and applicable for peri-urban policy development. Furthermore, "natural capital assessments" which economically value a given area have gained policy traction in Europe (Ruijs et al., 2019) These, however, do not quantify spatial heterogeneity in supply.

To address these important research and policy gaps, this paper aims to answer the following questions: (1) How does the supply of ecosystem services differ within Green Belts? (2) What trade-offs and synergies exist between these ecosystem services? (3) What levels of ecosystem service multifunctionality exist in Green Belts? And (4) do current built developments allocations in Green Belts conflict with ecosystem service multifunctionality?

2 Methods

To answer the research questions multiple ecosystem services were quantified in the North-East Green Belt using both modelling and participatory mapping quantifications and analysed.

2.1 Case region

The North-East Green Belt is located around the cities of Newcastle, Gateshead, Sunderland, and Durham and extends north and west into Northumberland (Figure 1), with the wider region home to around 2.5 million people. A Green Belt was first designated around the North-East conurbations in the 1960s and has grown to covers 772 km^2. There is no regional strategic planning of the Green Belt, instead it is sub-divided amongst seven local authorities. Historically, the region has been home to coal and heavy industries which declined in the latter 20^{th}, resulting in land-use reclamation mainly for agriculture and housing. As shown in Figure 1, the Green Belts land cover mainly consists of arable land (42%); improved grassland (30%) and broadleaved woodland (17%). Given the range of land covers, its size, mix of rural and urban local authorities and varying development pressures it provides an ideal case region to study the ecosystem services provided by an English Green Belt.

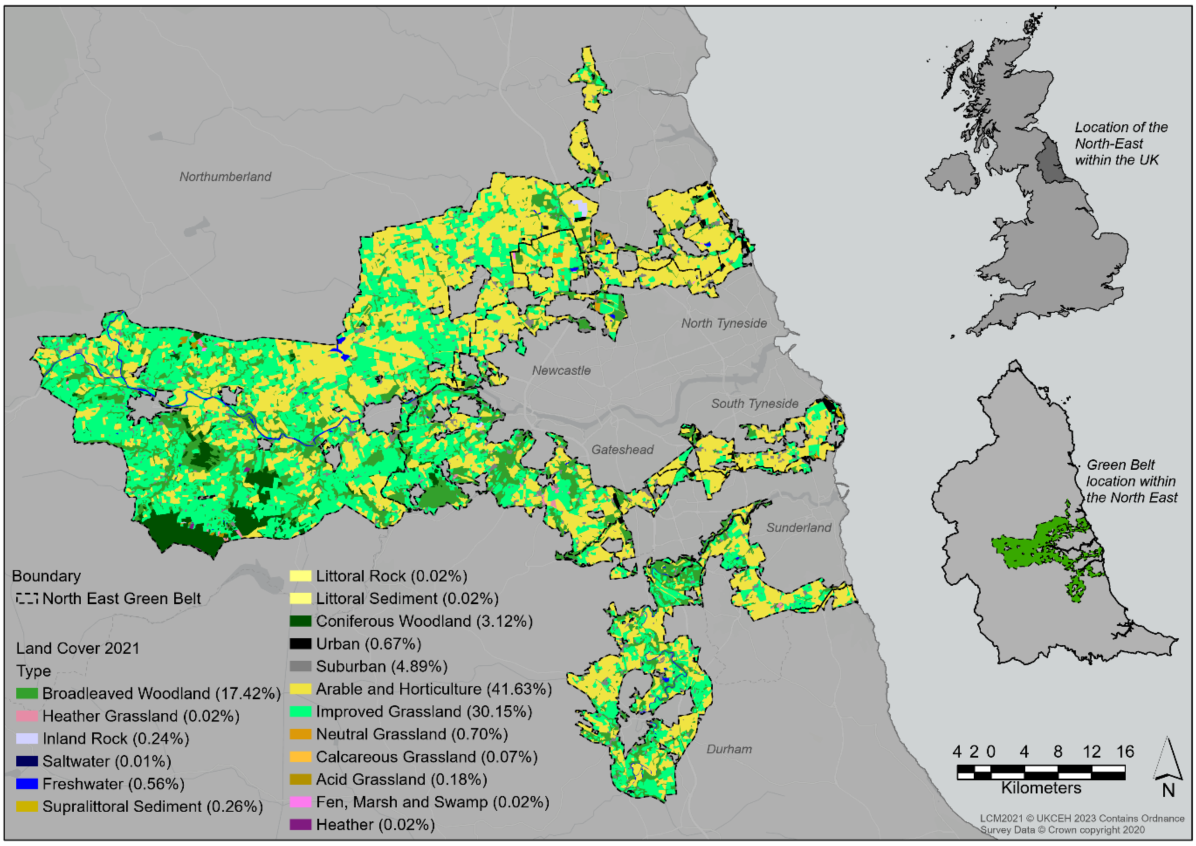


Figure 1: Location and land cover classification of the North East Green Belt using UKCEH Land Cover Map Data (Morton et al., 2022) (adapted from Kirby, Scott & Walsh. 2023)

2.2 Ecosystem service assessments

Ten ecosystem services were quantified consisting of six regulating, two provisioning and two cultural in the North-East Green Belt, through a mixed-method approach as summarised in Table 1. The choice of ecosystem services was based on model and data availability as well as relevancy to the peri-urban Green Belt context identified by a research project stakeholder steering group[3]. Regulating and provisioning services, with the exception of crop production were estimated using the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) ecosystem services suite of models, which are spatially explicit, internationally adaptable and based on production functions (Natural Capital Project, 2022). Whilst there is variation in results when comparing models (Sharps et al., 2017), the InVEST suite have been widely applied in academic research internationally, including the

[3] The group was composed of 10 regional and national stakeholders from local and private sector planning, professional institutes, politicians, and environmental charities and took place in a workshop format.

English context (Karimi et al., 2021; Rayner et al., 2021; Zawadzka et al., 2017). Given the InVEST Crop Production model utilises a global look up table for crop yield, agricultural crop production as a provisioning service was estimated through a bespoke modelling approach, based on crop types and regional average yields. The two cultural ecosystem services were estimated using a Public Participatory GIS (PPGIS survey (Kirby, Scott, & Walsh, 2023). A full and detailed outline of data inputs, data processing, parametrisations and assumptions for all models are available in Appendix 1 of the Supplementary Material.

Table 1: Overview of ecosystem services quantified including, ecosystem service category method of estimation and summary. Adapted from CICES 5.1

Ecosystem Services	**Category**	**Method of Estimation**	**Data Inputs**	**Summary**
Carbon Storage	Regulating	InVEST (3.12.0) Carbon Storage	LULC Map and carbon values for different stocks per LULC classifications	Aggregates the total values in these stock per pixel according to the land use classification and a raster output is produced showing total carbon per pixel.
Potential Pollination	Regulating	InVEST (3.12.0) Crop Pollination	LULC Map, associated nesting availability and floral resources. Foraging activity, nesting suitability and flight range	Uses estimates of availability of nest sites and floral resources within pollinator flight ranges to derive an index of abundance per cell of wild bees, represented as a raster.
Erosion Control	Regulating	InVEST (3.12.0) Sediment Delivery Ratio	DEM, rainfall erosivity, soil erodibility, LULC and associated C & P factors	Calculate the amount of soil loss per pixel and its transportation in the landscape using the universal soil loss equation. A raster output is produced showing sediment retention per pixel.
Nutrient retention (Nitrogen & Phosphorous)	Regulating	InVEST (3.12.0) Nutrient Delivery Ratio	DEM, quickflow, LULC and associated N & P loadings, critical flow length and retention efficiency	Using a mass balance approach it inputs to model the movement of nutrients across a landscape producing a raster output showing per pixel load which reaches a water course.
Flood Mitigation (1 in 20 year event)	Regulating	InVEST (3.12.0) Urban Flood Risk Mitigation	Design storm (rainfall depth), soil hydrological group, LULC map and associated curve numbers	Estimate the run-off retention per pixel compared to the storm volume, producing a raster of relative run-off retention per pixel.
Water Recharge	Provisioning	InVEST (3.12.0) Seasonal Water Yield	ET0, precipitation, soil hydrological group, DEM, LULC map and associated curve number, Kc value per soil and LULC classification.	The model determines the value of baseflow, quickflow and local recharge. A raster output for per pixel local recharge is produced.
Crop Production	Provisioning	Bespoke modelling approach	LULC map, regional average crop yields per crop	Average regional crop yield values were aggregated to the pixel level and the crop cover extent reclassified in ArcGIS Pro to create a raster output of crop yield.
Recreation	Cultural	Participatory GIS Survey	Volunteered data gathered through an online PPGIS survey (Kirby, Scott & Walsh., 2023)	Participants plot areas of recreation use by placing point on an online map.
Perceived Connection with Nature	Cultural	Participatory GIS Survey	Volunteered data gathered through an online PPGIS survey (Kirby, Scott & Walsh., 2023)	Participants plot areas where they perceived a connection with nature by placing point on an online map.

PPGIS generates spatial data from participants who answer questions by placing points on maps, and is considered one of the most effective ways to estimate and map cultural ecosystem services in a landscape (Fagerholm et al., 2020; Gottwald et al., 2022). As shown in Table 1, two cultural ecosystem services were quantified from PPGIS data from a recent study into the cultural ecosystem services in the North-East Green Belt reported in Kirby, Scott & Walsh (2023). The online PPGIS survey was conducted between October 2022 and January 2023 resulting in 779 respondents plotting 2388 points, with most participants recruited through volunteering sampling from community social media groups across the study area. The full methodology for the participatory derived datasets and wider study can be found in Kirby, Scott & Walsh (2023). Our study utilises the two most abundantly mapped cultural ecosystem services from this study, Recreation and Connection with Nature to further understand their relationship with provisioning and regulating services. Recreation refers to physical use i.e. walking, running, cycling, whereas "connection with nature" is where participants perceived nature as an important benefit to using the Green Belt. This distinction is important for the plurality of CES where they are perceived differently by individuals as well as challenging the expert-led conceptualisation of ES (Maund et al., 2020). Whilst modelling approaches exist to quantify cultural ecosystem services, they lack the use of these directly collected community and social values which are key given the human-environment interactions which form cultural ecosystem services (Fagerholm et al., 2020).

2.3 Data processing & analysis

The individual ecosystem service raster outputs were imported into ArcGIS Pro for data processing and analysis, as shown in Figure 2. Different analyses were chosen to answer the respective research questions drawing on previously applied methods (Salata et al., 2020; Sylla et al., 2020; Verhagen et al., 2018; Zawadzka et al., 2017, 2019). The analytical approach was also informed by a stakeholder steering group, which co-designed elements of the analysis, including the spatial scale of outputs, ecosystem service prioritisation and highlighting evidence gaps. Incorporation of stakeholders in the design process can help account for the range of interests, values and demands on ecosystem services (Hölting et al., 2020) and increase usability of outputs (Salata et al., 2020).

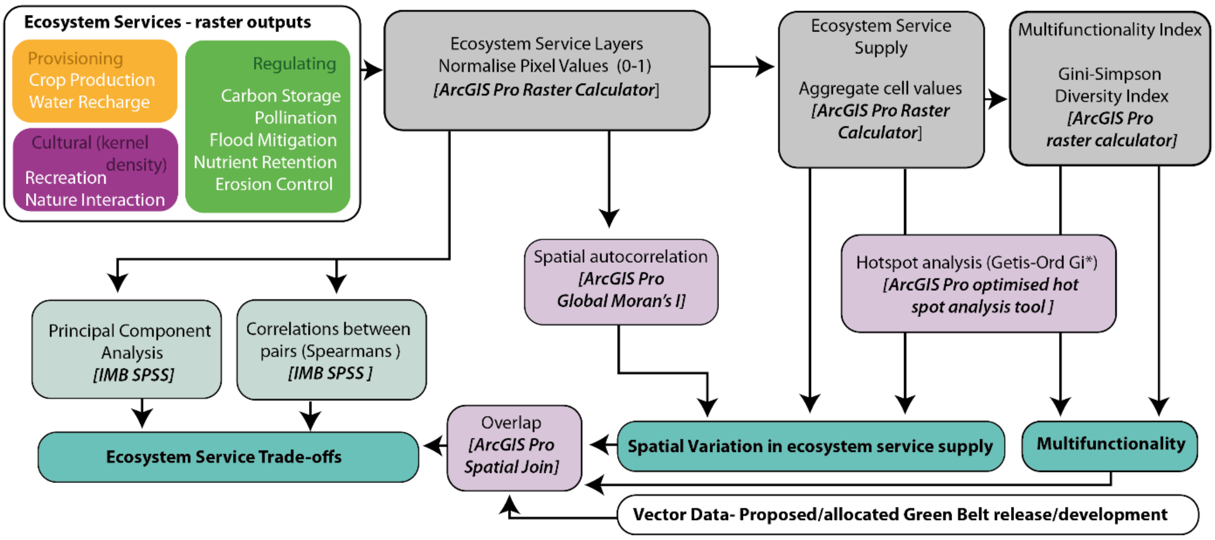


Figure 2: Flow diagram of ecosystem services key data analysis steps. White boxes = data input, grey = raster analysis, purple = vector analysis, light green = statistical analysis and dark green = outputs of analysis. Nutrient Retention include quantification of both Nitrogen and Phosphorus retention.

2.3.1 Data processing

Firstly, pixel values of the induvial ecosystem service outputs were normalised between 0-1 using the ArcGIS Pro raster calculator. Normalisation allowed the comparison and aggregation of services which are quantified in different units and scales (Sylla et al., 2020). Additionally, it acknowledges low accuracy of some modelled 'absolute values' compared to more accurate "relative" values (Natural Capital Project, 2022). To reduce spatial noise in the data, raster outputs were resampled to 100x100m spatial resolution.

2.3.2 Multifunctionality

One way to combine ecosystem services is through the lens of multifunctionality (Hölting, Beckmann, et al., 2019; Manning et al., 2018), which can be represented as richness (number of services), abundance (total supply of services) and diversity (evenness of services) (Hölting, Jacobs, et al., 2019). Although, ecosystem service supply (abundance) provides an important multifunctionality metric (Hölting, Jacobs, et al., 2019; Stürck & Verburg, 2017), it can be skewed by the dominance of a single high supplying ecosystem service. Therefore, diversity indices such as Simpsons and Shannon-Wiener have been applied to landscape contexts including ecosystem services as a form of multifunctionality (Hölting, Jacobs, et al., 2019). In a landscape context Shannon-Wiener diversity emphasises richness (Nagendra, 2002), whereas, Simpsons diversity index better represent the evenness aspect of services (Hölting et al., 2020; Hölting, Jacobs, et al., 2019; Stürck & Verburg, 2017).

Therefore, multifunctionality was represented both as supply and diversity of ecosystem services. Ecosystem services supply was calculated by equally aggregating the normalised pixel values using the ArcGIS Pro raster calculator. Even though the stakeholder group expressed differences in demand between services, ultimately, they felt that a weighted aggregations would be more appropriate for smaller spatial areas, therefore services were aggregated equally.

Given the study focused on a fixed set of ecosystem services, diversity was calculated using the Simpson Diversity Index (D) $= 1 - \sum_{i=1}^{N} Pi^2,$ (Simpson, 1949) where N= the total number of ecosystem services in the Green Belt, pi=the supply of each ecosystem service per pixel and (i) proportionally to the supply of all ecosystem services in the Green Belt. Simpson Diversity Index for the Green Belt ecosystem services was calculated using the ArcGIS Pro raster calculator and converted (1/D) into the Simpson's Reciprocal Index to better show variation (Stürck & Verburg, 2017). The stakeholder workshop informed the appropriate scales to display both multifunctionality outputs. Here the group felt outputs were needed at both the site scale (using a grid size of 250x250m) and at the landscape scale (using a grid size of 1.5x1.5km) to support multi-scalar planning.

2.3.3. Spatial variations

Several vector analyses were used to establish spatial variation in service provisions; therefore, raster datasets were converted to vectors using the ArcGIS Pro raster to vector tool. To avoid misidentifying of patterns (Shaikh et al., 2021) spatial autocorrelation was tested for in ArcGIS Pro using the Global Moran’s I tool to determine if ecosystem services were significantly clustered. Following comparable studies (Salata et al., 2020; Sylla et al., 2020) ArcGIS Pro optimised hot spot analysis tool (Getis-Ord Gi*) was used to identify statistically significant spatial hot spots and cold spots in ecosystem service multifunctionality. Overlay analysis using the ArcGIS Pro spatial join tool was then used to determine the distribution of hot and cold spots amongst LULC classes. To determine the significance of classes compared to their proportional land covers, z-scores were calculated. Scores ≥1.96 (α =0.05) suggest significantly greater proportion of points than expected scores ≤ -1.96 suggesting significantly less (Brown, 2013).

2.3.4 Trade-offs and synergies between ecosystem services

Statistical analysis was used to analyse trade-offs and synergies between ecosystem services. A 250x250m grid was created in ArcGIS Pro and grid squares attributed with the mean normalised ecosystem services values. Spearman correlation coefficient was calculated in IMB SPSS to identify positive and negative correlations (synergies and trade-offs) between ecosystem services (Fagerholm et al., 2012; Hölting et al., 2020). Relationships were classed as statistically significant for $p < 0.05$ and correlation coefficients were categorised as strong when $r_s \geq 0.5$ (synergies) / $r_s \leq -0.5$ (trade-offs), moderate from $r_s \geq 0.3$ to <0.5 (synergies) / $r_s \geq -0.3$ to <-0.5 (trade-offs), and weak when $r_s < 0.3$ (synergies) / $r_s \geq -0.3$ (trade-offs) (Fagerholm et al., 2012; Sylla et al., 2020).

Given its application and ability to identify ecosystem services bundles principle component analysis (PCA) was conducted in IMB SPSS (Karimi et al., 2021; Plieninger et al., 2019). Kaiser-Meyer-Olkin (KMO) and Barlett's test of sphericity (KM0= 0.621 and Barlett's test of sphericity =$p<0.001$) showed the data was suitable for PCA. The number of retained factors were selected according to the Kaiser Guttman rule (Eigenvalue ≥1) and the scree plot, (Appendix 2: Figure A2.11). The factor analysis was applied using a Varimax rotation.

To identify trade-offs between multifunctionality and potential Green Belt development, hotspots were spatially overlayed with allocated Green Belt releases in ArcGIS Pro and attributed with their mean multifunctionality values. Published and emerging local authority plans in the North-East Green Belt were reviewed for proposed releases. Four (Durham, Gateshead, Sunderland, and Newcastle) of the seven local planning authorities in the Green Belt have adopted plans with Green Belt release. Two local authorities (Gateshead and Durham) have representatives on the project steering group, and as such these authorities were used as case studies for the analysis.

3 Results

The ten ecosystem services quantified each show spatial heterogeneity in their supply across the Green Belt extent, as well as differing patterns of distribution of higher and lower ecosystem service supply (Figure 3). All ecosystem services were statistically significantly clustered spatially in the Green Belt (Appendix 2 Table A2.1).

3.1 Ecosystem service synergies, bundles & trade-offs

Of the 45 pairwise correlations between ecosystem services, 37 were significant ($p \leq 0.001$). Of these 5 were strong, 14 were moderate and 13 weak (Table 2). Strong synergies were found between regulating services: (1) P & N Retention; (2) N Retention & Flood Mitigation. However, the strongest synergy was between recreation and connection with nature (r_s=0.943).. Notably, most synergies were with pollination (7 synergies), carbon storage (5 synergies), flood mitigation (5 synergies) and water recharge (5 synergies) with the latter being a provisioning service (Table 2).

All trade-offs between pairs of ecosystems services involved a provisioning service (Table 2). The strongest trade-offs were between crop production and flood mitigation (r_s =-0.52) and between crop production and pollination (r_s=-0.53). That is, the difference in supply was highest between these services. Moderate trade-offs were found between water recharge and (1) flood mitigation, (2) pollination and (3) carbon storage. Likewise, crop production had moderate trade-offs with (1) carbon and (2) nutrient retention. Overall, cultural ecosystem services had the lowest synergies and trade-offs with other ecosystem services categories.

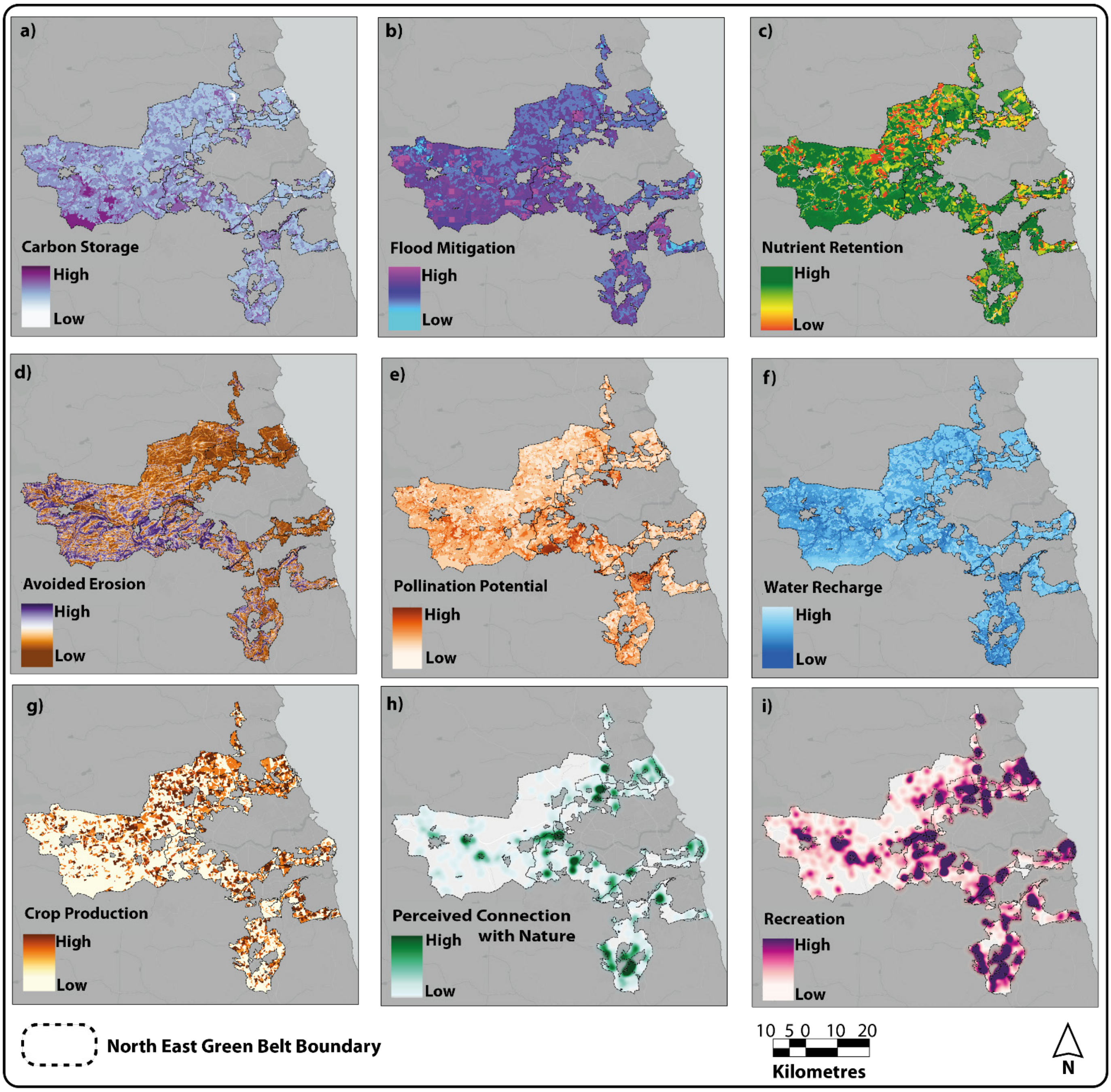


Figure 3: Individual Ecosystem Services estimated for the North-East Green Belt. All values are shown as relative (low-high) in the landscape. a-e: regulating services, f-g: provisioning services and h-i: cultural services. Full size figure for each are available in Appendix 2 of the supplementary materials (Figures A2.1-A2.10).

Table 2: Pairwise correlations (Spearman's rank correlation coefficient) between ecosystem service pairs

	Nutrient Retention P	Nutrient Retention N	Flood Mitigation	Avoided Erosion	Water Recharge	Potential Pollination	Crop Production	Carbon Storage	Recreation	Connection with Nature
Nutrient Retention P	1.000									
Nutrient Retention N	.747**	1.000								
Flood Mitigation	.463**	.518**	1.000							
Avoided Erosion	.187**	.214**	.333**	1.000						
Water Recharge	-.097**	-.140**	-.344**	-.261**	1.000					
Potential Pollination	.251**	.344**	.481**	.315**	-.325**	1.000				
Crop Production	-.247**	-.372**	-.520**	-.228**	.365**	-.533**	1.000			
Carbon Storage	.221**	.221**	.448**	.340**	-.410**	.369**	-.353**	1.000		
Recreation	-0.016	0.009	-.033**	.038**	-.133**	.222**	0.008	0.016	1.000	
Connection with Nature	-0.019	0.003	-.032**	.028**	-.127**	.211**	0.004	0.014	.943**	1.000

Weak Trade-off	Moderate Trade-off	Strong Trade-off	Weak synergy	Moderate synergy	Strong synergy
rs ≥ -0.3	rs ≥-0.3 to <-0.5	rs ≤ -0.5	rs <0.3	rs ≥0.3/ to <0.5	rs ≥0.5

n=10134
**p= <0.001

The principal component analysis further grouped the ecosystem services into mutually beneficial or exclusive bundles. Three axes were selected from the scree plot (Appendix 2, Figure A2.11), based on the eigenvalues ≥ 1, corresponding to three ecosystem service bundles (Table 3 & graphically: Appendix 2, Figure A2.12) explaining 64.9 % of variation based on loading of 0.4. Bundle 1 explains 26.1% of the variance and includes flood mitigation, avoided erosion, pollination, and carbon storage that are in a synergy, distinctly trading off with crop production and water recharge (Table 3 & graphically: Appendix 2, Figure A2.12). Bundle 2 explains 21.3% of the variance and includes nutrient retention N & P and Flood Mitigation. And bundle 3 explained 17.5% of the variance and includes the two cultural ecosystem services. Interestingly, flood mitigation features in both bundles 1 and 2. The correlations in Table 2 visual analysis of the PCA component plot (Figure Appendix 2: A2.12) also suggest crop production and water recharge are somewhat bundled.

Table 3: Results from the principal component analysis for ecosystem services showing first three factors

	Rotated Components		
	1 *(26.1% variance)*	2 *(21.3% variance)*	3 *(17.5% variance)*
Nutrient Retention P	-0.048	**0.956**	-0.001
Nutrient Retention N	-0.044	**0.955**	0.005
Flood Mitigation	**0.507**	**0.592**	-0.087
Avoided Erosion	**0.478**	0.004	0.037
Water Recharge	-0.608	0.128	-0.100
Potential Pollination	**0.675**	0.182	0.143
Crop Production	-0.732	0.118	0.052
Carbon Storage	**0.670**	0.193	-0.025
Recreation	0.068	-0.020	**0.966**
Connection with Nature	0.063	-0.015	**0.965**

Varimax with Kaiser Normalization.
*Factor loadings≥ 0.40 are shown in bold

3.2 Ecosystem Service Multifunctionality

The aggregation of the individual ecosystem services into multifunctionality indices are shown in Figure 4. Here multifunctionality is represented as total ecosystem services supply (4a) and Simpson's Reciprocal Index (diversity) (4b). Whereas, both representations of multifunctionality show comparable spatial distribution and heterogeneity in multifunctionality, by accounting for evenness of ecosystem service through Simpson's Reciprocal Index, Figure 4a shows greater spatial heterogeneity and contrasts in multifunctionality especially at the higher and lower value ranges. Simpson-Reciprocal scores were on average higher than aggregated ecosystem service supply. Multifunctionality scores (Simpson-Reciprocal index) in the Green Belt ranged from 2.04 to 7.32 (out of a possible range of 1-10) with the mean multifunctionality score 4.482 (sd:0.64). Total ecosystem service supply ranged from 0.21-6.64 (out of a possible range of 0-10) with the mean total ecosystem service supply 3.49 (sd: 0.69).

Figure 4 shows clustering of areas of high and lower multifunctionality. Statistically significant "hotspots" and "colds spots" of ecosystem service multifunctionality (Simpson-Reciprocal Index) were confirmed to exist in the Green Belt as shown in Figure 5. Notably, many of the hotspots were found close to the urban edge of the Green Belt in the "green wedges" as well as discrete habitat patches such as woodland. Cold spots are more variedly distributed in the landscape, with far fewer coldspots close to the urban edge. The presence of cold spots on the coastal areas of Green Belt is likely the result of no data areas generated from the two InVEST nutrient model outputs.

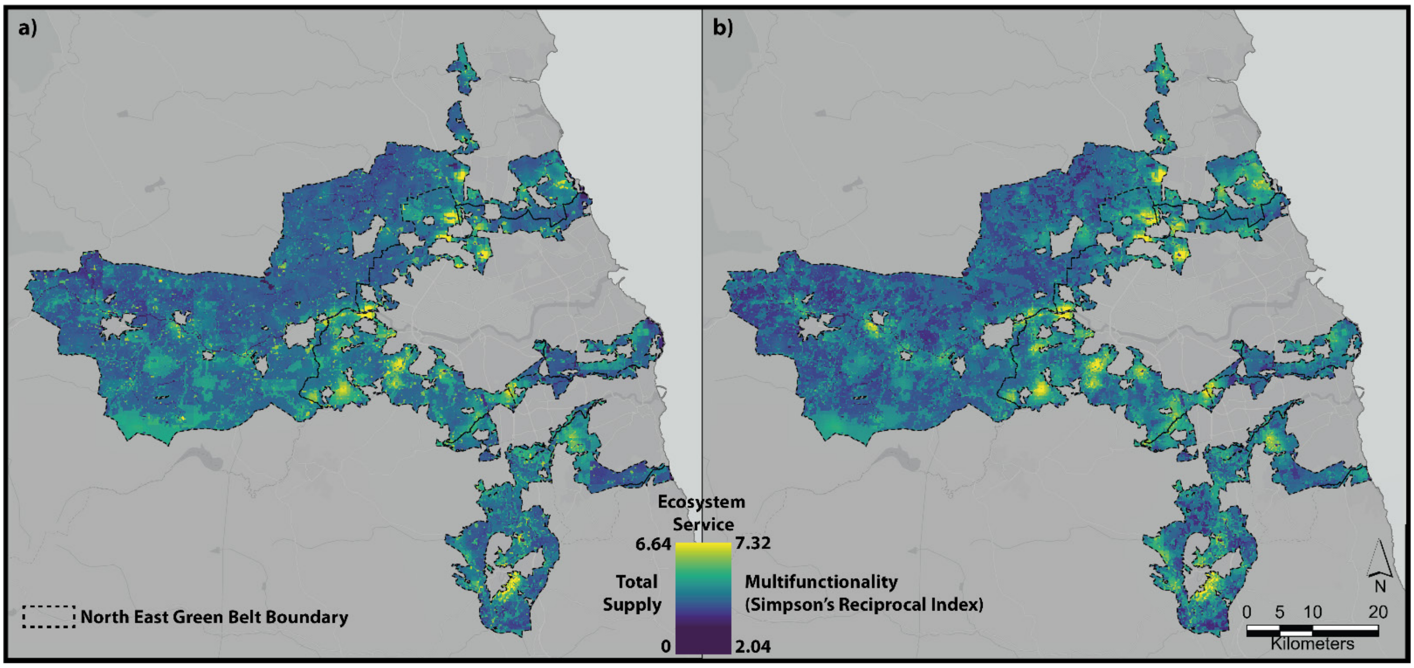


Figure 4: Ecosystem Service Multifunctionality in the North-East Green Belt represented as a) total ecosystem service supply and b) Simpson's Reciprocal Index (diversity). For both aggregations the possible maximum score is 10.

The spider diagrams in Figure 5 show the proportion of hot and cold spots per the five dominate land use land covers in the Green Belt. The results show that ecosystem service multifunctionality hotspots were significantly located in areas of broadleaved woodland (42%, z-score=6.77) and coniferous woodland (11%, z-score=2.08), when compared to the actual land use land cover of the Green Belt. Whereas arable (19%, z-score= -5.58) and improved grassland (16%, z-score= - 3.26) areas had notable hotspots, they had significantly lower amounts than their proportionate coverage. Ecosystem service multifunctionality cold spots were significantly located in areas of improved grassland (54%, z-score=5.96). Whereas a notable proportion of cold spots were in arable land (36%) this was not significant compared to the actual land cover. Deciduous woodland had significantly less (1.8%, z-score= -3.86) cold spots.

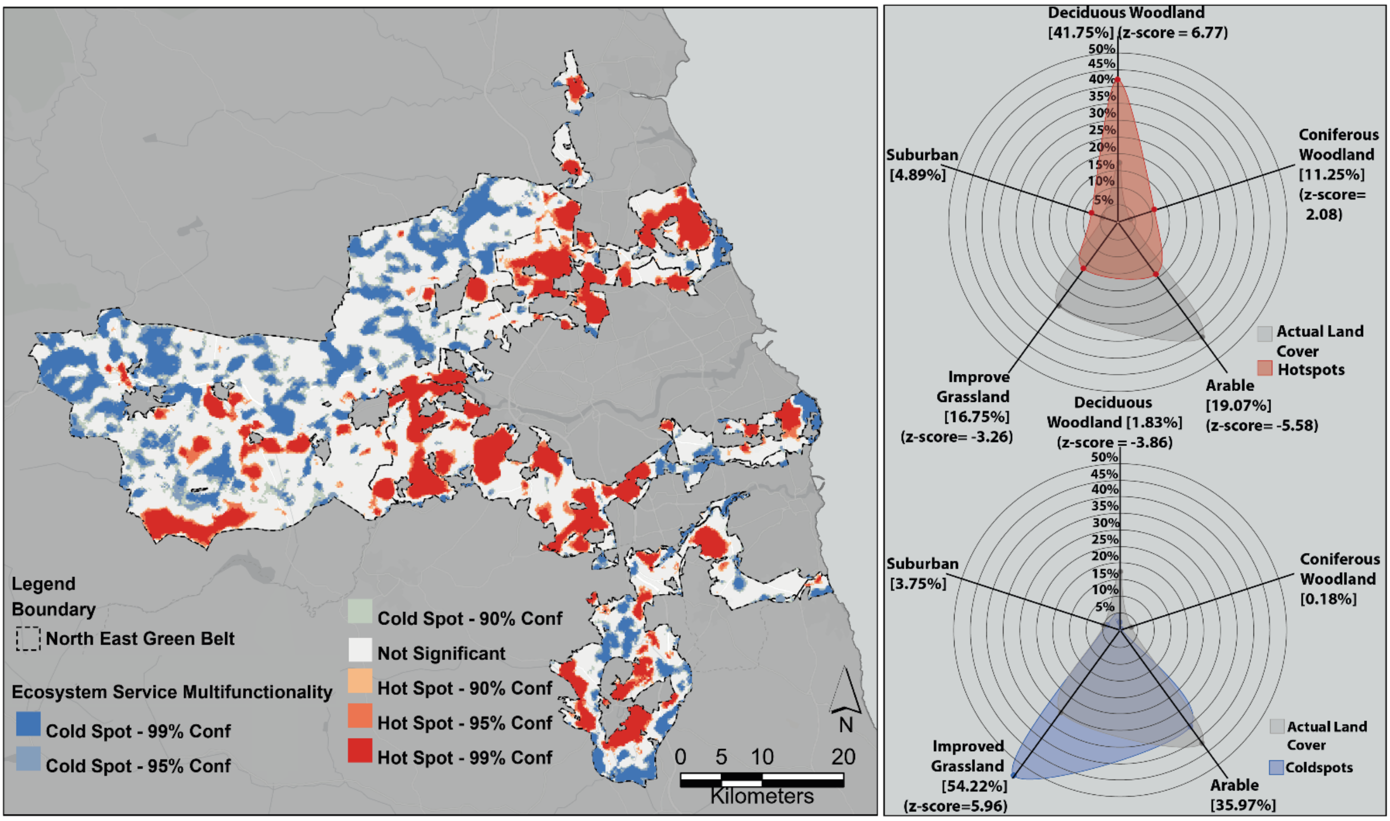
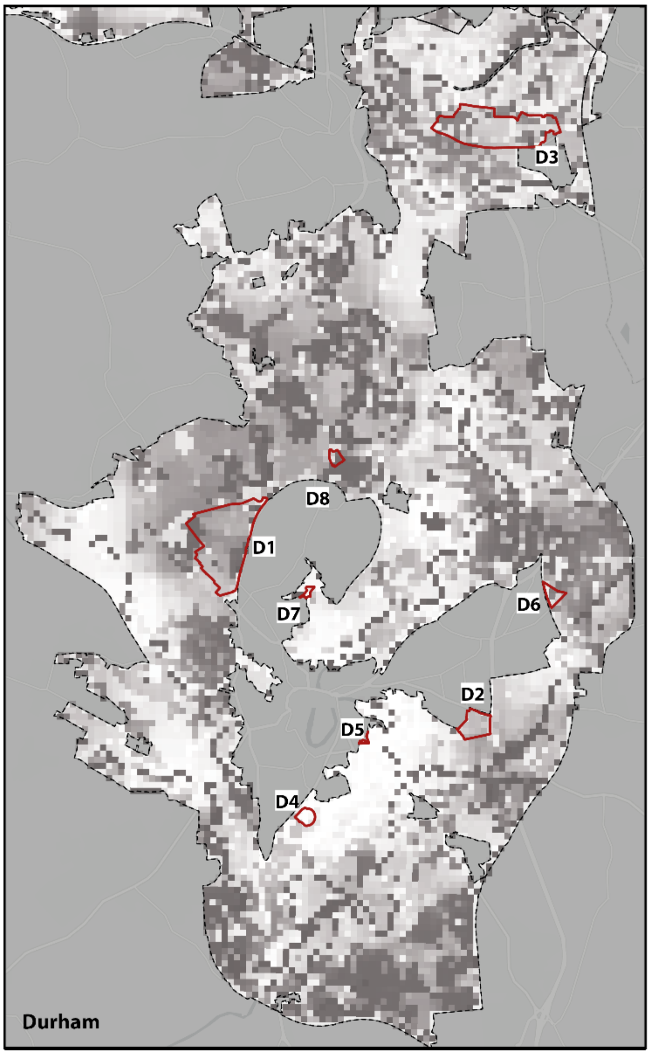
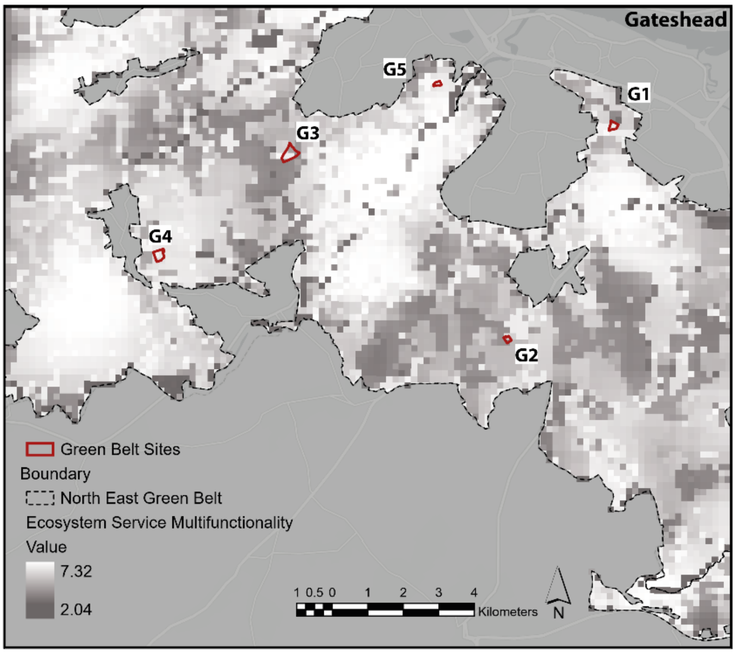


Figure 5: Statistically significant ecosystem service multifunctionality hotspots and cold spots (Getis-Ord Gi*). Spider diagrams show distribution of hotspots and cold spots per top five land-use land cover classes compared. Significant z-scores are also shown indicating percentage is significant compared to proportionate total land cover in the Green Belt (z-scores ≥1.96/≤-1.96 (α =0.05))

3.3 Planning & multifunctionality

The results of the overlap analysis with allocated Green Belt sites in the local authorities of Gateshead and Durham are shown in Figure 6 below. Most sites currently allocated for development in the two local authorities local development plans are above the mean Green Belt value for ecosystem service multifunctionality and supply, resulting in a potential net loss in ecosystem service benefits. Notably, three sites (D4, D5 & G5) are in areas of high ecosystem service multifunctionality. Durham has much larger development proposals in its Green Belt, including two urban extensions (D1 & D2), both close to the mean level of multifunctionality, but both slightly below mean supply. To support future decision making in the region and policy approaches to Green Belt by local authorities in the region, outputs were produced in 1.5x1.5km and 250x250m grids (Appendix 2, Figure A2.13-A2.14) allowing for consideration of multifunctionality at the site and landscape scales.





Development Allocation	Map ID	Footprint (ha)	Local Authority	Mean site Multifunctionality Score (Simpson-Reciprocal Index, max possible =10)	Mean Site Ecosystem Service Supply (max possible = 10)
Sniperley Park	D1	108	County Durham	4.29	3.21
Sherburn Road	D2	18.7	County Durham	4.60	3.42
Lambton Park	D3	95.7	County Durham	4.51	3.55
Howlands	D4	6.3	County Durham	5.36	4.19
Durham Comprehensive	D5	2.56	County Durham	6.06	4.76
Pittington Land	D6	6.60	County Durham	4.57	3.68
Former Skid Pan	D7	1.90	County Durham	4.66	3.54
Finchale College	D8	4.23	County Durham	4.20	3.58
Dunston Hill	G1	1.39	Gateshead	4.80	3.42
Marley Hill	G2	0.81	Gateshead	4.61	4.05
Former Care Village	G3	4.03	Gateshead	3.97	1.81
Hooker Gate	G4	2.36	Gateshead	4.98	3.95
Axwell Hall	G5	0.63	Gateshead	5.24	4.64

Figure 6: Ecosystem Service supply & multifunctionality scores for allocated Green Belt sites in Development Plans. Scores shaded in red show values above the overall mean scores for the Green Belt.

4 Discussion

This research shows that contrary to some prevalent populist discourse, Green Belts in England can and do provide multiple benefits to people when studied through ecosystem services and multifunctionality lenses. Importantly, through these lenses not all areas of Green Belt are the same, with notable contrasts spatially in the supply of individual ecosystem services and multifunctionality. Therefore, the results present compelling evidence that Green Belt should be seen as strategic green infrastructure opportunity spaces to meet multiple land-use demands. More broadly, our results extends the international evidence-base on the holistic benefits of Green Belt landscapes beyond growth management (Ruiz-Sandoval et al., 2019; Zepp, 2018), both in terms of number and type of ecosystem services, as well as geographically. Methodologically, the study also further demonstrates the merits of diversity indices, specifically Simpsons Reciprocal Index in mapping ecosystem service multifunctionality (Hölting, Jacobs, et al., 2019; Stürck & Verburg, 2017) and their application to a planning context. Drawing on the original research questions and wider literature the results are discussed in terms of their interdisciplinary policy implications and wider applicability to ecosystem service multifunctionality and peri-urban landscapes.

4.1 Green Belts – planning, policy and practice implications

The heterogeneity in the levels of ecosystem service multifunctionality demonstrates that not all Green Belt is the same. Therefore, there is a need for more flexible place-based policy responses, which account for variation, as opposed to the current one-size-fits-all approach to Green Belt policies regionally and nationally (Amati & Taylor, 2010). The importance of adapting UGMP approaches to local contexts has been shown in Green Belts in China which largely failed due to not adapting to local governance frameworks (Sun et al., 2021). Thus, any evolution of Green Belt policy to explicitly support multifunctionality needs to be flexible enough to adapt to differing ecosystem service priorities spatially, and differing governance mechanisms such as market-based interventions.

In the English context, the results provide key evidence supporting the legitimacy of secondary Green Belt policies, which to date are insufficient in many development plans (Kirby & Scott, 2023). Specifically, our presented approach can help identify deficits in supply of some ecosystem services and support the need for natural environment and Green Belt policies to be more joined up, which was found to be a barrier by Kirby & Scott (2023). Equally, our results illustrate how opportunity areas could be identified in Green Belts where development could catalyse ecosystem services provision through incorporation of green infrastructure and nature-based interventions in development design. The importance of this is shown in the overlap of development allocation with multifunctionality (Figure 6), which reveals that proposals do not avoid multifunctional hotspots. Thus, the results support the need for more holistic policy responses which account for functionality, beyond commonly applied proxies such as biodiversity (Spyra et al., 2020).

In planning, ecosystem service information has mainly been used to raise awareness of the benefits from nature but as a concept it is not fully mainstreamed in planning policy (Wei & Zhan, 2023), leading to important questions over how to operationalise results such ours. Here, working with planners at the offset of the research process is particularly important as Salata et al. (2020) demonstrated through operationalising ecosystem services in an Italian development plan. Though the stakeholder steering group our results are being implemented in an emerging green infrastructure strategy for the study region, highlighting the value of green infrastructure as a hook (Kirby & Scott, 2023; Korskou et al., 2023) and involving stakeholders (Scott et al., 2021). Furthermore, policies may benefit from a participatory prioritisation of ecosystem services to inform policy direction and the in demand ecosystem services, which have been shown to be important and varied locally (Filyushkina et al., 2022; Hölting et al., 2020). Moreover, our results suggest that contrary to pursuing urban growth from the urban edge (Mace, 2018), where some of the most multifunctional areas were found development may be more suited to away from the urban edge. Here concepts such as "new towns[4]" which advocate meeting development though large development projects away from the urban edge, may be more appropriate, if informed by holistic evidence bases. For example, the use of hotspot analysis effectively demonstrates areas of high ecosystem service multifunctionality which can be understood by stakeholders and decision-makers without technical knowledge (Salata et al., 2020). Though exact patterns of multifunctionality cannot be applied to other peri-urban contexts, the study illustrates the importance of more holistic peri-urban planning and the methods used here provides a replicable approach to working towards this.

Green Belt is a political and socially contentious designation from local to global (Kirby et al., 2023). In England, politicians have suggested allowing the development in the Green Belt in "land of poor quality". However, as our results illustrate to objectively understand quality, socio-ecological benefits need to be considered. Therefore, there is a need for quantifying environmental and social benefits in Green Belts to identify areas of low and high ecosystem services supply. Without such evidence there

[4] The "new towns" concept emerged in the 1940s in England, and refers to large scale and state-led planned development of new towns away from existing urban areas in an attempt to relocate growth (TCPA, 2014)

is a danger that ecosystem services would be lost. This situation is not confined to English Green Belts, but is experienced in peri-urban regions internationally, such as development proposal in Green Belts in Ontario Canada, which unlike in English have formal goals to promote ecosystem services (Macdonald et al., 2021), showing the wider international applicability of the results and approach, but also the vulnerability of nature when balancing land-use pressure and ecosystem services (Hedblom et al., 2017). However, as shown in the Netherlands, there can be a disconnect between multifunctional and perceived multifunctionality, (Filyushkina et al., 2022), meaning people may contest protecting land if they don't understand its wider benefits. Therefore, communicating benefits should not only be limited to policy makers, but involve the wider public at the outset of plan-making processes. In this context, the partnerships approach which includes the public, planners and scientists may be important for social learning (Scott et al., 2018).

4.2 Managing trade-offs and synergies in the peri-urban

Of all the ecosystem services assessed, crop production had the most trade-offs, especially with regulating services. Arable land and improved grassland[5] also had the most of the multifunctionality cold-spots. As both of these land cover types are under agricultural land use this is not unexpected, but notable given this is the main land use in English Green Belts. This finding is comparable to other studies which identified similar trade-offs internationally (i.e. Turner et al., 2014), including peri-urban landscape (Sylla et al., 2020), therefore extending these findings to a new geographical and policy context. Additionally, these trade-offs are noteworthy given that several studies have shown that whilst people perceive crop production to be an important ecosystem service, there is a lower preference of these ecosystem services compared to others (Martín-López et al., 2014), including in multifunctional peri-urban areas (Filyushkina et al., 2022). Given that current peri-urban governance has failed to identify and address such trade-offs (Spyra et al., 2020), including through Green Belt policy (Kirby & Scott, 2023), there is an opportunity for wider stakeholder and public engagement in

[5] Contrary to its name "improved grassland" indicates agriculturally improved grassland which is distinguished from semi-natural grasslands by higher productivity due to intensive agricultural practices such as drainage and applications of fertilisers (Marston et al., 2023)

the management of multifunctional landscapes (Hölting et al., 2020) to understand opportunities to increase ecosystem service multifunctionality, through policy, especially given Green Belts contention (Dockerill & Sturzaker, 2020).

The ecosystem services were mostly bundled in terms of ecosystem service category, namely regulating and cultural services. Notably, flood regulation was shown to be largely important, featuring in bundles 1 & 2 indicated important spatial synergies. Bundles could be used to target design of interventions such as natural flood management provide multiple benefits that are not currently mutually beneficial. For example, questions such as "how can flood reduction and nutrient retention interventions in the Green Belt also contribute to additional benefits such as cultural ecosystem services" which did not feature in the same bundle, nor had moderate or strong bivariate correlations. This is important given nature-based interventions are often driven by a primary ecosystem service, for example natural flood management (Walsh et al., 2022). Here mapping of individual ecosystem services combined with knowledge on current bundles may provide important knowledge to help spatially prioritise interventions and associated co-benefits currently not widely found together (Bush & Doyon, 2019).

Interestingly, water recharge and crop production were in a trade-off with the regulating services featured in bundle 1, including flood mitigation. Whilst crop production has previously been found in a trade-off with other regulating services (Turner et al., 2014), the synergy with water recharge was not expected. We justify the moderate synergy between crop production and water recharge, as indicated by moderate correlation, by good permeability of soils under a significant portion of arable use within the study area. Moreover, the trade-off between water recharge and the regulating services in bundle 1 could be the consequence of a greater importance of soil properties compared to pollination, carbon storage and avoided erosion, which are more dependent on vegetation characteristics (Natural Capital Project, 2022). Moreover, the lack of synergy between water recharge and flood mitigation could be due to the differences between the services they estimate and underlying models. The InVEST Seasonal Water Yield model calculates water recharge as a function of the wider hydrological process including annual precipitation and evapotranspiration as well as topography data, whereas the InVEST flood risk mitigation model is primarily dependent on different soil properties and a short storm event, thereby the latter is more dependent on saturation characteristics of the soils and not evapotranspiration from vegetation. This example points to the importance of bespoke ecosystem services assessments for any given area, as bundles may change with the different biophysical characteristics of landscapes. It is also important to understand which biophysical processes are represented by available modelling tools to aid interpretation of the resulting bundles in support decisions making.

So far, the results have primarily been discussed in the context of planning policy. However as landscapes, Green Belts are also indirectly governed through natural resources and environmental policies, with peri-urban areas often the incidental byproduct of the two policy areas (Shaw et al., 2020) which are disintegrated and operating in silos (Scott et al., 2018). Our results show that as well as ecosystem service multifunctionality, notable parts of the Green Belt have low multifunctionality, including improved grasslands and arable land, or are dominated by a single high supplying service i.e., crop production. Kirby, Scott & Walsh (2023) suggests that given the unique functional qualities and processes in peri-urban landscape (Shaw et al., 2020; Spyra et al., 2020) more area specific agri-environment programmes are needed which account for this. Our results reinforce this further and such an approach may not only allow the targeting of ecosystem service bundles in the peri-urban but also spatial prioritisation in areas of low supply.

4.3 Limitations

Ecosystem services models are sensitive to input data and model complexity (Sharps et al., 2017). One of potential limitations of this study is reliance on a single ecosystem services model to represent each service, which could have affected the accuracy of the values used in the assessment. Ensemble modelling, i.e., using more than one set of models to represent a given service, could gain accuracy and more certainty behind the modelled values (Willcock et al., 2020). Consequently, the results obtained from single-model studies are not meant to be prescriptive, but informative and complementary to other evidence bases. Likewise, participatory generated data used to map cultural ecosystem services has inherent limitations due to sampling biases which come from survey data

(Brown, 2017). Finally, an obvious caveat in terms of ecosystem service multifunctionality is that the results are largely dependent on the number and range of services quantified. Whereas we quantified a range of services from across the three categorisations (regulating, provisioning and cultural) there was a greater number of regulating services. In other Green Belts or peri-urban contexts other ecosystem service may be more appropriate or in demand. Future work needs to ensure that the ecosystem services considered for decision-making are representative of the potential ecosystem services that an area can supply to avoid under or over estimation of multifunctionality of an area. Finally, the spatial resolution of the ecosystem service outputs was changed in the analysis, most notably to create "stakeholder requested" reflecting site and landscape scales (section 2.3.2). This reduced "extremes values" in the data, resulting in underestimation of areas of high ecosystem services. These limitations need communicating with stakeholders, especially given the importance of operationalising ecosystem services in planning.

5 Conclusions

This study has demonstrated for the first time that English Green Belts, are in part, able to live up to their "green" name and provide notable and valued ecosystem services to urban populations which they encircle. Within our case study hotspots of ecosystem service multifunctionality were found close to the urban edge and in areas of woodland. At a time where peri-urban landscapes internationally face increased urban-centric pressures on land-use for development, this new evidence is important for the development and application of more holistic policy responses in these contentious and dynamic landscapes. Especially though development plans and through important hooks such as Green Infrastructure. Of the ten ecosystem services quantified, there was notable variation in the supply spatially as well as trade-offs between them, with crop production and corresponding arable and improved grasslands found to trade-off most with other ecosystem services. The results point to the importance of spatially quantifying ecosystem services regionally, and the need for prioritisation of ecosystem services, for which spatial and land-use planning is ideally placed. However, policy mainstreaming is still needed to join up planning approaches if Green Belts are to be realised as an opportunity space for people, climate and nature.

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